



GOVERNMENT OF KENYA

MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE IKUTHA AREA

DEGREE SHEET 60, N.W. QUARTER

(with coloured geological map)

by

J. WALSH, B.Sc.

Geologist

UNIVERSITY OF NAIROBI
GEOLOGY DEPARTMENT
LABORATORY REFERENCE BOOK
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FOREWORD

The Ithuka area is one that is little visited as a whole, for though the railway and the Mombasa-Nairobi road pass through its south-west corner, much of it is not easily accessible except on foot. Part of it lies, however, in the north-west corner of the Tsavo Royal National Park, and may become better known in the future.

The area is noteworthy in so far as it contains a graphite mine that has operated for a number of years, and has produced some 3,000 tons of the mineral. A general account of the graphite deposits of this part of Kenya was given in a previous report (No. 37, 1957) on the South Kitui area, which adjoins the Ithuka area on the north. Mr. Walsh, in the present report, continues the account, giving details of the process that is used for extraction, and a proposed process including winnowing, which has been suggested in view of the acute shortage of water in the mine area.

The area is crossed by a part of the Yatta plateau, which is one of the unique features of Kenya geology. Much argument has centred round the emplacement of its thin capping of phonolite lava. Mr. Walsh adheres to the valley-flow hypothesis and provides an interesting calculation to show that such a lava could have flowed the length of the plateau in a period of about seven months.

Nairobi,
30th January, 1959.

WILLIAM PULFREY,
Ag. Commissioner (Mines & Geology)

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MAPS

Geological map of the Ikutha Area (degree sheet 60, N.W. quarter). Scale 1: 125,000 at end

located A

Introduction and Geology

Previous Geologic Work

Physiography

ABSTRACT

Summary of Geology

The report describes an area of approximately 1,200 square miles in the Kiambu and Machakos Districts of Kenya, bounded by parallels 2° and 2° 30' S. and meridians 38° and 38° 30' E. Physiographically the area is divided into five units: (1) the Athi river drainage, of gently undulating country in the west and south-west, (2) the Yatta Plateau, (3) the fairly deeply dissected catchment area of the Tiva river, east of the Yatta Plateau, (4) the Yamala-Kimathena-Ithumba range, and (5) the scrub-covered plains in the east, grading to the end-Tertiary peneplain, with erosion residuals.

The solid rocks of the area fall into three groups (1) Basement System (Precambrian), consisting mainly of para-gneisses with minor intrusions, all strongly folded and metamorphosed, (2) Tertiary volcanics, represented by a single extensive phonolite lava flow, and (3) Recent volcanics, comprising two flows of olivine basalt. Superficial deposits of Pleistocene and Recent age include red and black soils, secondary limestones and alluvium.

The petrography of the various rock types is described, and the structure, metamorphism and granitization of the Basement System rocks are discussed.

Occurrences of economic minerals are described, with special attention to graphite, which is being worked in the area.

Map of the area

(1)

(2)

(3)

(4)

(5)

I—INTRODUCTION AND GENERAL INFORMATION

General.—The area described in this report is approximately 1,200 square miles in extent, and is bounded by parallels 2° and 2° 30' S. and meridians 38° and 38° 30' E. It comprises the north-west quarter of degree area No. 60 (Kenya), and is the area covered by the ~~Directorate~~ of Overseas Surveys Sheet No. 175. It lies in the Southern Province, the part north and east of the Athi river being administered from Kitui and the remainder from Machakos. More than one-third of the area, in the east and south-east, lies in the Tsavo Royal National Park, and of the remainder, most of the land north-west of the National Park forms part of the Kamba Native Land Unit, the rest being Crown Land. There are three blocks of land in the south-west leased from the Crown, two of which are planted with sisal, by Dwa Plantations Ltd. near Kibwezi (LR 917), and by Masongaleni Sisal Estate Ltd. at Masongaleni (LR 5903). The third block, (LR 3685) at Manoni, produces sugar-cane and paw-paw under a system of irrigation which taps the Kibwezi river and a large spring near the snout of the Kibwezi lava. Approximate boundaries of these estates are marked on the map as a guide to their position and extent.

The only village in the area is Ikutha, which existed before European settlement in East Africa. Although small it is important as the focal point of many scattered small-holdings, and contains a primary and an intermediate school, a dispensary, a Government rest-house, several small Indian and African shops and a covered market-building. It is the home of the Ikutha Dancers, one of the best-known troupes of Wakamba dancers. There is nowhere else a large enough collection of huts to justify even the term village, although the country east of the Yatta Plateau and north of the National Park is fairly well settled.

The Athi valley, which has a perennial river and is in many places bordered by fertile alluvial flats, is devoid of settlement except at the crossing of the Kibwezi-Kitui road. Various explanations were given to the writer for this—abundance of big game, liability to flooding, and seasonal infestation by mosquitoes and tsetse flies. The latter would appear to be the true reason, since the local Wakamba have little fear of elephant and rhinoceros, and serious flooding appears to be a rare occurrence.

The African Land Development Board has instituted the Athi-Tiva Reclamation Scheme, whereby thousands of acres of bush country between the two rivers have been cleared by tractors and bull-dozers and, by a planned and controlled system of burning, rich pastures free from tsetse fly have been developed for stock grazing. Many earth dams have been built and wells sunk for watering. It is hoped that by levying a small annual grazing charge on each animal the scheme will be made self-supporting. Grazing will be strictly controlled to prevent soil erosion, which is a serious problem in the extreme north of the area. There tracts of land many square miles in extent have been denuded of grass cover by cattle, goats and sheep, which has led to serious gullying and the loss of much of the top-soil. Serious efforts to prevent further erosion and to reclaim lost grazing land are being made by compulsory purchase of cattle to keep numbers down to a safe figure, and by "scratch-ploughing", the cutting of shallow furrows across the gullied tracts at intervals of a few feet to trap rain-water run-off and to stimulate the growth of new grass. The gullies themselves are dammed at short intervals with rocks and woven sticks. Such a ploughed area is usually regenerated to a sufficient extent to allow light grazing again within two or three years.

Game is abundant in the less settled regions and in the Tsavo Royal National Park, particularly elephant and rhinoceros. In the National Park, particularly near the Tiva river, the number of elephant is so great that vast areas have been flattened and trampled and the ground is littered with fallen trees. Buffalo are common in the thick bush of the Yatta Plateau. In the more open grasslands around Ithumba there are large herds of zebra, gazelle and impala, with lesser numbers of giraffe, oryx, wild pig, wart-hog and ostrich.

Climate and Vegetation.—Rainfall statistics, which are recorded only at Ikutha, Dwa and Masongaleni are tabulated below, together with readings made at Kanziku, two miles outside the northern border of the area, east-north-east of Ikutha.

Locality	Total Rainfall (inches)			No. of Rainy Days, 1956	Yearly Average	No. of Years Recorded
	1954	1955	1956			
Ikutha	17.67	*	23.51	32	18.27	5
Dwa	21.53	14.19	27.71	52	24.30	37
Masongaleni ..	20.48	*	†	†	23.97	47
Kanziku	11.22	16.84	25.78	51	23.71	14

*Records incomplete.

†Not recorded.

The rainfall is bi-annual, with a marked maximum in November-December, and a lesser peak in April.

The main agricultural crops are maize, beans and cassava, with castor-oil beans as a cash-crop. A small amount of tobacco is grown for local consumption and in a few favourable locations there are plantations of bananas and plantains. Two crops are planted each year, to coincide with the rainfall maxima, but it is not uncommon for rains (and crops) to fail completely, as they did in early 1956, when the rainfall for March to May was confined to a few short showers. In such times the Wakamba must rely to a great extent on their livestock for food, supplemented by wild honey. It is common to find, even in apparently trackless bush, a native beehive in almost every large tree.

Much of the area is covered by *acacia* thorn scrub with occasional *baobab* trees, and where game tracks are few penetration is a slow and difficult business. Natural water is almost completely lacking over most of the area, since only the Athi and Kibwezi rivers are perennial, though water can be found along the whole length of the Tiva river only a foot or two below the surface. All the springs mapped are very small with the exception of that in the Kibwezi lava near Manoni, which has a measured flow of 25,000 gallons per day. The water-holes mapped are either shallow pans, dry for most of the year, or hollows and crevices in rock platforms which are regularly cleaned and enlarged to provide domestic water. The wells at Kitubua, in the north-east, are dug through sandy soil down to the water-table a foot above bed-rock, to a depth of up to 25 ft., and ramps for cattle are made down to the water. There are here upwards of 20 wells in an area of about one-sixth of a square mile, each belonging to a particular family. As already mentioned a large number of earth dams and two concrete dams have been constructed, many of which hold water for the greater part of the year. Bore-holes have been sunk on the Dwa and Masongaleni sisal estates, and a public bore-hole is in operation at Ndovoini, north of Dwa.

In the past few years only, small-holdings have been cleared on the Yatta Plateau at Kabete and Mwala, and the red soil derived from the underlying phonolite has proved particularly fertile. However, since the soil is nowhere above two feet in thickness and frequently less than one foot, such small-holdings are particularly dependent on a good and well-spaced rainfall.

Communications.—The main Nairobi-Mombasa road and the East African railway cross the south-west corner of the area, and two railway stations lie within it, Masonga-

leni and Kikumbuli. The latter is a new station built as part of a scheme to increase the traffic-carrying capacity of the single-track line by providing a passing point for trains travelling between Masongaleni and Kibwezi.

The main road from Kibwezi to Kitui passes through Ikutha, crossing the Athi river by a low concrete bridge and running across the sandy bed of the Tiva. It follows the route of an old footpath across the Yatta Plateau, where a fault has given rise to a col some 200 ft. below the plateau level. There is said to be a Stone-age living site near this col but neither the writer nor Dr. B. N. Temperley of the Ministry of Works were able to find it.

From Ikutha a fairly good road runs east and north-east to Kanziku, with motorable tracks branching south to Kasaala and Kimathena. An excellent road has been made through the Tsavo Royal National Park northwards from Voi to meet the latter track at Kimathena. From just south-west of Ikutha a new motor-track runs north-west to Kalebu and Kitui as an access road for the Athi-Tiva Reclamation Scheme. Two roads reach the Athi river in the south-west, the most northerly, primarily a fire-break for the Dwa sisal estate, reaching the river at Masalani, and the other a few miles to the south-east running to Kithiulu from Manoni, which is reached from either Kibwezi, via Dwa, or Masongaleni.

Maps.—Two maps covering the area have been published, sheet South A.37
O on a scale of 1:250,000, dated 1912, and Voi (E.A.F. No. 1714) on a scale of 1:500,000, dated 1946. The latter map appears to be based largely on the 1912 sheet which, while good in parts, contains glaring inaccuracies which have been perpetuated on the 1946 sheet. In view of the unreliability of these maps the whole of the topography for the geological map was taken from air photographs made by the R.A.F. in 1948, controlled by a plane-table survey based on surveyed trigonometrical stations. The form-lines are based on corrected spot heights obtained by a single aneroid barometer and must therefore be considered as only approximate. The area to the north was mapped in 1952 by E. P. Saggerson of the Mines and Geological Department (Saggerson, 1957)* since which time a new triangulation survey has been made and several new stations fixed near the common border, enabling points on the border to be fixed with greater accuracy. It will be seen that some common points on the border differ by up to half a mile on the two maps.

ACKNOWLEDGEMENTS

Thanks are due to the Administrative Officers of the Kitui area for their assistance during the survey, and to the Manager and staff of Dwa Plantations Ltd. for help and hospitality.

II—PREVIOUS GEOLOGICAL WORK

The first traveller who left a record of his journeyings in the area was Ludwig Krapf (Richards, 1950, pp. 54-83) who passed through the north-western part of the area in 1849, but made no mention of the geology.

In 1877, J. M. Hildebrandt (1879, pp. 334-342) followed the Athi river for several miles north-west from Mikomani (possibly Ngomano) and crossed the Yatta Plateau to reach the Tiva somewhere west of Ikutha. He mentions various soil types, and of the Yatta Plateau he says "It seems to be an outflow (*auslaufer*) of the snow-mountain Kenya".

* References are quoted on page 36.

J. W. Gregory (1896, pp. 76-79) in 1893 followed the route of the present-day railway between Masongaleni and Kibwezi, where he stayed at the East African Scottish Mission whose station was situated near Dwa Rock, at the edge of the Kibwezi lava, to which he refers, commenting that its surface features indicate that it must be of recent age. He again visited East Africa in 1919, and in his subsequent book (Gregory, 1921, pp. 184-191) discussed the Yatta Plateau and the Kyulu (Chyulu) volcanoes.

Captain L. Aylmer in 1907 travelled from Kibwezi to Ikutha, where he began a traverse down the Tiva which took him eastwards beyond the limits of the present area (Aylmer, 1908). The geology is tersely summed up in the sentence "Quartz abounded everywhere but no shale formation was seen which gave promise of coal."

Brief reports on the geology were made by E. E. Walker (1902, pp. 4-5) and H. B. Muff (Maufe) (1908, p. 21). Both mention gneisses, and the volcanic rocks of the Yatta Plateau and Kibwezi valley.

E. Krenkel visited the area in 1908 and later (Krenkel, 1911, p. 257) briefly referred to crystalline schists, strongly folded on N-S axes, with variations to N.W. In a later book (Krenkel, 1925, p. 241) he identified the Yatta Plateau as an extension of the Kapiti phonolites, probably quoting Gregory, and his map XXI included the area in broad detail.

Fritz Behrend's map (Behrend, 1918) shows the area as crystalline schists overlain by younger volcanics of the Chyulus and the Yatta Plateau, the latter being shown as an isolated sheet.

The existence of graphite in the area was first recorded in 1940, and a good deal of prospecting has been done since then. This is discussed at greater length on p. 22.

Much of the area to the south was mapped by J. Parkinson (1947), but there is a gap of a few miles between the limits of the two areas.

B. N. Temperley (1956, Vol. II, pp. 64-122) studied the lavas of the Kibwezi and Masongaleni valleys as part of a wider survey concerned with water-supplies.

E. P. Saggerson (1957) mapped the adjoining area to the north, and there are differences between the nomenclature of rock types used for his map and that of the present map. Saggerson's group *Xh'* (biotite-hornblende gneisses including hornblende granulites) has been subdivided in the present area into *Xh'* (hornblende-biotite gneisses) and *Xhh* (hornblende gneisses), the latter symbol being used for rocks in which biotite does not exceed 20 per cent of the total hornblende-biotite content. In addition Saggerson's group *Xs* (psammitic bands in a semi-pelitic series) is represented by *Xgg* (quartzo-felspathic gneisses and granulites) and in one case by *Xn* (granitoid gneisses).

III—PHYSIOGRAPHY

The most noticeable feature of the area is the Yatta Plateau, which is roughly paralleled by the Athi river on the west and the Tiva river on the east, each of which has its own distinctive drainage system. To the east of the Tiva system is a gently sloping bush-covered plain with poorly defined drainage, broken by a major range of hills and other isolated hills and ridges.

The Yatta Plateau is capped by lava which is considered to have flowed out on the sub-Miocene peneplain (Schoemann, 1948, p. 3), and is here taken as the datum level for the erosion surfaces in the area (Fig. 1), there being no fossil evidence of the

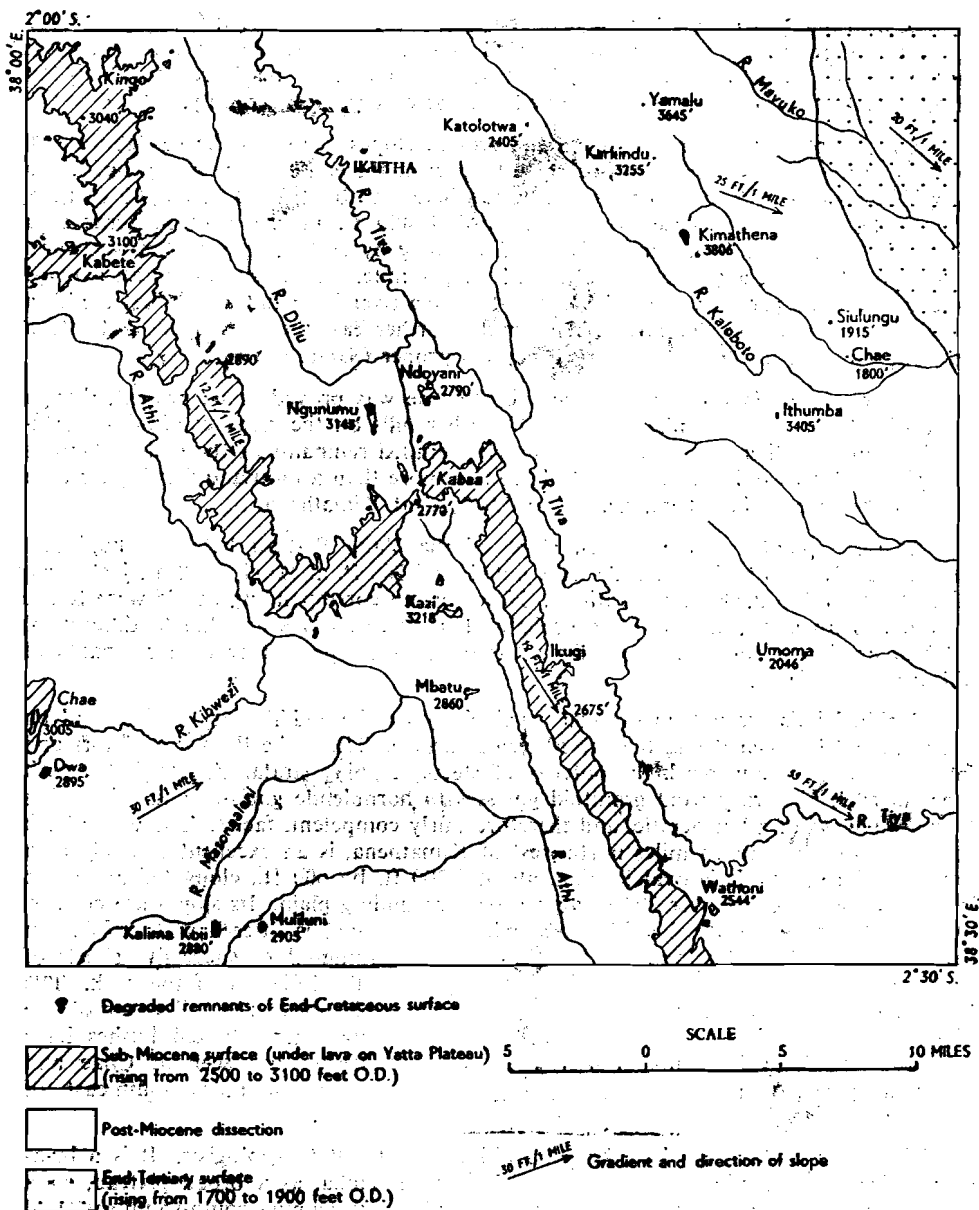


Fig. 1—Physiographical sketch-map of the Ikutha area

age of the sub-Miocene or any other of the surfaces. The spot-heights marked on Fig. 1 were read on the present-day surface of the lava, which maintains a fairly constant thickness of about 30 ft. The plateau thus falls from about 3,100 ft. in the north-west to about 2,500 ft. in the south-east, a steady fall of 12 ft. per mile, excluding the portion of the plateau in the north-west, which is tilted by post-Miocene faulting and locally slopes down to the north. Further remnants of the sub-Miocene surface are represented by well-defined shelves on the hills of the Ngunumu-Mbatu ridge in the centre of the area, and in the south-west by the isolated hills of Chae, Dwa, Kalima

Koii and Muliluni, which, while high in relation to the Yatta Plateau (perhaps a result of post-Miocene tilting), show a good accord of summit levels. Poorly marked shelves and ridges on Kimathena and neighbouring hills may also mark remnants of this surface, but this could not be determined with any degree of certainty.

East of the Tiva drainage system the ground slopes gently to the east-south-east, and the extreme north-east is considered to be part of the end-Tertiary peneplain, which is well developed over much of Kenya. It lies between about 1,700 and 1,900 ft. here, and grades down to a base-level of erosion of 400 ft. in the Kilifi-Mazeras area (Caswell, 1956, p. 6). This surface is still developing by cutting back to the westward, across country with a gradient of about 25 ft. per mile. In the south-east an average gradient of 55 ft. per mile along the line of the Tiva river is an indication that the Tiva is still cutting down to this level. A few miles further east the Tiva opens out into a flat, swampy bed in the end-Tertiary peneplain proper (Sanders, 1963).

No erosion surface older than the sub-Miocene was proved to be present, though both Kimathena and Ithumba, and possibly other hills on the ridge continuing northwards from Kimathena, probably mark much-degraded remnants of the end-Cretaceous peneplain, which would be expected to have lain more than a thousand feet higher than the sub-Miocene surface here, i.e. above 4,000 ft. at Kimathena.

At three points on the eastern slope of the Yatta Plateau between Ikugi and Wathoni shelves up to 150 ft. wide were noted, at 2,260 ft. at Ikugi, 2,345 ft. just north of Wathoni and at 2,230 ft. at Wathoni. However, no corresponding bevels were found on the western slope, and it seems probable that these shelves are due to differential rates of erosion in an area of rapidly alternating rock types rather than remnants of old erosion surfaces.

Residual hills are not uncommon, particularly on the end-Tertiary surface and on the pediment between it and the sub-Miocene surface. They take the form of tors and inselbergs, and usually mark the outcrop of steeply-dipping strata. Although the rock types in such hills vary from granitoid gneisses to hornblende gneisses and migmatites they are always of a leucocratic, and therefore fairly competent, facies. The whale-back rock of Katolotwa, seven miles north-west of Kimathena, is an excellent example of a miniature inselberg. It is oval in plan, about 1,200 ft. by 600 ft., elongated along the strike, its summit being over 200 ft. above the surrounding plain. Its slopes are convex, but vertical or near vertical at the foot, where the ground is littered with exfoliation debris resulting from "onion-skin" weathering, the splitting-off of successive sheets of rock parallel to its outer surface, with little regard to the foliation of the rock. The final stage of such weathering which still remains visible above the soil cover of the plains is a flat rock platform, bare of vegetation except where stunted bushes have gained a root-hold in joints and crevices. Such platforms are seen at Chae and Siulungu, parts of a discontinuous elongated outcrop seven miles south-east of Kimathena.

The Yatta Plateau has long been an object of interest to geologists. It is a lava-capped feature beginning at Ol Doinyo Sabuk, near Thika, as a broad plateau, soon narrowing to an average width of one to two miles and running south-south-east and finally east to a point east of Tsavo, a total length of about 180 miles. Gregory (1921, pp. 184-189) summed up the salient facts as follows:—the lava caps the summit of a long, high ridge, and nowhere shows evidence of having overflowed the ridge or flowed over the plain at the foot of the ridge; there is no evidence that the lava flow ever covered an appreciably wider area than that of the present-day plateau: the lava surface falls gradually along its whole length, and never at a steeper gradient than 30 ft. in a mile. He made errors in some minor details, e.g. "Its width E. of Masongaleni is between three and four miles . . .". Later work has disclosed that pebbles of the lava are found up to 15 miles from the plateau, across a watershed, in the area west of Kitui township (Schoemann, 1948, p. 6) and pebbles have also been found at

Kinyiki hill, south-west of the present area, and 13 miles from the plateau and separated from it by the Athi river. East of Tsavo (Sanders, 1963) records a gradient of 35 ft. per mile. Some variations of gradient also occur due to post-Miocene faulting, as in the north-west part of the present area. Gregory concluded that the lava flowed down a valley, subsequent erosion having worn down the flanking gneisses at a much greater rate than the lava itself, which protected the underlying rocks to leave the plateau as it is today, in this area up to 1,000 ft. higher than the bed of the Tiva and up to 600 ft. higher than the Athi. Dodson (1953, pp. 4-5) has put forward several arguments against this hypothesis. He writes that it seems highly improbable that a single lava flow could continue to flow over such a great distance, especially since the thickness of the flow seldom exceeds 50 ft., and that the characteristics of the lava suggest that it must have been fairly viscous. He adds that nowhere in the south-east Machakos area were underlying valley deposits found. He therefore advances the alternative theory that the lava was extruded along fault-line fissures extending along its whole length and that the surface flow nowhere spread for a distance greater than 500 yards from its point of extrusion. One obvious weak point in his argument is his tacit acceptance of the *original* thickness of the lava as 50 ft. He accepts the fact that the lava was extruded on the sub-Miocene peneplain, and his map shows dissection in the gneisses to a depth of about 600 ft. below this surface. Much of this erosion is due to pediplanation, and the main process of erosion of the phonolite must be by lateral spalling, but surface erosion of the lava is taking place, proved by altitudes taken across the plateau which showed the present surface of the lava to be as much as 15 ft. higher in the centre than on the flanks. It must therefore be concluded that the flow might well have been twice its present thickness.

The writer made extensive traverses along and across the summit of the plateau, and looked for basal contacts at 38 different localities. The base of the lava could seldom be fixed with any degree of accuracy owing to the heavy bush and thick soil cover and the large amount of lava scree that masks the slopes. Nothing suggesting valley deposits was found, and often it appeared that the lava rests on the red soil of the original peneplain, which is indistinguishable from more recent soils. (The phonolite itself weathers to a bright red soil on the plateau, not to black soil such as so often occurs on phonolites in Kenya.) Fairly reliable fixes of the lava base gave thicknesses varying between 10 and 55 ft., but the average is about 30 ft. The width of the plateau (excluding spurs) varies from two and a half miles to three-quarters of a mile, and at two places the lava is breached along fault-lines. Both of these gaps and the area between the plateau and the large outlier of Ndoyani in the centre of the area were carefully traversed in a search for feeder dykes as envisaged by Dodson. In the two fault gaps the country rock is greatly obscured by scree and huge boulders fallen from the summit, but south of Ndoyani lava float is almost completely lacking over much of the country, and clearly no dyke exists here. Similarly no dykes of phonolites were found flanking the plateau, and it seems certain that none exist, since by the evidence of the rock of the plateau itself such a dyke would form a prominent feature. The S-bend at Kabaa is difficult to explain on the dyke hypothesis, but is a very characteristic river feature.

Frequently the large phenocrysts of the phonolite show a marked preferred alignment over fairly large areas. Sixty-five such alignments were recorded and almost without exception they lie parallel or sub-parallel to the margins of the lava at those points. It is considered that the phenocryst alignments here indicate the direction of flow of the lava.

The lava is visibly vesicular, and must have had a high gas content when molten, and would therefore have been very fluid. Gregory considered that local vesicular structure may have been due to steam generated as the lava flowed over swamps and lakes, and if the volume of water was not enough to have "frozen" the lava the steam caught up may have increased its fluidity.

Dodson's main point, that "It seems highly improbable that a single lava-flow could continue to flow for a distance of about 170 miles" will bear further investigation. In much of the present area, the gradient of the surface on which the lava flowed is now as low as 12 ft. per mile, but it has been proved from bore-hole logs kept by the Ministry of Works that the Kapiti phonolite, the parent mass of the Yatta phonolite, has been tilted since its deposition, and it is clear that the whole sub-Miocene surface must have been tilted to the south-east. The overall fall from the northernmost point of the flow to its end is 3,000 ft. over 180 miles, a gradient of 16.6 ft. per mile, but the gradient of the mature peneplain would have been only about half that figure, or eight feet per mile. Kempe's Engineers Year Book (1954, Vol. 1, p. 146) gives a formula for the flow of water in open channels. $V = C\sqrt{RS}$, where V is velocity in feet per second, C is a constant (usually found to be 100) R is the ratio of area of cross-section of the channel to the wetted perimeter of the channel in that cross-section, and S the slope of the channel. Considering a flow of water down the valley in which the Yatta lava flowed, assuming a depth of 60 ft., and a V-shaped channel several miles wide (since the width of the channel is very large compared to the depth the wetted perimeter is virtually the same as the width), R becomes $60/2 = 30$, and S is $8/5280$, and V is calculated as 21.3 ft. per second. Thus a water flow comparable in shape with what the lava is thought to have had originally would take only 12.4 hours to cover the 180 miles. If, for the purpose of argument, both water and molten lava are considered as ideal Newtonian liquids, in the formula $V = \frac{g d^2 \sin \alpha}{3\eta}$, for both liquids g (gravity) h (depth) and $\sin \alpha$ (gradient) remain the same, so that the two velocities vary according to $\frac{d}{\eta} = \frac{\text{density}}{\text{viscosity}}$. The density of the congealed lava was found to be 2.49, indicating a maximum figure for the molten lava of 2.4. No viscosity figures of phonolites are available, but Daly (1933, p. 72) quotes measured viscosities of flowing Hawaiian (basaltic) lavas as low as 11 times that of water. That felspathoidal lavas have a relatively low viscosity is indicated by figures quoted in the Handbook of Physical Constants (Geol. Soc. America, Special Paper No. 36, 1942, pp. 134-135).

<i>Laboratory melts of Japanese lavas</i>						<i>poises</i> (at 1200° C.)
Andesine basalt, Motomoura	..	..	..	..	..	31,200
Olivine basalt, Gembudo	..	..	..	..	..	3,180
Olivine basalt, Konoura	..	..	..	..	..	732
Nepheline basalt, Nagahama	..	..	..	..	..	190

(The viscosity of water at about 20° C. is .01 poises).

Since these are laboratory melts of congealed lavas it is certain that most or all of the volatile fluxes had been lost, and the true viscosity of the original lavas must have been many times lower than those quoted. The large phenocrysts of nepheline and anorthoclase in the Yatta phonolite clearly formed before extrusion, but both would crystallise at above 1100° C., so that the above figures can be taken as some guide to the viscosity of the lava. Assuming that the original viscosity of the Yatta lava was of the order of 1,000 times that of water, if the same viscosity were maintained throughout the flow and assuming the lava to be an ideal Newtonian liquid of density 2.4, the flow would have required 214.9 days to cover the 180 miles.

The movement of lava flows at Parícutin has been described by Krauskopf (1948, pp. 1267-1283). Soon after extrusion the surface of a lava hardens to scoriaceous blocks which are carried along with the flow, building marginal moraines which dam the lava to a great extent, and also forward over the snout to be overrun by the still molten lava. Krauskopf likens the mechanism to that of a caterpillar tractor. Temperatures in the lava fall only very slowly along its length, and a lava comparable with the Yatta phonolite above 100 ft. thick (before congealing the thickness in places may have

been several times this figure, as the depth of lava would fall as the flow moved on) would hold its heat by its very bulk, aided by the insulating effect of the cooled blocks on its surface and latent heat of crystallization given off by individual minerals as the lava congealed.

The actual time taken for emplacement of the flow may have been several times the estimate for an ideal flow. There is nothing in the microscopic detail of the rock to suggest that a time of even seven or eight hundred days would be too great. The groundmass is fine but holo-crystalline, and never glassy as it would be if very quickly chilled.

Undoubted flows of lava of lengths roughly comparable with that of the Yatta Plateau have been described. Barth (1952, p. 148) quotes a lava flow along a water-grade in the western part of the Grand Canyon which flowed for 135 km. with a drop of only 210 m.—a gradient of little more than eight feet per mile.

It therefore seems certain that Gregory's hypothesis is the true one, and that the Yatta Plateau marks the course of an old valley. In the present area the S-bend in the plateau is very characteristic of a river feature, though the reason for the double bend is not now clear. The fault that runs north-north-east from Kabaa may have influenced the course of the river, though it was not traced to the south-west of the bend. Gregory followed his theory to the logical conclusion that the emplacement of the lava must have diverted the original river into two rivers, one on each side of the flow, now represented by the present-day Athi and Tiva rivers. Sanders (1963) has proved that the Tiva formerly paralleled the Yatta Plateau far to the south of the sharp easterly bend near Wathoní, which he attributes to river capture.

The Athi and Tiva rivers show very dissimilar characteristics. The Athi, which has a perennial flow compared to the very intermittent surface flow of the Tiva, shows few of the features of a mature river system. Long stretches are perfectly straight, and shallow rapids are not uncommon. Its average gradient is fairly low, however, about 14 ft. per mile in the present area, and the river is frequently bordered by alluvium which stretches up to 500 ft. from either bank, but is generally less. Its local catchment area is gently undulating country, and even its major tributaries seldom cut down to solid rock. The Masongaleni river in fact meanders sharply for several miles.

In contrast the Tiva's catchment is fairly deeply dissected, and the river's course is frequently determined by steep bounding rock faces, usually steeply dipping ridges of quartzo-felspathic or granitoid gneisses. It has nevertheless cut a flood plain about a mile wide across which it meanders. The gradient of the flood plain is 21 ft. per mile, but the meandering reduces the gradient of the river bed to 12½ ft. per mile. The eastward portion of the river from the bend of capture near Wathoní is not taken into account in these calculations since, as mentioned earlier, the gradient shows a marked steepening here to 55 ft. per mile.

The dissection of the Tiva catchment area is a result of the river capture. Altitudes read along the old course of the Tiva south of Wathoní show that the capture led to a cutting-down of the river-bed to 200 ft. below its original level. The marked meanders of the river are an indication that the river itself is approaching grade, but the shortness of its tributaries and the low rainfall have not yet allowed them to cut down the catchment area to keep pace with the Tiva's downcutting. The final episode in the river's history is an accelerated down-cutting, which has incised the river bed to a depth of 15 ft., sweeping away the alluvium which the flood-plain must have contained. North-west of Ikutha two cut-off meanders can still be recognized whose beds are now above the Tiva's bed, showing that they were cut off before the meanders completed their incision. The reason for this last downcutting was not found, but is probably a result of Pleistocene rejuvenation.

The third river system of the area is the poorly defined drainage of the end-Tertiary peneplain and the pediment above it in the north-east. The rivers here, the largest of which are the Mavuko and Kaloboto, are choked with sand and flow only after prolonged rains, and then only for a few hours. They rarely show rock exposures, and the nature of the country suggests that down-cutting is not keeping pace with the weathering of the underlying rocks. These rivers, like the Tiva, drain towards the central reaches of the Tana, but it is not known if they reach that river or are lost in the plains before then.

IV—SUMMARY OF GEOLOGY

The solid rocks underlying the whole area are of the Basement System, considered as Archaean in age, with very minor intrusions. For the most part they are covered with superficial deposits of Pleistocene and Recent age. Two series of lavas are present, one of Miocene and the other of Recent age.

Basement System.—The Basement System rocks consist of a succession of paragneisses, mainly hornblendic in character, with biotite appearing as an important constituent towards the east. Relatively minor intercalations in this series are diopsidic, quartzo-felspathic and granitoid gneisses, with crystalline limestones, quartzites, and one small band of sillimanite gneiss. All are strongly metamorphosed and metasomatized, and contain no fossils by which they can be dated. They are assigned to the Basement System from their close resemblance to rocks of that system in many other parts of Kenya, some of which have been dated by chemical means and proved to be Precambrian in age.

The granitoid gneisses and quartzo-felspathic gneisses, both of which consist of little more than quartz and feldspar, form the most conspicuous features of the area, other than the Yatta Plateau. They are usually steeply dipping and form long sharp ridges. The granitoid gneisses which form the highest point in the area, the ridge of Kimathena, are tightly folded into the almost vertical core of a syncline which has remained as an erosion residual. The hornblendic gneisses are generally poorly exposed owing to their ease of erosion, and the most mafic facies of these gneisses, the plagioclase amphibolites, generally form negative features. The crystalline limestones, while sometimes forming distinct positive features, are often planed off to the level of the surrounding gneisses and, where superficial cover is thick, are often impossible to trace for any distance along the strike. They usually carry small flakes of graphite, and locally include or overlies workable deposits of graphite.

Intrusives into the Basement System rocks are few and small. They include a dyke of pyroxenite, a plug of olivine norite and a few small pegmatites consisting of quartz, feldspar and mica.

The Basement System rocks are all of sedimentary origin. The hornblende-biotite gneisses are thought to represent a difference of composition in the original sediments, perhaps an abundance of chlorite, as compared with those which gave rise to the hornblende gneisses, rather than a difference in metamorphic grade. The granitoid and quartzo-felspathic gneisses are considered to be of sedimentary origin, and originally were sandy strata and lenses in rather muddy sediments. Similarly the crystalline limestones and diopsidic gneisses reflect local increases in the calcareous content of the original sediments. The plagioclase amphibolites probably developed from fine-grained mudstones with a low sand content. They are always conformable with the strike of the neighbouring rocks.

Tertiary Volcanics.—The lava capping the Yatta Plateau is of the type that covers the Kapiti Plains south and south-west of Nairobi, where it is known as Kapitian Phonolite. It has a fine-grained groundmass, but carries large phenocrysts of anorthoclase and nepheline. It is considered to be Miocene in age, since it lies on the sub-Miocene peneplain. Over most of the Kapiti Plains the phonolite weathers to a black

clay soil, but here the soil, where it does not exceed two feet in depth, is free from waterlogging and weathers bright red.

Pleistocene and Recent.—Much of the solid rock of the area is mantled with red-brown sandy soils, mainly residual in character and derived by weathering and mechanical breakdown of the underlying rocks. Where drainage is poor black-cotton soils have developed. The Athi river has a narrow band of sandy alluvium along most of its length, sometimes interstratified with thin grey layers of fine silt deposited during floods. Most of the larger rivers have sandy beds, but none have alluvial flats.

Small deposits of surface limestone (*kunkar*) have developed on and near most of the limestones and over the more mafic hornblende rocks. Nodules of *kunkar* are also developed at and near the surface of the black-cotton soils.

Two tongues of olivine basalt invade the south-west corner of the area along the valleys of the Kibwezi and Masongaleni rivers, having their origin in the Chyulu hills. They have been intensively studied by Temperley (1956, Vol. II, pp. 64-122), who has recognized three superimposed flows, all of olivine basalt, in the part of the Kibwezi valley in this area. There is no evidence of any considerable lapse of time between successive flows. They have a coarse, blocky and sometimes ropy surface, and though they are well wooded all the trees and bushes are rooted in soil which has been blown or washed into crevices in the lava, and the upper surface is virtually unweathered and free from soil. These are characteristics of lavas of a recent origin, and the age of the Kibwezi and Masongaleni lavas is probably in the order of 1,000 years.

In the northern part of the area the succession appears to be:—

3. Yatta Plateau Phonolite. Average thickness 30 ft.

Long period of erosion.

2. Hornblende gneisses with granitoid and quartzo-felspathic gneisses, and minor intercalations of crystalline limestones, biotite gneisses and plagioclase amphibolites. Present thickness about 70,000 ft.
1. Hornblende-biotite and hornblende gneisses with granitoid and quartzo-felspathic gneisses, plagioclase amphibolites and well-developed crystalline limestones. Thickness about 10,000 ft.

V—DETAILS OF GEOLOGY

1.—The Basement System

The rocks of the Basement System in this area are classified as follows:—

(1) Metamorphosed psammitic sediments—

- (a) Quartzites.
- (b) Granitoid gneisses.
- (c) Quartzo-felspathic gneisses and granulites.
- (d) Biotite gneisses.
- (e) Biotite-garnet gneisses.

(2) Metamorphosed semi-pelitic sediments—

- (a) Hornblende-biotite gneisses.
- (b) Hornblende gneisses.
- (c) Hornblende-garnet gneisses.
- (d) Hornblende-diopside gneisses.

(3) Metamorphosed pelitic sediments—

- (a) Plagioclase amphibolites.
- (b) Sillimanite gneisses.

- (4) Metamorphosed calcareous sediments—
 (a) Crystalline limestones.

- (5) Migmatites.
 (a) Hornblende migmatites.
 (b) Biotite migmatites.

Intrusives into the Basement System comprise—

- (a) Pyroxenites.
 (b) Olivine norites.
 (c) Minor acid pegmatites.

The lowest part of the succession that can be determined with any certainty is the Yamalu-Kimathena syncline, where it is as follows:—

	<i>Approximate average thickness (feet)</i>
Biotite migmatites	500
Hornblende gneisses	400
Hornblende-biotite gneisses, with minor bands of quartzo-felspathic gneiss	1,400
Granitoid gneisses with thin biotite migmatites	1,200
Plagioclase amphibolites	1,000
Granitoid gneisses	300
	4,800

This group is separated from adjoining exposures to the west by a fault which probably downthrows to the west, though this was not proved. The next highest rocks are the hornblende-biotite gneisses about Ndawemwe, which enclose a single band of crystalline limestone near the base, refolded to outcrop three times, and another near the top, together with a band of hornblende-diopside gneiss, and discontinuous bands of granitoid gneiss, quartzo-felspathic gneiss, plagioclase amphibolite and biotite migmatite, the broad outlines of the succession being as follows:—

	<i>Approximate average thickness (feet)</i>
Hornblende-biotite gneisses with crystalline limestone and plagioclase amphibolites	1,500
Quartzo-felspathic gneisses	150
Hornblende-diopside gneisses	350
Hornblende-biotite gneisses with quartzo-felspathic gneisses	1,800
Crystalline limestone	400
Hornblende-biotite gneisses/granitoid gneisses	1,000
	5,200

The remainder of the Basement System rocks fall into one group, characterized by hornblende gneisses with intercalations of granitoid gneiss, quartzo-felspathic gneiss and crystalline limestone, and lesser bands of hornblende-biotite gneiss, biotite gneiss, hornblende-diopside gneiss, plagioclase amphibolite, hornblende migmatite and quartzite.

The present thickness of this group is about 70,000 ft. but, as discussed later, the true thickness must be much less, the width of outcrop being exaggerated by repetition of beds by strike-faulting and folding. Averaging out across the whole area of the outcrops, the 70,000 ft. ~~breaks down~~ as follows (not in stratigraphical order):—

	Approximate thicknesses (feet)
Hornblende gneisses	59,000
Granitoid gneisses	3,700
Quartzo-felspathic gneisses	3,300
Crystalline limestones	1,480
Hornblende-biotite gneisses	740
Biotite gneisses	740
Hornblende-diopside gneisses	440
Plagioclase amphibolites	370
Hornblende migmatites	150
Quartzites	80
	70,000

(1) METAMORPHOSED PSAMMITIC SEDIMENTS

The rocks included in this section had their origin in sandstones and arkoses containing only minor amounts of ferruginous or calcareous minerals. The distinction between granitoid gneisses and quartzo-felspathic gneisses and granulites was made on their aspect in the field, the granitoid gneisses weathering into craggy tors and broken and rugged topography, against the much more even outlines and smooth rock pavements typically developed in the quartzo-felspathic gneisses and granulites. Later examination of microscope sections showed that the granitoid gneisses almost invariably contain a large proportion of microcline, and where field identification was doubtful this criterion has been used for classification.

(a) Quartzites

True quartzites are few in the area, the feldspar content of most of the psammitic rocks being high enough to put them into the quartzo-felspathic or granitoid gneiss classes. A true quartzite which occurs at Utundani on the Tiva river, specimen 60/202*, is a dark grey-brown rock with numerous small cavities coated with brown iron oxide. It has only a vague foliation, which is marked by the alignment of the cavities. In this section it shows a mosaic of coarse anhedral interlocking unstrained quartz grains which enclose numerous small euhedral or subhedral pale pinky-brown garnets, and small grains of augite surrounded by and intergrown with opaque iron ore. It contains 92 per cent quartz, with 4 per cent garnet, 1 per cent augite and 3 per cent iron ore.† Specimen 60/187 from Imiwa seven miles north-east of Ikutha, is light red in colour, due to staining by iron oxide. It contains 80 per cent quartz and 20 per cent microcline, with iron oxide and tiny prisms of apatite as accessories.

(b) Granitoid gneisses

These are generally coarse-grained rocks, varying in colour from cream to pink, and often carrying very small amounts of mafic minerals, usually magnetite, hornblende and biotite. Foliation is usually only poorly marked, and shows itself by alignment of

* Numbers prefixed 60/ refer to specimens in the regional collection for Degree Sheet 60 in the Mines and Geological Department, Nairobi.

† All modes quoted are volumetric and estimated.

mafic crystals and sometimes by the flattening and elongation of quartz and feldspar grains. In thin section this flattening is seen to be due to re-crystallization of quartz, and to a lesser extent feldspar (usually microcline), individual grains showing as large, clear blebs with rounded outlines, interlayered with finer-grained angular aggregates of quartz and feldspar, the latter usually cloudy and altered, and all showing fracture and undulose extinction. These rocks always contain plagioclase feldspar, of the composition of albite-oligoclase or oligoclase, which occurs in the older generation of feldspars. The re-crystallization of quartz and feldspar is due to preferential attack by alkali metasomatizing fluids which have affected the original quartz and feldspars at a late stage in the metamorphic history of the area and permitted them to re-crystallize in an unstrained or only slightly strained condition. Accessories include magnetite, hornblende, biotite, muscovite, garnet, epidote, sphene and zircon. Some estimated modes are:—

	60/167	60/132	60/165	60/144	60/191	60/139	60/148
	%	%	%	%	%	%	%
Quartz	55	40	40	27	25	23	12
Orthoclase	—	32	—	24	6	10	28
Microcline	36	—	40	40	58	60	55
Plagioclase	8	25	18	6	10	7	4
Accessories	1	3	2	3	1	+	1

60/167—Dwa Rock.

60/132—Ngunumu.

60/165—Iviani Ithieti.

60/144—Kimathena.

60/191—Chamwalanya.

60/139—Kimakimwe.

60/148—Dudini.

(c) Quartzo-feldspathic gneisses and granulites

These vary in colour from cream to buff, or more rarely pink or red, and are usually of finer grain than the granitoid gneisses, and are sometimes granulitic. They usually show good foliation marked by alignment of mafic accessory minerals. Interstitial recrystallization of quartz and feldspars as described in the granitoid gneisses sometimes occurs, as in specimen 60/151 from Ndoyani, but the newer generation of feldspars here are orthoclase, not microcline, only slightly micropertthitic against the strongly micropertthitic orthoclase of the older generation. Plagioclase feldspars are all of the composition of oligoclase. Accessory minerals include hornblende, biotite, muscovite iron ore and apatite.

Some estimated modes are:—

	60/211	60/151	60/130
	%	%	%
Quartz	50	27	15
Orthoclase	12	65	45
Plagioclase	34	6	35
Accessories	4	2	5

60/211 Quartzo-feldspathic granulite, Ithangathi.

60/151 Quartzo-feldspathic gneiss, Ndoyani.

60/130 Quartzo-feldspathic gneiss, Kwambleti.

mafic crystals and sometimes by the flattening and elongation of quartz and feldspar grains. In thin section this flattening is seen to be due to re-crystallization of quartz, and to a lesser extent feldspar (usually microcline), individual grains showing as large, clear blebs with rounded outlines, interlayered with finer-grained angular aggregates of quartz and feldspar, the latter usually cloudy and altered, and all showing fracture and undulose extinction. These rocks always contain plagioclase feldspar, of the composition of albite-oligoclase or oligoclase, which occurs in the older generation of feldspars. The re-crystallization of quartz and feldspar is due to preferential attack by alkali metasomatizing fluids which have affected the original quartz and feldspars at a late stage in the metamorphic history of the area and permitted them to re-crystallize in an unstrained or only slightly strained condition. Accessories include magnetite, hornblende, biotite, muscovite, garnet, epidote, sphene and zircon. Some estimated modes are:—

	60/167	60/132	60/165	60/144	60/191	60/139	60/148
	%	%	%	%	%	%	%
Quartz	55	40	40	27	25	23	12
Orthoclase	—	32	—	24	6	10	28
Microcline	36	—	40	40	58	60	55
Plagioclase	8	25	18	6	10	7	4
Accessories	1	3	2	3	1	+	1

60/167—Dwa Rock.

60/132—Ngunumu.

60/165—Iviani Ithieti.

60/144—Kimathena.

60/191—Chamwalanya.

60/139—Kimakimwe.

60/148—Dudini.

(c) *Quartzo-feldspathic gneisses and granulites*

These vary in colour from cream to buff, or more rarely pink or red, and are usually of finer grain than the granitoid gneisses, and are sometimes granulitic. They usually show good foliation marked by alignment of mafic accessory minerals. Interstitial recrystallization of quartz and feldspars as described in the granitoid gneisses sometimes occurs, as in specimen 60/151 from Ndoyani, but the newer generation of feldspars here are orthoclase, not microcline, only slightly micropertthitic against the strongly micropertthitic orthoclase of the older generation. Plagioclase feldspars are all of the composition of oligoclase. Accessory minerals include hornblende, biotite, muscovite iron ore and apatite.

Some estimated modes are:—

	60/211	60/151	60/130
	%	%	%
Quartz	50	27	15
Orthoclase	12	65	45
Plagioclase	34	6	35
Accessories	4	2	5

60/211 Quartzo-feldspathic granulite, Ithangathi.

60/151 Quartzo-feldspathic gneiss, Ndoyani.

60/130 Quartzo-feldspathic gneiss, Kwambleti.

(d) *Biotite gneisses*

Biotite gneisses are few and small in outcrop, occurring mainly as thin discontinuous bands in the hornblende gneisses. A typical example, specimen 60/131 from Chunguni, is a light buff, medium-grained gneiss containing up to 10 per cent of biotite in fine flakes, whose alignment gives a marked foliation to the rock. Granitization has caused a small-scale development of porphyroblastic feldspars.

(e) *Biotite garnet gneisses*

The only occurrence of this rock type large enough to be shown on the map is the isolated outcrop of Nduni, south of Ithumba, which forms a hill over 100 ft. high elongated along the strike. In hand-specimen (60/149) it is cream in colour, speckled with black biotite flakes which are aligned in bands along the foliation. In thin section the biotite is seen to be dichroic from yellow to dark brownish-green, and the garnets bright pink, much fractured, and with subhedral outlines. Both orthoclase and plagioclase feldspars occur, the latter of the composition of sodic oligoclase. A second representative, specimen 60/195, is a local variation of the quartzo-feldspathic gneiss at Mkongweni. In hand-specimen it closely resembles 60/149; under the microscope the feldspars are turbid, and appear to be mainly plagioclase, again of sodic oligoclase composition, with a small amount of orthoclase and microcline.

Estimated modes of these two rocks are:—

				60/149	60/195
				%	%
Quartz	..	..	..	32	35
Orthoclase	..	..	..	44	12
Microcline	..	..	..	—	+
Plagioclase	..	..	..	17	44
Biotite	..	..	..	5	6
Muscovite	..	..	..	—	+
Garnet	..	..	..	2	3
Iron ore	..	..	..	+	+

60/149 Nduni.

60/195 Mkongweni.

(2) METAMORPHOSED SEMI-PELITIC SEDIMENTS

The metamorphosed semi-pelitic sediments are divided into four groups, viz.:—

- Hornblende-biotite gneisses.
- Hornblende gneisses.
- Hornblende-garnet gneisses.
- Hornblende-diopside gneisses.

The divisions tend to overlap, and to grade towards the plagioclase amphibolites. The distinction between hornblende-biotite gneisses and hornblende gneisses has been made where biotite amounts to 20 per cent of the total hornblende/biotite content. All these rock types are thought to have developed by metamorphism of relatively fine-grained sediments with marked calcareous content.

(a) *Hornblende-biotite gneisses*

These occupy a large region in the north of the area and pass westward into hornblende gneisses, the transition being gradual over a width of outcrop of a quarter of a mile. They are typically buff or grey in colour, with the mafic minerals arranged in layers interspaced with more leucocratic layers, giving a poorly defined banding usually on a fine scale, though locally alternating bands up to half an inch thick were noted. In thin section the hornblende is found to be pleochroic from light to very dark olive-green, and the biotite dichroic from yellow to dark greenish-brown or black. The biotite is usually associated with grains of opaque iron ore and is often marginal to or intergrown with the hornblende, to which it sometimes shows a clear replacive relationship. Plagioclase feldspar present has the composition of oligoclase or oligoclase-andesine. In specimen 60/134 from Kasasi much of the original rock material has recrystallized under pressure. Most of the hornblende and biotite is in wisps and grains aligned along the foliation, and much of the microcline of the original rock has been replaced by later quartz and orthoclase. Garnet, zircon, apatite and iron ore occur as accessories.

Four estimated modes, listed in order of decreasing hornblende content, are:—

	60/175	60/143	60/169	60/134
	%	%	%	%
Quartz	22	25	15	13
Orthoclase	13	13	22	19
Microcline	—	44	—	55
Plagioclase	52	8	40	6
Hornblende	7	5	4	3
Biotite	5	4	14	1
Accessories	1	1	5	1

60/175—Masalani.

60/143—Twanili.

60/169—Dwa.

60/134—Kasasi.

(b) *Hornblende gneisses*

The hornblende gneisses are exposed in a broad band flanking the Tiva river and a narrower band along the Athi river, though it is fairly certain that they underlie the superficial soils covering the whole of the south-western part of the area. Their resistance to erosion is small, and they outcrop only in river sections and in the dissected catchment area of the Tiva. They vary in colour from buff to almost black, according to their content of mafic minerals. Where exposures are continuous, as in stretches of the Tiva and Diliu rivers, the colour index changes rapidly over short distances, and in places the rocks are clearly banded on all scales from a fraction of an inch to tens of feet. Along the Tiva river north-west of Ikutha the gneisses contain bands of reddish quartzo-feldspathic gneiss, perfectly conformable with the strike and which, while often as little as two feet thick, can be traced for several miles as they cut successive meanders of the river. Sometimes these bands reach hundreds of feet in thickness, when they are shown on the map as quartzo-feldspathic or granitoid gneisses. Similarly other bands and lenses of crystalline limestone, hornblende-dioptase gneiss, biotite gneiss etc. are intercalated with the hornblende gneisses. In all the microscope slides examined the

hornblende is strongly pleochroic in shades of olive-green and frequently has small amounts of biotite in contact with it, sometimes as a replacement, the latter being dichroic from straw-yellow to dark grey-brown or black. In specimen 60/121 the biotite occurs as ~~shreds in~~ hornblende at wide angles to the foliation and occasionally as cores to hornblende crystal aggregates, suggesting here a replacement of biotite by hornblende, though in one part of the slide biotite is seen to be followed by hornblende without replacement. Quartz occurs in all the slides examined, and in all but one plagioclase feldspar is an important constituent, ranging in composition from acid oligoclase to andesine. Orthoclase feldspar occurs in varying amounts in most of the sections, but microcline occurs only in the slide in which plagioclase is lacking. This slide, specimen 60/194, from Kaandui, is much finer in grain than normal and is almost schistose. Except where quartz and feldspar have been re-crystallized the constituent minerals all show shattering and strain effects, as a result of strong shearing.

Minerals present as accessories in the hornblende gneisses are biotite, garnet, zircon, apatite and iron ores, and in specimen 60/108 hypersthene and diopside.

Some estimated modes are:—

	60/120	60/153	60/121	60/210	60/108	60/194	60/209
	%	%	%	%	%	%	%
Quartz	7	20	3	40	8	40	53
Orthoclase	15	—	35	8	22	9	10
Microcline	—	—	—	—	—	35	—
Plagioclase	55	62	45	35	55	—	25
Hornblende	22	16	15	12	10	8	8
Biotite	1	+	1	2	2	2	2
Other minerals ..	+	2	1	3	3	6*	2

*Mainly iron ore.

60/120—Kisou.

60/153—Diliu.

60/121—Ngwate.

60/210—Mbatu.

60/108—Muthungwoi.

60/194—Kaandui.

60/209—Kazi.

(c) Hornblende-garnet gneisses

The aspect in the field of the hornblende-garnet gneisses points to their being local variations of the hornblende gneisses in which two of the three exposures were found, lying conformably to their strike. In no case were contacts between the two rock types found, however, and the sedimentary origin of the hornblende-garnet gneisses cannot be regarded as proven. The two specimens examined in thin section, 60/127 from Nzauni and 60/188 from Makaiye, are from outcrops separated in the field by six miles, and apparently are not parts of one continuous outcrop. In hand-specimen both are fine-grained, dark grey-brown in colour, with foliation poorly marked by a fine-scale alternation of leucocratic and melanocratic bands. Under the microscope both show the hornblende to be pleochroic in olive-green, associated with opaque iron ore, and pale pink garnets, euhedral or subhedral and fractured, but without embayed outlines. The only feldspar is plagioclase of composition $An_{60}+$ (labradorite). Hypersthene is a major constituent in 60/127 and an accessory in 60/188, and is strongly pleochroic,

X = pink, Y = yellow-green and Z = blue. Diopside occurs only in 60/188 where it is a major constituent.

The modes of these two rocks were estimated as:—

	60/127	60/188
	%	%
Quartz	—	5
Plagioclase	50	41
Hornblende	15	8
Biotite	—	+
Diopside	—	18
Hypersthene	25	2
Garnet	8	23
Iron ore	2	3

60/127—Hornblende-hypersthene-garnet gneiss, Nzauni.

60/188—Hornblende-diopside-garnet gneiss, Makaiye.

(d) *Hornblende-diopside gneisses*

The hornblende-diopside gneisses are dark grey in colour, of medium or coarse grain, and usually foliated on a fine scale by the concentration of the melanocratic minerals in marked layers. In thin section the hornblende is seen to be pleochroic from light to dark olive green, and intergrown with diopside, faintly pleochroic in light blue-greens. Where hypersthene occurs it is strongly pleochroic from pink to green. In specimen 60/157 from Ndoyani there is clear evidence of replacement of both diopside and hypersthene by hornblende, a good deal of iron ore having been thrown out in the process. In the same specimen are a few flakes of red-brown biotite derived from hornblende. Plagioclase occurs in all the sections examined and is andesine except in specimen 60/118, from Katakolo, where it is oligoclase-andesine, and is accompanied by orthoclase.

Estimated modes of the hornblende-diopside gneisses are:—

	60/161	60/157	60/180	60/118
	%	%	%	%
Quartz	—	—	20	5
Orthoclase	—	—	—	15
Plagioclase	55	45	61	47
Biotite	—	1	+	+
Hornblende	28	23	12	12
Diopside	16	15	4	8
Hypersthene	—	13	—	8
Garnet	1	—	+	—
Apatite	+	1	1	2
Iron ore	+	2	2	3

60/161—Koala.

60/157—Ndoyani.

60/180—Uthainga.

60/118—Katakolo.

(3) METAMORPHOSED PELITIC SEDIMENTS

This section comprises only two rock types, of very varying aspects—plagioclase amphibolites and sillimanite gneisses.

(a) *Plagioclase amphibolites*

The field relationships of the plagioclase amphibolites could usually be determined with some degree of certainty, and proved that they are conformable with the trend of the rocks in their vicinity, or are found in conformable contact with other rocks, and all are considered to be of sedimentary origin. As already mentioned there is a graduation of types between the plagioclase amphibolites and the hornblende-bearing gneisses. Rocks included in this section are those with a high amphibole/pyroxene content and a fairly calcic plagioclase. All are of fairly coarse grain, dark grey-green to black in colour, speckled with white or pale pink feldspars. Foliation is usually fairly well marked by alignments of individual crystals and the tendency for the feldspars to occur in discrete layers. In thin section the hornblende is found to be pleochroic in olive, green, and sometimes shows clear evidence of replacing diopside and/or hypersthene, the hornblende itself sometimes showing replacement by biotite. No quartz was found in any of the slides and the only feldspar is plagioclase, varying from andesine to labradorite. Calcite occurs in specimen 60/159 from Maindunduni as lobate patches intergrown with hornblende. Other calcic minerals are rare, being represented only by sphene and apatite, both in trace amounts.

Estimated modes are as follows:—

	60/113	60/159	60/176	60/201	60/145
	%	%	%	%	%
Plagioclase	25	31	25	52	44
Biotite	—	2	—	+	—
Hornblende	67	65	55	38	37
Diopside	—	—	20	8	—
Hypersthene	7	—	—	—	18
Calcite	—	1	—	—	—
Apatite	—	+	—	+	—
Sphene	—	—	+	—	—
Iron ore	1	1	—	2	1

60/113—Mavia.

60/159—Maindunduni.

60/176—Ngomano.

60/201—Wathoni.

60/145—Kimathena.

(b) *Sillimanite gneisses*

Only one representative of this rock type was found, in the nose of a plunging anticline along the railway at Kabingo. It is poorly exposed in drainage trenches and is not thought to exceed 30 ft. in thickness, its outcrop having been necessarily exaggerated on the map. In hand-specimen (60/172) it is of medium grain, fairly friable, white and purple in colour, the latter due to powdery iron oxides. Under the microscope the sillimanite is seen to occur in felted clusters of fine fibres enclosed in a quartz matrix. Associated minerals are rutile, in stubby prisms and anhedral grains, anhedral grains of opaque iron ore and lesser amounts of translucent red iron oxide. Its mode was estimated as:— Quartz 47 per cent, sillimanite 50 per cent, rutile 1 per cent, iron minerals 2 per cent.

(4) METAMORPHOSED CALCAREOUS SEDIMENTS

The only representatives of this class of rock in the classification adopted for the area are the crystalline limestones. Other rocks with a lesser calcareous content have been classified as hornblendic gneisses and migmatites, and included with the pelitic and semi-pelitic rocks, or the migmatites.

(a) Crystalline limestones

These occur as bands and lenses sometimes reaching a thousand feet in width of outcrop. All are very coarse in grain, that at Otekilawa having grains of calcite up to 2 cm. in diameter. Colours range from pure white to light red and shades of grey and blue-grey. The colour often varies widely in different parts of the same outcrop, and could not be used as a criterion for identifying discontinuous outcrops of the same band. Specimens from all the larger outcrops were tested by a colorimetric method and found to contain a small percentage of dolomite except 60/124, from Kasaala.

Graphite occurs in the majority of the exposures examined, usually as single flakes disseminated throughout the rock, but occasionally in large lenses enclosed in and marginal to the limestone. At Kamstoi, on the northern boundary of the area, such lenses are being worked as graphite ore. A microscope section of a hand-picked specimen of this ore, 60/190, shows graphite in flakes up to 5 mm. in diameter intergrown with quartz and felspar and associated with small amounts of apatite, phlogopite and a pale green mica. The graphite content of the slide was estimated as 30 per cent.

Other accessory minerals in the marbles occur both as disseminated grains and as knots and lenses which seldom reach a diameter of more than 10 cm. Such knots tend to stand out sharply on weathered surfaces. One such knot, specimen 60/117 from a point two miles south-east of the Kamstoi graphite workings, was sectioned and found to consist mainly of cloudy felspars, chiefly microcline but with small amounts of orthoclase and plagioclase (oligoclase). Other minerals present in significant amounts are carbonate relics, quartz in clear, elongated belts and pale brown to colourless phlogopite. Apatite, sphene and opaque iron ore occur in trace amounts.

Quartz is a fairly common constituent of the limestones, and chalcedony occurs in specimen 60/106 from Muthungwoi. Scapolite occurs in large grains in specimens 60/141 from Kasasi and 60/164 from Mutula, and in a slide of the latter is associated with phlogopite. Forsterite occurs widely, sometimes altering to talc. In specimen 60/208 from Waamata on the Tiva river in the extreme south-east scapolite is seen in large rounded grains. This last specimen is interesting as being particularly impure, knots of greenish black mineral aggregates making up one third of the bulk of the rock, the calcite groundmass being pink in colour. In addition to scapolite the following minerals were identified in this section:—pinkish brown sphene, apatite, quartz, diopside and actinolite.

(5) MIGMATITES

In the east of the area and locally in the hornblende gneisses in the centre there are outcrops of rocks that are characterised by the intermixing of mineral aggregates of very marked contrast, taking the form of leucocratic host-rocks enclosing lenses and schlieren of melanocratic character. They are characterised by acute contortions on a small scale, indicative of tight folding whilst in a semi-plastic state. Where such rocks are weathered to smooth pavements or low rounded erosion residuals, as is often the case, it is usually possible to determine their overall strike and dip, which always prove to be in good accord with the regional pattern. The melanocratic components of these rocks are always hornblendic, but the host-rock sometimes contains biotite and sometimes hornblende, and it is on this criterion that they are divided.

(a) Hornblende migmatites

The hornblende migmatites occur as narrow bands near the centre of the area and in larger exposures in the south-east. Along the Tiva river east of Wathoni there is a gradual transition westwards into hornblende gneisses, and the division marked between the two types on the map is only approximate. A typical specimen, 60/182

from Kwambagi, is coarse-grained, and cream in colour with black inclusions which frequently take the form of boudinage bodies. In thin section the leucocratic facies is found to consist predominantly of feldspar, including both slightly microperthitic orthoclase and plagioclase of the composition of andesine. Other constituents are quartz and hornblende, the latter reaching 3 per cent of the whole, with trace amounts of biotite and iron ore. The melanocratic facies, specimen 60/183, is black in colour, banded with buff layers of leucocratic material that occasionally reach 2 cm. in thickness and give the rock a wavy foliation in good accord with the regional foliation. A thin section was cut across such a leucocratic layer, and shows it to consist of quartz and orthoclase feldspar, sometimes microperthitic, with occasional ill-defined lobate patches of myrmekite. The melanocratic layers in this section are virtually plagioclase amphibolites, with an almost equal percentage of hornblende and andesine. Other minerals, in order of their importance, are hypersthene, opaque iron ore, orthoclase, apatite, biotite and garnet.

Specimen 60/197 from Chumanenze shows an unusual texture in the melanocratic parts. Its black groundmass is dotted with buff-coloured blebs consisting of aggregates of garnet grains rimmed by feldspar. Such blebs sometimes reach 2 cm. in diameter, and often show a good crystal outline, with prism edges and dome or pyramid terminations. Their outline suggests that they may be pseudomorphs after staurolite or possibly andalusite, though these minerals were nowhere found in the area. In thin section the garnets are seen to be pale pink in colour with frequent inclusions of opaque iron ore. They generally have a sutured and embayed outline, but occasionally show good crystal faces in part. The feldspar is andesine. Hornblende, pleochroic from light to dark olive-green, is the predominant mafic mineral, and hypersthene also occurs. The estimated mode of the mafic parts of the rock is plagioclase 28 per cent, hornblende 47 per cent, hypersthene 12 per cent, garnet 10 per cent, iron ore 3 per cent and a trace of apatite.

(b) *Biotite migmatites*

A typical example of the biotite migmatites is provided by specimen 60/116 from Ndulukye. The leucocratic component is mineralogically a fairly typical biotite gneiss, except that the plagioclase is rather basic, being of the composition of andesine. It usually shows albite twinning. Biotite, dichroic from yellow-brown to black, makes up 12 per cent of the rock and quartz and orthoclase are important constituents. In the melanocratic components biotite makes up only 2 per cent against 65 per cent of hornblende. Plagioclase feldspar here is mostly untwinned, again andesine. Small amounts of orthoclase and quartz also occur. In specimen 60/204 from Nza the plagioclase feldspar is oligoclase in the leucocratic parts but again andesine in the dark components. In the latter biotite occurs in minor amounts partly replacing hornblende and pyroxene; the hornblende itself seems to have been derived from diopside and hypersthene, both of which are still present in significant amounts. No quartz or orthoclase were seen, and the mode was estimated as plagioclase 33 per cent, biotite 3 per cent, hornblende 40 per cent, diopside 7 per cent, hypersthene 15 per cent and apatite and iron ore 1 per cent each.

(6) INTRUSIVES INTO THE BASEMENT SYSTEM

Intrusives that have penetrated into the Basement System rocks are few and small, those recognized being a pyroxenite at Makaiye, west of Ikutha, a biotite pyroxenite at Wathoni, an olivine norite at Yumba, two miles south-south-west of Ikutha, and minor acid pegmatites at various localities, all too small to map. Some of the pegmatites are not true intrusives, but are considered here for convenience.

(a) *Pyroxenite*

The pyroxenite at Makaiye (specimen 60/126) takes the form of a slight ridge elongated along the strike of the neighbouring hornblende gneisses, the sharp junction between the two being exposed only in one small gully. It is considered to be an ultra-

basic dyke or sill emplaced in the Basement rocks before metamorphism. In hand-specimen it is non-foliated, of medium grain and dark blue-grey in colour, speckled with white feldspars. In thin section the predominant mineral is a hedenbergitic diopside, pleochroic from yellow to medium blue-green. The feldspar is all plagioclase (labradorite), with strong albite twinning, and is usually somewhat saussuritized marginally. Epidote and sphene occur in small irregular grains, and opaque iron ore in fairly large anhedral grains, always in contact with or enclosed by diopside. The mode was estimated as plagioclase 27 per cent, diopside 70 per cent, epidote 1 per cent, iron ores 2 per cent and sphene in trace amounts.

In the biotite pyroxenite at Wathoni, specimen 60/47, the predominant mineral is enstatite, pleochroic from pale green to pink, intergrown with lesser amounts of hornblende and pale green diopside. The biotite, which is dichroic from straw-yellow to deep red-brown occurs in large ragged flakes. Oligoclase is the only feldspar present, totalling less than 10 per cent of the slide.

(b) *Olivine norite*

The outcrop of this rock is slightly exaggerated on the map. It is seen as large rounded boulders exposed in red soil over a roughly elliptical area 300 by 150 ft., the long axis being aligned along the regional strike. No other solid rock is exposed nearby, and it was concluded that the outcrop represents an eroded volcanic plug. In hand-specimen (60/154) the rock is very coarse, dark grey and black, with no trace of foliation. The most conspicuous mineral is a black mica in plates up to 2 cm. in diameter. It is not vermiculitic. In thin section the mica is pleochroic from very pale straw yellow to light brown or green, and is considered to be phlogopite rather than biotite. Olivine occurs in large anhedral crystals, much fractured and frequently rimmed by very pale green hypersthene. This hypersthene does not appear to be an alteration product after olivine but rather a reaction product between the early-crystallized olivine and the residual magma. Almost colourless hypersthene, with ex-solution lamellae, and sometimes small inclusions of olivine, also occurs as large discrete crystals. The feldspars sometimes show very poor albite twinning and more frequently a vague cross-hatching reminiscent of microcline. Refractive index determinations show it to be a sodic oligoclase. It includes many prisms of apatite and blebs and streaks of calcite. That such a sodic feldspar should occur in a rock basic enough to contain a large proportion of olivine can be explained by the separating out of calcium from originally basic feldspars in the course of metamorphism thus raising them to a more sodic status (the present oligoclase), the calcium being recrystallized as calcium carbonate. By this criterion alone it is considered that the rock was emplaced before the conclusion of the regional metamorphism and granitization of the Basement System rocks. The mode of the rock, estimated from examination of two thin sections, is plagioclase 18 per cent, phlogopite 22 per cent, hypersthene 20 per cent, olivine 38 per cent, apatite 1 per cent, calcite 1 per cent, iron ore a trace.

(c) *Minor acid pegmatites*

Two occurrences of coarse pegmatites were noted, but in neither case could their relationship to the surrounding gneisses be established. Specimen 60/178 was taken from large float blocks on the slopes of the Yatta Plateau near Masalani. It consists of white quartz, pale cream feldspar (determined microscopically as albite) and lesser amounts of biotite and muscovite. The biotite occurs in fractured plates up to 5 cm. in diameter, and is slightly vermiculitic. The muscovite flakes never exceed a few millimetres. No other minerals were seen.

The second example is exposed in an old prospecting pit at Manoni. The only minerals seen were quartz, feldspar and vermiculitic biotite in flakes up to 15 cm. in diameter. The pegmatite lies under a cover of red soil up to three feet in thickness, and its relationship to the country rock could not be determined.

Specimen 60/123 from Mongua was taken from a pegmatite seen cross-cutting quartzo-felspathic gneisses. It is cream and pink in colour, and consists only of quartz, feldspar and biotite, flakes of the latter averaging 2 cm. in diameter. It is one of many stringers that reach a width of up to 30 cm. growing outwards from knots up to 1 m. in diameter the ~~stringers~~ narrowing with increasing distance from the centres. They show no displacement of the country rock nor any chilled margins, and are replacement pegmatites formed by re-crystallization *in situ* of the minerals of the country rock under the influence of metasomatizing agencies.

In the bed of the Tiva river at Munyuni where the hornblende migmatite is cut by minor shears, replacement veins in the form of stringers follow the shears. They seldom exceed 20 cm. in thickness, but are unusual in that they consist of a groundmass of magnetite which supports phenocrysts of feldspar and a little quartz. In specimen 60/205 about 75 per cent of the rock is magnetite, with white translucent feldspar phenocrysts which average about 1 cm. in diameter making up 24 per cent, the remaining 1 per cent being quartz.

2.—Tertiary—Yatta Plateau Phonolite

In hand-specimen the phonolite of the Yatta Plateau, which corresponds to that of the Kapiti Plains south of Nairobi, is dark grey in colour with a grain so fine as to be barely distinguishable to the naked eye, supporting numerous phenocrysts of white anorthoclase in elongated plates and a lesser amount of nepheline in short stubby prisms, almost black in colour and with a resinous lustre. Anorthoclase phenocrysts were seen that measured as much as 8 cm. in length, but the average is about 2.5 cm. The nepheline phenocrysts seldom exceed 1 cm. No difference in texture or phenocryst content was noted along the whole length of the flow in this area. Hollow vesicles are rare but are sometimes seen with a thin coating of zeolites, tentatively identified as natrolite. Smaller vesicles up to 3 cm. in diameter completely filled with analcime, are fairly common. A typical specimen, 60/129 from Nzauni, was sectioned and, besides anorthoclase and nepheline, anhedral and euhedral microphenocrysts of olivine, usually rimmed by coesynite, were identified. The groundmass consists of a felted mass of laths of anorthoclase, small crystals of nepheline, coesynite pleochroic from brown to black, kataphorite pleochroic from very pale green to purple, and laths and angular grains of deep green aegirine. Augite also occurs, pale green or brownish-green in colour, often simply twinned on 100. Other minerals identified were a few small anhedral grains of apatite, small grains of opaque iron ore, and analcime which forms an abundant base, and is particularly noticeable in irregular patches scattered throughout the rock in which there are deficiencies of dark minerals.

3.—Pleistocene and Recent

(1) LAVAS

Specimens of the Chyulu lavas that flowed down the Kibwezi and Masongaleni valleys were sectioned (60/168 and 60/170) and identified as olivine basalts. In the field the lavas are dark blue-grey in colour, very scoriaceous, with a fine granular texture and no visible phenocrysts. Zeolites are rare, and where seen lining vesicles were identified as natrolite. In thin section the rocks consist of a fine-grained holocrystalline groundmass supporting microphenocrysts of euhedral olivine and sometimes prisms of plagioclase. Minerals identified in the groundmass were plagioclase of composition An_{50} (andesine-labradorite), olivine, very pale green augite and octahedra of magnetite. In section 60/170 the olivine phenocrysts are marginally altered to iddingsite.

The chemical composition of the Kibwezi lava has been determined as follows:—

	Per cent		Norm Per cent
SiO ₂	43.73	or	10.57
Al ₂ O ₃	13.40	ab	4.73
*Fe ₂ O ₃	15.07	an	14.75
MgO	10.21	ne	14.20
CaO	9.58	di	26.59
Na ₂ O	3.70	ol	18.52
K ₂ O	1.80	mt	5.33
TiO ₂	3.01	il	5.78
MnO	.20		
	100.70		100.47

Anal. East African Industrial Research Board, Feb., 1951.

* Total iron as Fe₂O₃. From more recent, as yet unpublished analyses of Chyulu lavas the ratio FeO:Fe₂O₃ is assumed to be 7:1

No feldspathoids were recognized in the thin section and the presence of so much nepheline in the norm is remarkable. Presumably there is an alkaline mesostasis that is not easily detectable.

(2) ALLUVIAL DEPOSITS

Along the course of the Athi river are alluvial deposits consisting mainly of fine sand with occasional thin layers of grey silt marking seasonal floods. Thicknesses of alluvium up to 12 ft. were measured, but the base was seldom seen and it may be much thicker in places. The alluvium stretches for up to 500 ft. on either side of the river in the north-west, narrowing southwards to less than 100 ft. Very thin unconsolidated gravel sheets sometimes occur, consisting of poorly-rounded pebbles of Basement rocks and phonolite. Many of the other rivers, notably the Tiva, Mavuko and Kaloboto, have sandy beds but no flanking alluvium. Panned concentrates from the Tiva river showed (after removal of quartz, felspar and biotite) magnetite, ilmenite, garnet, hornblende, diopside, rutile, zircon, apatite and sphene. In addition to all these minerals a concentrate from the Athi river (specimen 60/165a) showed a high proportion of epidote, which is very rare in the rocks of the present area.

(3) SUPERFICIAL DEPOSITS

Over much of the area a red or red-brown soil, usually sandy, has developed by weathering of the underlying rocks. Where the vegetation cover has been removed by overgrazing or poor husbandry gullyng quickly develops and leads to barren sandy areas. The phonolite of the Yatta Plateau weathers to a non-sandy red soil very similar in appearance to that derived from Basement System rocks. Crops planted in the few places where the bush has been cleared on the Plateau show that this soil is more fertile than those derived from Basement System rocks.

In areas of poor drainage typical "black-cotton" soils are developed, hard and fissured when dry but tenacious clays when wet. In most of the black soil areas examined a discontinuous layer of nodules of secondary limestone occurs at or a few inches below the surface. Unlike the red soils, which support a thorn-scrub vegetation, often dense, the black soil areas are always open grassland.

Over and near outcrops of the more calcareous rocks secondary limestones are widely developed. They are usually buff or pink in colour due to iron-staining, and often include angular fragments of quartz and felspar. They seldom exceed a few inches in thickness.

VI—METAMORPHISM AND GRANITIZATION

Like many other areas of Basement System rocks in Kenya the sequence of events appears to have been firstly deposition of sediments, secondly widespread folding with accompanying regional metamorphism, and lastly granitization. That the granitization was later than the regional metamorphism is proved by the formation of fine-scale layering of re-crystallized quartz and feldspar, seldom showing strain shadow, between layers of cloudy, fractured and strained minerals. The abundance of orthoclase or microcline feldspar in these later layers, compared with the feldspars in the older portions of the rock, show that the metasomatizing agents were potassic. Where granitization has been locally more intense feldspar porphyroblasts developed and grow laterally into the minerals of the surrounding rock without noticeably displacing them, showing that the porphyroblasts grew by assimilation of the existing minerals, without significant addition to the rock mass. At the highest degree of granitization the rocks invaded attained a degree of plasticity that led to the contortions and swirlings seen in the migmatites and finally to the obliteration of most of the original sedimentary characters of the rocks, and giving granitoid gneisses.

The metamorphic grade of the area is high, and is characteristic of the almandine-diopside-hornblende sub-facies of the amphibolite facies (Turner, 1948, pp. 87-88), a typical mineral assemblage being hornblende-plagioclase-hypersthene-diopside with or without quartz and orthoclase. Plagioclase is commonly of the composition of oligoclase or oligoclase-andesine. Hornblende is sometimes clearly secondary to the pyroxenes but sometimes apparently in equilibrium with them. Where biotite occurs it is usually secondary after hornblende. Further evidence as to the high grade of metamorphism is given by the occurrence of sillimanite in one exposure, the alumina content of the original sediments being too small to allow this mineral to develop elsewhere. In the crystalline limestones actinolite, forsterite and diopside are commonly developed. The appearance of these minerals is in good accord with metamorphism to the stage of the amphibolite facies.

VII—STRUCTURE

The main structural features of the area are shown in Fig. 2. The general strike of the rocks is west-north-west to east-south-east, and is in good accord with many of the other Basement System areas of Kenya so far mapped. In the extreme south-west the strikes trend east of north. The lack of exposures between this corner and the remainder of the area makes correlation of the two parts difficult, but for reasons stated later the writer considers that there is a gradual transition between the two strike directions and not an abrupt change such as might be caused by a major fault.

Foliations are readily determined in most of the exposures, and are marked mainly by the preferred orientation and alignment of mineral grains and the tendency for mafic minerals to occur in well-marked bands. The foliation invariably parallels the junctions of the different rock types, and marks the bedding planes of the original sediments.

Lineations are marked by fine-scale puckering on foliation planes and the alignment of elongated minerals and mineral grains.

Six hundred poles to observed foliation planes were recorded in the area (excluding the south-west corner, which is considered in detail later) and were plotted on a Schmidt equal-area stereographic net and contoured (Fig. 3a). The concentration of poles along the great circle π indicates a single system of folding with β as fold axis. The mean strike, shown by the maximum point of concentration, is 340° , with a westerly dip of 55° . It will be noted that the mean strike differs slightly from the direction of the fold axis, which is 334° , owing to the plunging of the fold axis to the north at 10° from the horizontal.

In the same part of the area 173 lineations were recorded, and the contoured plot is shown in Fig. 3b. The maximum of this diagram corresponds to a mean lineation direction of 330° with a northerly plunge of 12° . The regular extension of contours into the southern part of the plot shows that the southerly-plunging lineations belong to the same system, and indicates that the variations in plunge result from minor flexures.

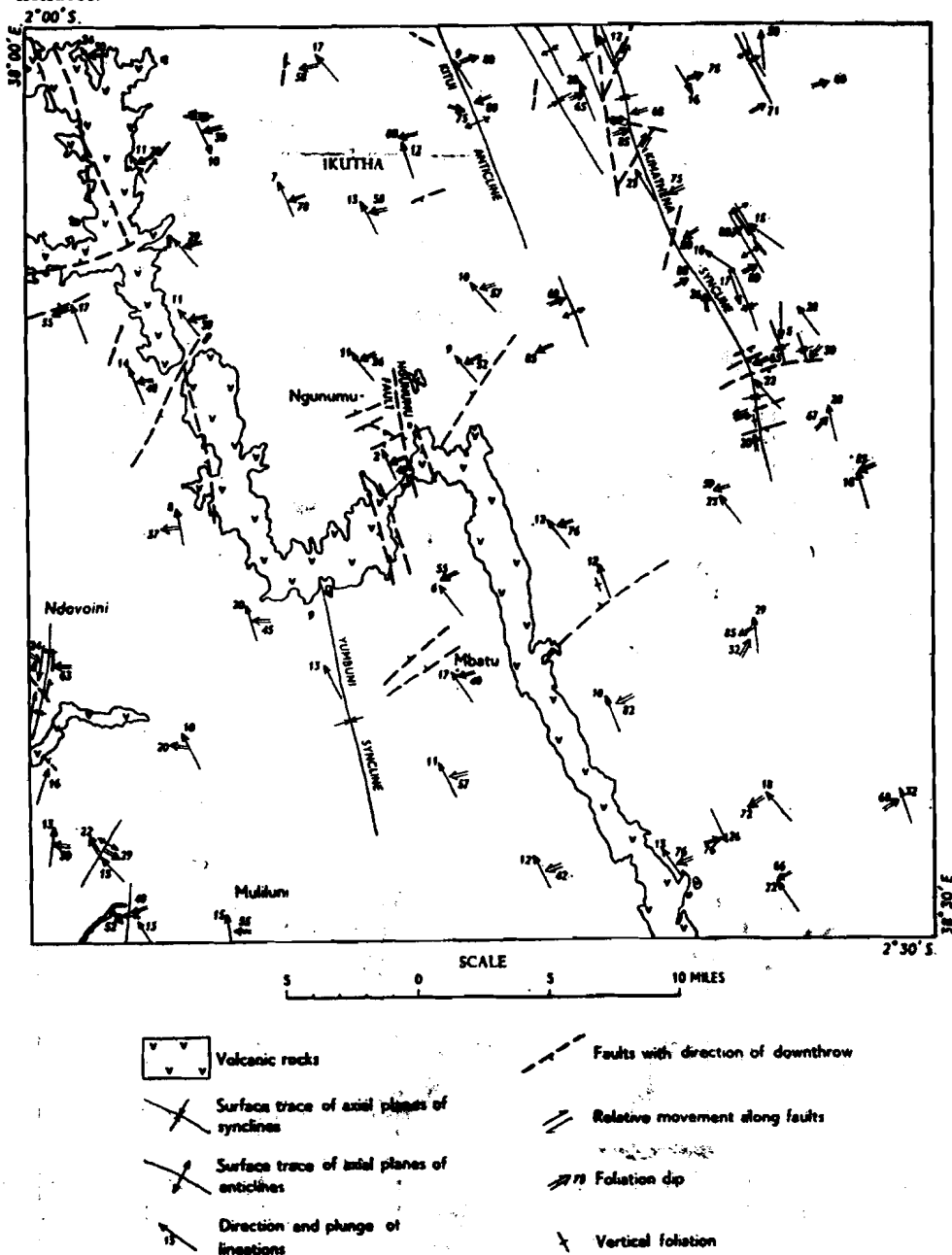


Fig. 2—Generalized structural sketch-map of the Ikutha area

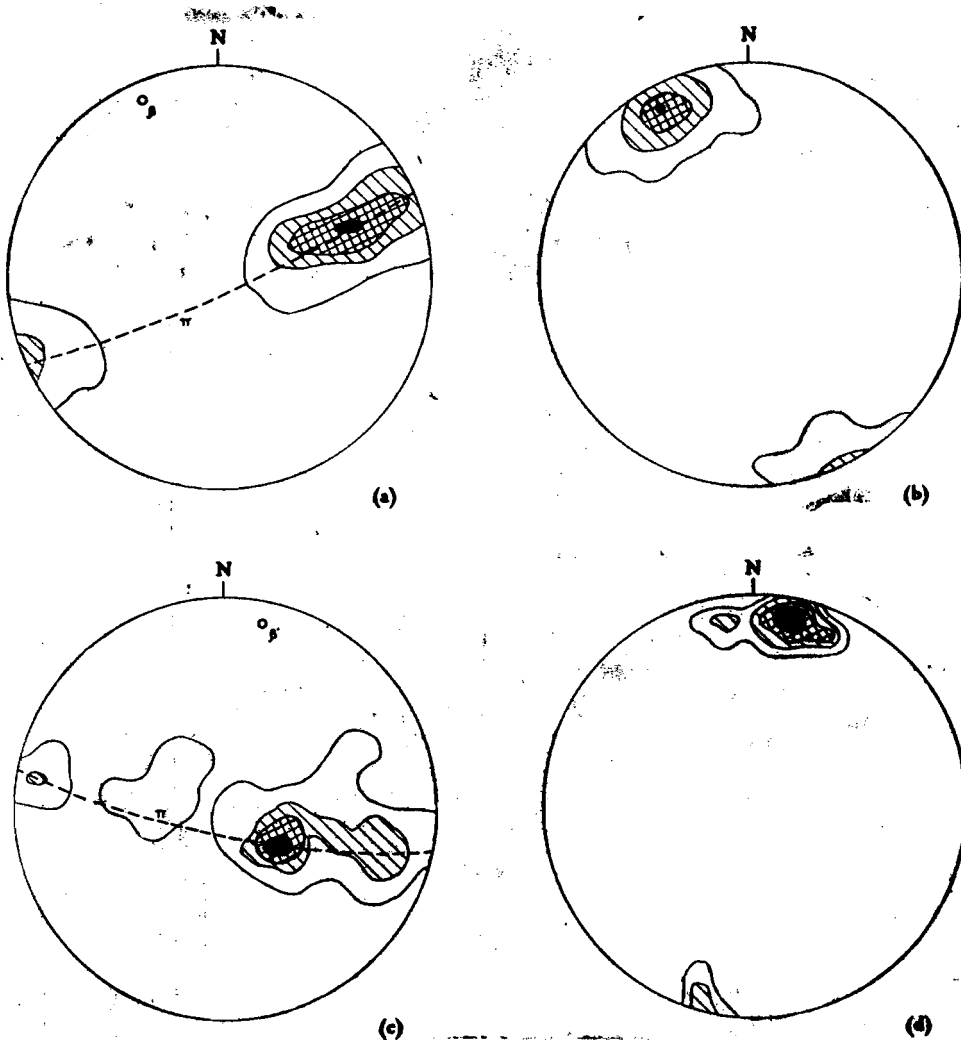


Fig. 3—Contoured stereographic diagrams of poles to foliation planes and of lineations in the Ikutha area:—

- (a) Poles to foliation planes, Ikutha area excluding the south-west corner. Six hundred readings, contours at 1, 5, 10 and 15 per cent per one per cent area.**
- (b) Lineations, Ikutha area excluding the south-west corner. One hundred and seventy-three readings, contours at 1, 10, 20 and 30 per cent per one per cent area.**
- (c) Poles to foliation planes, south-west corner of the Ikutha area. Seventy-one readings, contours at 1, 5, 10 and 15 per cent per one per cent area.**
- (d) Lineations, south-west corner of the Ikutha area. Twenty-three readings, contours at 5, 10, 15 and 20 per cent per one per cent area.**

The good accord of the axis of folding of Fig. 3a with the lineation maximum of Fig. 3b is a clear indication of monoclinic symmetry in the rock structure, and proves that the lineation is a true b-lineation marking the axis of folding. Thus the structure of the area is the result of a single major tectonic phase in which pressure was applied along west-south-west to east-north-east directions, the overturning of folds to the east-north-east indicating that the pressure was applied from the west-south-west.

Figs. 3c and 3d are contoured stereographic plots of poles to foliation planes and lineations respectively observed in the south-west corner of the area, which is delimited roughly by a line from Ndovoini south-east to Muliluni. Fig. 3c, while showing a wider spread of points than Fig. 3a, shows a marked concentration of poles along the great circle π , and again shows a single system of folding with β as fold axis. The axis of folding here is 042° , with a plunge of 12° to the north. Although only 23 readings were made of lineations, the plot nevertheless shows a good maximum, again coinciding with the fold axis and proving homogeneity in the rock structure. The contours of lineations are elongated towards the west of the diagram, suggesting that the lineations swing over gradually between the south-west corner and the remainder of the area, without a sharp break.

The major fold in the area is the Kimathena syncline, with a near-vertical core of granitoid gneiss and biotite migmatite which has, by its compacted nature, resisted erosion to a much greater extent than the flanking gneisses and now forms a steep-sided ridge rising to 2,000 ft. above the plain. In direct contrast the Kitui anticline to the west has been eroded at the same rate as the flanking rocks and makes an ill-defined feature. The Kitui anticline was so named by Saggerson (1957, Fig. 2.), who traced it northwards through the South Kitui area and correlated it with an anticline terminating at Kitui township (Sanders, 1954, Fig. 3). Other lesser synclines and anticlines occur between these two major elements and in poor exposures east of Kimathena ridge. Several minor folds were mapped in the extreme south-west. Between these two areas of folding is a broad belt of predominantly hornblende gneisses in which only one fold was recognized, the Yumbuni syncline. The regular westerly dip of this band of hornblende gneisses would, if undisturbed, represent an original thickness of deposition of upwards of 70,000 ft. The writer considers that the width of this outcrop is rather due to repetition of the beds by strike-faulting such as the fault followed by the Ngunumu river in the centre of the area. Faults seen cutting the Yatta phonolite on either side of the Ngunumu fault may indicate late movement along Basement System strike-faults. Further evidence of such faulting is shown in the rocks of the line of ridges from Ngunumu to Mbatu. All the thin sections of rocks from these ridges showed characteristics of shearing in the plane of the foliation, though only cross-faults were identified in the field.

E. P. Saggerson, who at the time of writing this report was mapping the Simba-Kibwezi area to the west of the present area, informed the writer that plunging folds parallel to those in the present area reach to within a few miles of the common boundary, the meridian 38° E.

The evidence therefore suggests that some of the crustal shortening in the hornblende gneisses was accomplished by reversed strike-faulting. However the existence of one big fold (the Yumbuni syncline) and the folding on either flank of these gneisses suggests that other folds do occur, but have not been detected.

In the folded areas minor folding is common, with amplitudes of 20 ft. or more down to a few inches, always parallel or subparallel to the major folds, and marking puckers imposed on the major folds.

Prominent joints were recorded at 68 localities, all vertical or near vertical, and were plotted as a frequency diagram, Fig. 4. This shows a marked maximum at about

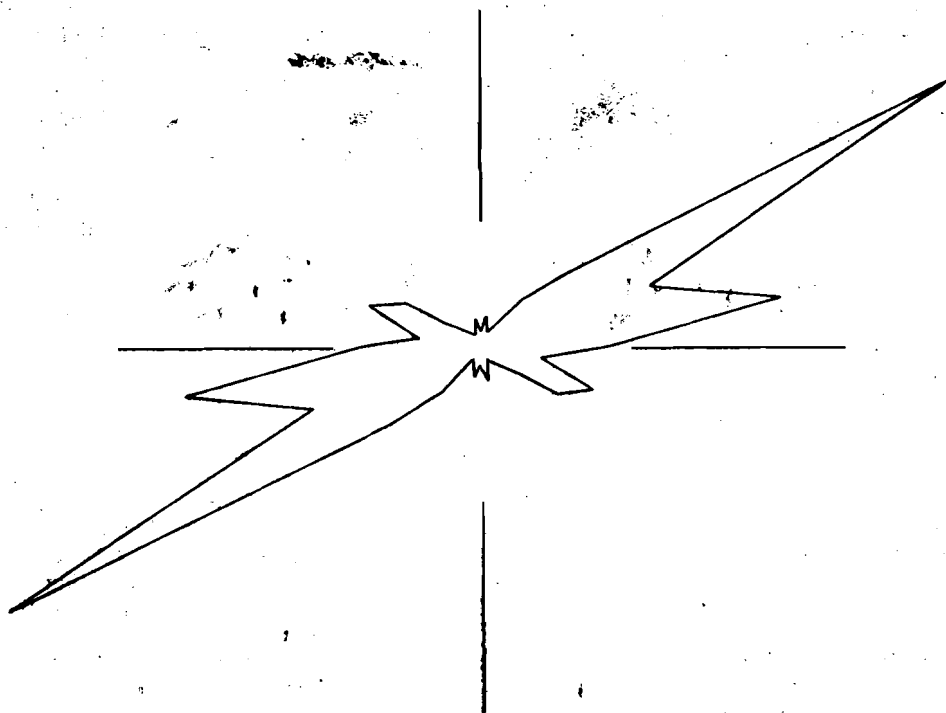


Fig. 4—Frequency diagram of joints in the Ikutha area. Sixty-eight readings

60°, at right-angles to the trend of fold axes, representing *ac* or cross-joints, produced by relief of stresses set up during deformation. Such joints would only occur upon relief of confining pressures such as would be produced by unloading, when the rocks would have lost any tendency to plasticity and would be able to adjust themselves only by fracture. Where such joints are large and relative movement has taken place along them, whether at the time of their formation or subsequently, true faults are produced. Most of the lesser faults of Fig. 2 are parallel to the *ac* joint system and are genetically related to the *ac* joints.

VIII—MINERAL DEPOSITS

The only minerals of economic importance which were found in the area are graphite, limestone, vermiculite and sillimanite, though only graphite is known to occur in sufficient quantities or of a suitable grade to warrant exploitation.

1.—Graphite

Graphitic gneisses occur as lenses and impersistent bands associated with the crystalline limestones crossing the Ikutha-Kanziku road and extending into the area to the north. In his report on that area Saggerson (1957, pp. 35-43) has given an exhaustive review of the prospecting and mining done up to 1953. Briefly, the first record of the existence of graphite was by E. V. Kinloch, then of Masongaleni, who does not appear to have pegged any claims. In 1942 and 1943 E. R. Wright pegged claims over one of the marble bands, these claims being abandoned in 1944, after their transfer to Raw Materials Development Ltd. C. R. Stokes-Fair held a single claim between 1945 and 1948. No commercial production was made from any of these claims. In 1950 R. O. Johnston erected a protection notice which was allowed to lapse, and in

1951 D. K. Hamilton (E.C.A. Geologist) and D. Hobden (Prospector) prospected the area for the Mines and Geological Department and proved the existence of economic deposits. In the same year claims were pegged by Bewick Moreing & Co. and by Shah Vershi Devshi & Co., both of whom carried out extensive prospecting. Bewick Moreing & Co.'s claims finally lapsed in 1955, and at the time of writing (January, 1957) only Shah Vershi Devshi & Co. have workings in the area, on claims at Kamstoi. In 1956 this company pegged most of the known graphite area under an Exclusive Prospecting Licence which is bounded by the triangle of roads joining Ikutha, Mutomo (to the north of Ikutha) and Kanziku.

Shah Vershi Devshi & Co., unlike other Kenya producers, have not concentrated on the production of graphite for crucibles, for which the rather exacting specifications are based on flake size, but on the production of graphite for surfacing moulds and for lubricants, where the main qualification is high carbon content.

Owing to the acute shortage of water near the workings for most of the year (bore-holes have been sunk but their yield is small) the flotation plant has been re-sited at the Tiva river near the road-crossing south-west of Ikutha, and the milled ore is carried by lorries the ten miles from the mine, the dried flotation product being returned to the mill for final processing, details of which are as yet confidential. In August, 1956, the flow-sheet for the mill was as given on Fig. 5. A new milling and separation technique, still in the experimental stage, the flow-sheet of which is shown in Fig. 6, has been devised by the company. The important feature of this new system is the winnow, developed in its present form in the laboratories of the Mines and Geological Department, Nairobi. After preliminary milling the graphite is blown from the gangue, giving a product which approaches 50 per cent graphite. With further screening and winnowing the graphite content can be raised to 80 per cent if necessary. The flotation unit is to remain at Ikutha, but much less transport will be needed to carry the enriched ore from the mine. At a later date it is intended to move all the equipment for final processing to the flotation plant, so that the finished graphite can be carried straight on to Kibwezi for railage.*

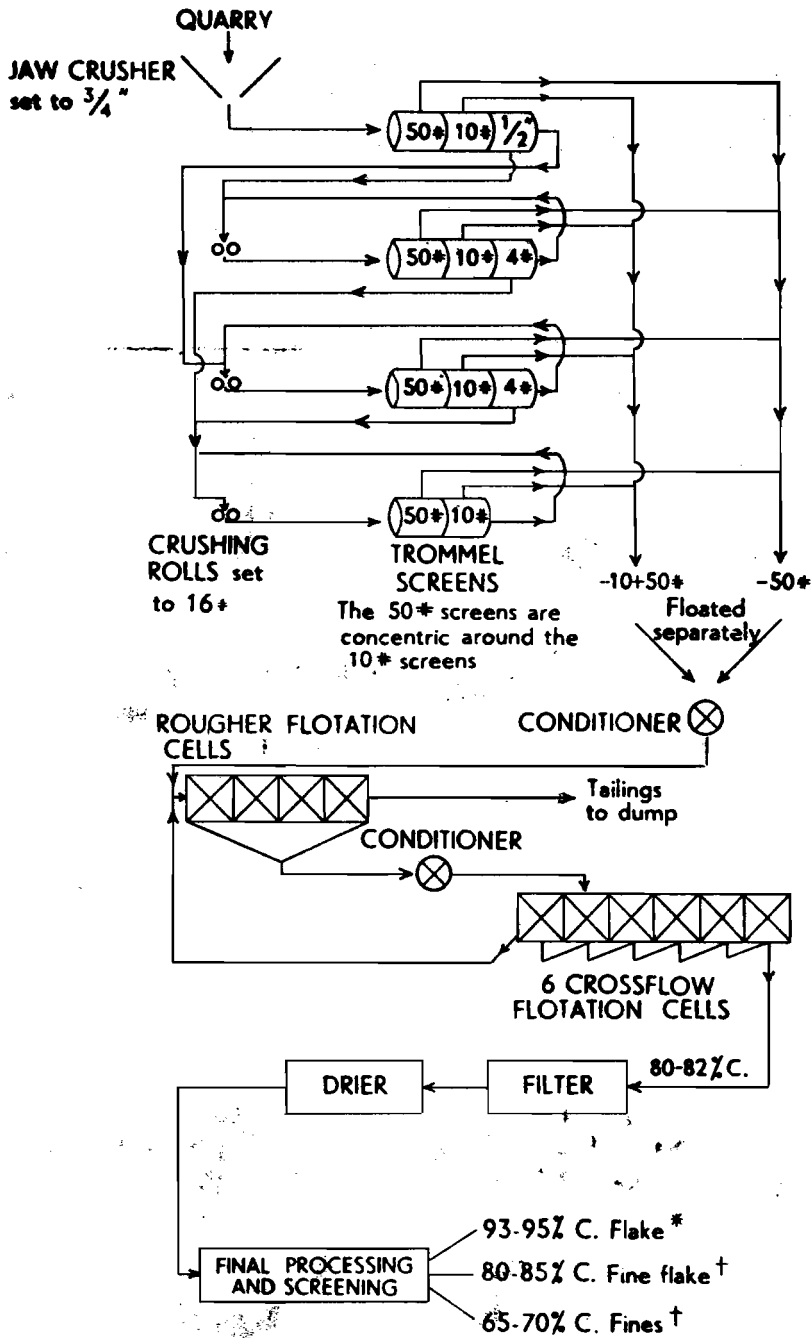
Graphite from Kamstoi commands a ready sale to lubricant manufacturers. The run-of-mill graphite reaches 80 to 82 per cent carbon content, but after final processing and screening three different products are obtained, 93 to 95 per cent carbon, 80 to 85 per cent carbon and 65 to 70 per cent carbon. The 93 to 95 per cent fraction has been further treated chemically, on a laboratory scale, to obtain a carbon percentage of 99.5 per cent, but a good deal of work requires to be done before such treatment can be regarded as an economic proposition. At the moment only a limited market exists for such a high grade product.

Production began in 1952, and records in the Mines and Geological Department show that the output since then has been:—

Year				Ore Milled	Production	Percentage Recovery	Value*
				<i>Tons</i>	<i>Tons</i>		<i>£</i>
1952	..	..	..	400	31	7.75	1,406
1953	..	..	..	1,870	127	6.27	5,765
1954	..	..	..	No production due to reorganization of mill			
1955	..	..	..	1,671	168	10.05	6,653
1956	..	..	..	6,551	492	7.51	19,680
1957	..	..	..	10,791	942	8.73	39,847

* Estimated value based on average price of graphite sold in that year.

* Final processing has been carried out at the flotation plant since late 1957.



*Can be brought up to 96-97% C.

†Can be brought up to 90% C.

Fig. 5—Graphite flow-sheet—Ganesh Claims, Kamstol

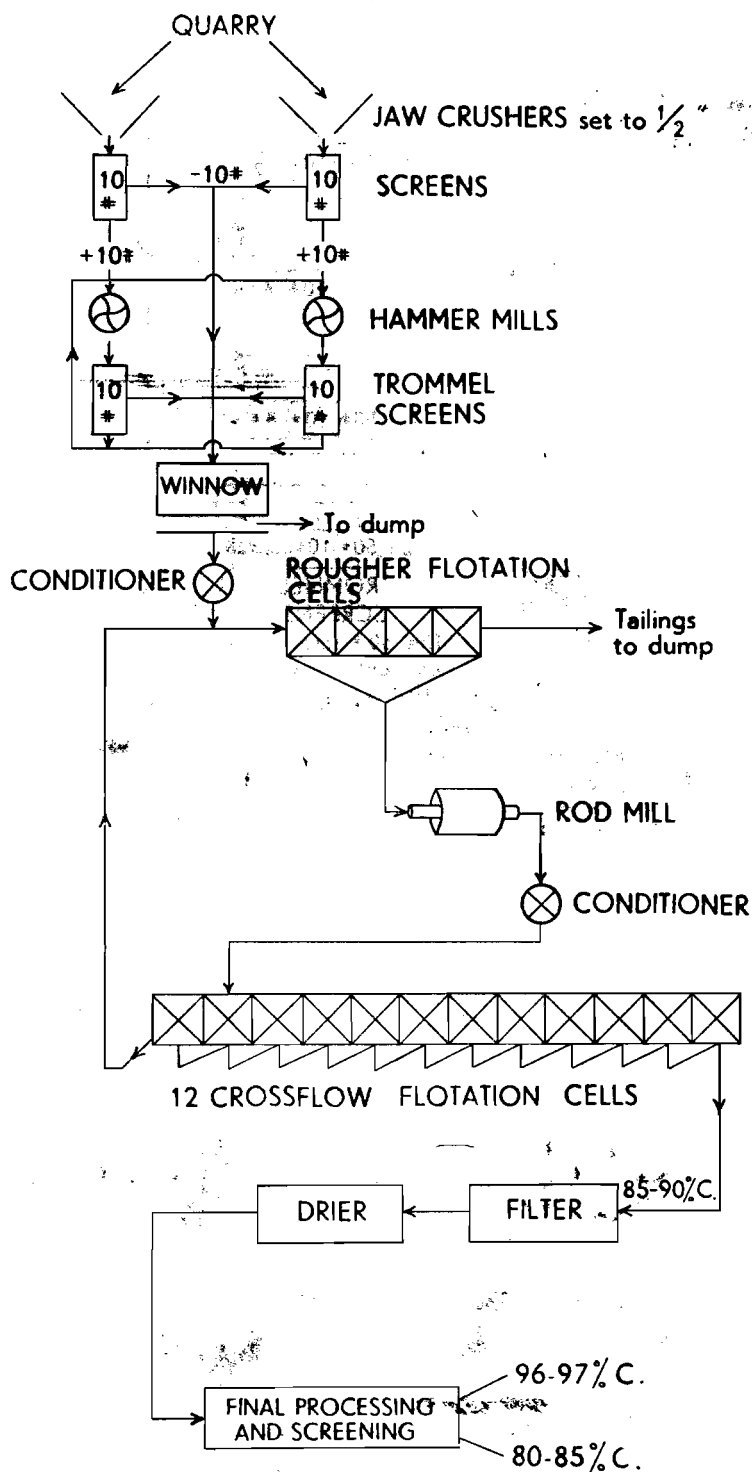


Fig. 6—Experimental graphite flow-sheet—Ganesh Claims, Kamstoj

In 1956 the graphite was shipped in roughly equal quantities of three grades, 93 to 95 per cent carbon, 90 to 92 per cent carbon and under 80 per cent carbon.

Messrs. Bewick Moreing & Co., in the course of their prospecting, cut trenches across the marble outcrops south of Kasaala, and uncovered bands of graphite gneiss up to four feet in thickness on the western flank of the more easterly of the two bands. These gneisses are nowhere seen at surface due to soil and scree covering from the limestone ridge, but it is probable that discontinuous bands or lenses of graphite gneiss occur along the length of the limestone outcrop, and may repay further prospecting.

Appendix on Graphite

Reprinted from "Kenya Trade and Supplies", October, 1958, pp. 233-234.

KENYA GRAPHITE

Until fairly recently, the world's graphite requirements were met chiefly by Madagascar and Ceylon, but it is the hope of Messrs. Shah Vershi Devshi and Company Limited, of Thika, the company which has developed the production of local graphite, that some of these requirements may in future be met by Kenya.

The Kenya graphite mine is situated in the Southern Kitui District, 175 miles from Nairobi on the road to Mombasa. Many difficulties were experienced by the company when the mine was started, chief among these being lack of water. Three boreholes were sunk at the site of the mine, without success, and water had to be brought in drums from the Athi river, 25 miles away. Communications were also a major problem and when breakdowns in machinery occurred it was necessary for messages to be sent to Thika, 165 miles away, by car over very bad roads. Two or three days usually elapsed before information regarding the breakdown reached Thika and it was then necessary for spare parts to be procured from Nairobi before repairs could be carried out. Conditions improved when the company found water was available from the Tiva river, about 12 miles south of the mine, and moved their refinery to the riverside. A road was constructed by the company which reduced the distance between the mine and the refinery from 12 to eight miles. Each year, nowadays, approximately 15,000 tons of ore are transported over this road to the refinery. The company has also installed radio-telephone communication between the mine and Thika and breakdowns are now usually dealt with in a day or two.

A further problem arose in that during the rainy seasons the levels of Athi river and Tiva river rose to such an extent that the road from the refinery to the railway station at Kibwezi became flooded and impassable. This difficulty was met by the building by Kenya Government of a bridge over the Tiva river and by the improvement of the roads in the district. These difficulties having been overcome, together with those of obtaining labour and administrative staff for such an isolated district, the company continued to develop the mine with an unshakeable faith in the future of Kenya graphite, which can bear comparison with graphite produced in most other parts of the world. Electric plant has been installed in replacement of the diesel engines previously used and testing apparatus has recently been introduced.

Production began on a small scale in 1953, but the necessity for training the labour and the "trial and error" methods which had to be adopted, rendered unprofitable the first years of operation. By dogged perseverance, production on a commercial scale began in 1956 and small exports of graphite were achieved in that year. An overseas tour by the Principal of the company resulted in good business contacts and production was stepped up to 100 tons a month. Exports rose in 1957, the principal purchasers being as follows:—

	Short tons
United Kingdom	44.8
Australia	11.2
Western Germany	196.0
United States of America	168.0
Japan	290.0
India	30.2
Canada and Newfoundland	1.1

The future looked bright when, at the end of 1957, there was a sudden slump in world demand for graphite. This state of affairs continued into 1958 and Mr. C. D. Malde, the youngest Director of the company, decided to set out on a world tour to study the trend of world markets, to make new business contacts and, thereby, to estimate the future of the graphite industry in Kenya. His four-month tour took him to most European countries, Canada, the United States of America, Japan and India and he reported on his return that he had received the utmost co-operation and assistance from the Governments of all the countries he visited. The demand for good quality graphite in the United States of America is great and there is every hope that a part of this market, at least, will be available to Kenya. Germany is also an important market for graphite and it is hoped that Kenya's sales to that country, also, will increase.

The company employs 250 Africans and eight Asians and now produces approximately 1,500 tons a year of a wide variety of graphite of from 50 per cent to 98 per cent carbon and ranging from fines through small flakes to large flakes. The graphite produced is used for lubricants and paints and in foundries, glass-works, etc.; orders to specification are also met. Kenya's own annual requirements are low at around 100 tons. If the demand from overseas increased, production could be stepped up to 2,000 tons a year.

Every effort is being made to reduce the cost of production whilst maintaining the quality of the product and there is every chance that the future of Kenya graphite will justify the faith and determination shown by the promoters of the Kenya mine in the early stages of its development.

2.—Limestone

All the larger outcrops of limestone were tested to determine their calcite:dolomite ratios, the method used being colorimetric, the ratios obtained being to the nearest five per cent. Results are as follows:—

Specimen No.	Location	Ratio	
		Calcite, CaCO ₃	Dolomite, CaMg (CO ₃) ₂
60/124	Kasaala	100	0
60/138	Kimakimwe	95	5
60/142	Otekilawa	95	5
60/164	Mutula	95	5
60/184	Kasaala	95	5
60/203	Utundani	80	20

Analyst—Mrs. R. Inamdar.

A ratio of 95:5 is equivalent to a magnesia (MgO) content of about 1 per cent, which is within the maximum allowable content in raw limestone used for Portland Cement. Only random samples, however, were taken for these determinations, and before the limestones as a whole could be proved suitable for cement-making systematic sampling along and across the strike would be necessary to prove that the low magnesia content persists throughout the outcrop.

All the occurrences are near to existing motor tracks or can be easily reached by new tracks. For small scale cement-making or for burning for quicklime brushwood fuel is readily available at all the outcrops.

3.—Vermiculite

Vermiculitic biotite occurs in a massive pegmatite exposed in an old prospecting pit about 15 ft. square and 8 ft. deep at Manoni. The pegmatite lies under about three feet of red soil, and no indication was found as to its extent. It was discovered in 1944, and reported on by the Mines and Geological Department. The bulk density of the raw unprocessed material was found to be 56 lb. per cubic foot, and that of the best quality expanded material between seven and nine pounds per cubic foot. While this indicates a fairly good quality the quantity available seems to be far too small to warrant exploitation. Flakes of vermiculite up to six inches in diameter were seen, but always in single crystals, and the percentage of vermiculite in the pegmatite where exposed does not exceed 5 per cent in volume. Thus even if the pegmatite proved to be of large extent the cost of extracting the vermiculite would far exceed its market value.

4.—Sillimanite

The only occurrence noted in the area was in a quartz-sillimanite gneiss exposed in drainage trenches along the railway about a mile south-east of Kikumbulu Station. The thickness of the outcrop, which is exposed around the nose of a plunging anticline, is apparently no more than 30 ft. From a single microscope section the percentage of sillimanite was estimated as 60 per cent, but the small extent of the ore reserves so far indicated makes the occurrence quite uneconomic despite its ideal situation on the railway.

5.—Water-supplies

The Athi and Kibwezi rivers are perennial, the former being fed from the Nairobi area and the latter from springs in the Kibwezi lava, which carries a considerable volume of underground water from the Chyulu hills (Temperley, 1956, Vol. II, pp. 64-111). There are two major springs, one at Chae, a mile west of Dwa rock, and the other at Manoni near the snout of the lava, both of which are extensively utilized for irrigation and stock-watering, and the former for the sisal factory at Dwa. The smaller lava tongue at Masongaleni also formerly gave a perennial flow to the Masongaleni river (Temperley, *op. cit.*, pp. 112-122), but this flow ceased almost overnight in 1918 for reasons which have not been determined, but which Temperley considers most probably due to diversion of the ground-water flow by faulting. (An earth tremor was recorded at Masongaleni on 17th April, 1918.) Water can be obtained by digging a foot or two into the sandy bed of the Tiva river. A few minor springs and water-holes occur in the area, but all have only a small supply and are liable to dry up within a few weeks after the rains have ceased. Bore-holes have been sunk on Dwa and Masongaleni sisal estates, and at Ndovoini, four miles north of Dwa Rock. Records of these bore-holes supplied by the Ministry of Works, Nairobi, are as follows:—

No.	Locality	Depth	Water Struck	Water Rest-level	Yield per 24 hours
		<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Gallons</i>
C.33	Masongaleni	400	?	42	8,640
C.34	Masongaleni	254	?	4	11,520
C.73	Masongaleni	313	40,200-230, 300-313	37	24,000
C.640	Ndovoini	335	315	45	64,800
C.1004	Dwa Plantation (2 miles N. of Masongaleni).	567	280	250	12,000
C.1005	Dwa Plantation (2 miles N. of Masongaleni).	190	150	150	7,200 (bitter)

In recent years many dams have been built to impound water in seasonal rivers and streams. They are mostly of earth, built by hand labour or with the aid of a single tractor, and the majority of them hold water for a considerable part of the year. At Ngali, south-east of the peak of Kimathena, and on the Katakolo river five miles south-south-east of Ikutha, concrete dams have been built across steep-sided channels. Five and a half miles south-west of Ikutha a very large stone-faced earth dam has been built across the Diliu river. At the time of the survey this dam was not completed, but when filled it is expected to impound many millions of gallons of water.

The building of numbers of small dams is clearly the right solution to the water problem in the area, both from the aspect of low cost and high proportion of success so far attained. It has often been proposed that dams should be built across the Tiva river, but at present this would appear to be rather unnecessary, since ample water for domestic use and stock watering is available in the sandy bed with a minimum of digging. A dam would very soon silt up, and digging would again be necessary to reach the water held in the sand behind the dam, unless the retaining wall was of sufficient height to allow sub-surface water to be piped to troughs or tanks.

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