

Report No. 17



MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

MINES AND GEOLOGICAL DEPARTMENT

A GEOLOGICAL RECONNAISSANCE
OF THE
COUNTRY BETWEEN EMBU AND MERU
(with colored geological map)

by

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FOREWORD

The Embu-Meru area of Kenya is strikingly different from other parts of Kenya in having large masses of basic plutonic rocks. Many such areas in other parts of the world have yielded valuable metalliferous deposits. No mineralization has yet been discovered in the area described in the following report, but the reconnaissance survey that has been carried out by Mr. Schoeman will be of great value in assisting future work and prospecting. His mapping will enable effort to be directed immediately to those parts of the area that are likely to be prospected with hope of success.

Mr. Schoeman's more detailed collection of material from near the basic intrusives has enabled him to demonstrate that they are older than has previously been thought, and that portions of them have suffered granitization, in common with the Archæan Sediments among which they were emplaced. Such a factor might have a profound effect on the possibility and the location of occurrence of metalliferous deposits.

The study of the granitization of such rocks has led Mr. Schoeman into a discussion of the origin of charnockitic rocks—a subject that has arisen on many occasions in various parts of the world during the past few decades—and his results may be considered as a valuable contribution to the subject.

Nairobi,
29th July, 1949.

WILLIAM PULFREY,
Chief Geologist.

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MAP

Geological map of the country between Embu and Mōru; Scale 1:125,000	At end
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A GEOLOGICAL RECONNAISSANCE OF THE COUNTRY BETWEEN EMBU AND MERU

ABSTRACT

The report describes an area in central Kenya of about 1,250 square miles extent, bounded by the equator and $0^{\circ} 30' S.$ latitude and by longitudes $37^{\circ} 30' E.$ and $38^{\circ} 00' E.$ Three divisions are recognized in the topography: (1) the lower-most eastern slopes of the Mt. Kenya volcanic pile which grade down to the sub-Miocene peneplain level on which the terminal lavas rest; (2) the end-Tertiary peneplain on Basement System rocks from which many inselberg groups and ranges stand out prominently; (3) limited areas of post-Tertiary peneplanation.

The rocks of the area comprise: (1) Migmatites, granitoid gneisses and granulites, schists, etc., of the Basement System intruded extensively by large masses of basic and ultrabasic rocks associated with intermediate and sub-acid rocks thought to be derived from the basic types by granitization. The basic rocks and derivatives are hypersthene-bearing and constitute a charnockitic suite. Other intrusives of minor importance also occur. (2) Tertiary volcanics of Mt. Kenya, preponderantly kenyte with other phonolitic and basaltic lavas. (3) Extensive thin sheets and outliers of basalts probably of lower Pleistocene age. (4) Bedded deposits of conglomerates and gravels. The petrology and petrography of the rocks is described in detail and the structure and metamorphism of the Basement System is discussed. An account is given of the economic prospects of the area including the history of the mica exploitation in the Kierra area.

I—INTRODUCTION AND GENERAL INFORMATION

The area discussed in this report is the north-eastern quadrant of degree sheet 44 (Kenya Colony) bounded by the equator and latitude $0^{\circ} 30' S.$ and longitudes $37^{\circ} 30' E.$ and $38^{\circ} 00' E.$, roughly 1,250 square miles extent. It includes portions of both the Embu and Meru districts. With the exception of the Mount Kenya Forest Reserve lying along the western side of the area, it is entirely native reserve, including a small portion of the Kamba Native Land Unit east of the Tana River.

As a result of a brief visit to the mica workings on the southern slopes of the Kierra Ridge during 1942, Dr. W. Pulfrey recognized the presence of large masses of basic rock in the area and the possibility of the occurrence in them of minerals such as nickel and chromium ores, platinoids and magnetite. A reconnaissance of the area was, therefore, undertaken between April and November, 1948, to determine the extent of the basic rocks, degree of mineralization and the most favourable localities for prospecting. The examination of the basic plutonics did not, however, give much promise, as well as could be judged in a reconnaissance survey, of deposits of economic value. In view of the fact that mica was worked in the past in a few pegmatite veins at Kierra it was thought possible that some of the abundant pegmatites of the area might also prove to be payably mineralized. The pegmatitic and other rocks of the Basement System revealed, however, no indications of valuable mineralization.

MAPS

The topography of the geological map is based on the degree sheet, No. 1764, G.S.G.S. (1,250,000) published in 1912, though much modification was found necessary in certain areas. The form lines on the present map are not accurate and serve only to indicate roughly the land forms. Names are taken from the degree sheet, and as many native names as possible have been added to features not named previously on the topographic sheet. West of approximately longitude $37^{\circ} 40' E.$, the topography was taken from air photographs and detail is more accurate than in the eastern part of the area.

The mapping of the geology was mostly done by plane table, assisted by cyclometer traverses.

The position of the Mount Kenya Forest Reserve boundary is for the greater part of its length based on the photographs since existing boundary maps show large discrepancies when compared with them.

NATURE OF THE COUNTRY

Over one-third of the area lies on the gentle eastern slopes of Mount Kenya which is cool, healthy and fertile, with a good rainfall supporting a dense native population subsisting on the cultivation mainly of maize, sorghums, bananas, beans and millet.

A gradual diminution in the rainfall, fertility and density of population takes place eastwards towards the Tana River corresponding to a drop in elevation from 6,500-7,000 ft. above sea level on the lower edge of the forest belt to 1,600 ft. in the Tana River valley. Cultivation is largely superseded by pastoral herding in the lower lying parts of the country. Large tracts here are virtually denuded of grass cover owing to grazing malpractice, and soil erosion has advanced apace so that considerable areas, especially along the Tana River and the lower stretches of the Mutonga River and its tributaries, are intensely eroded. In the tsetse fly belt, however, lying roughly between the 2,750 ft and 3,250 ft. contours and embracing almost the whole north-eastern corner of the area, the original coarse and dense grass cover is still well-preserved.

The following figures of the rainfall are representative for the higher western part of the area. In the first column the first figure is the total rainfall during 1947, the second the average annual total up to the end of 1946. No figures exist for the lowland part of the country which in common with the vast peneplain stretching eastward to the coast probably has an average rainfall of less than 20 inches per annum. There is a marked bi-seasonal division, the months of maximum precipitation being March and April and again November and December.

Station	Annual Total	No. of rainy days, 1947	No. of years recorded
Meru, Berresford Hospital	88.88 92.92	105	13
Meru, D.C.	62.73 51.69	118	34
Meru, Nkubu Dispensary	73.21 53.64	110	6
Meru, Kenyankini Dispensary	77.87 54.79	102	7
Meru, Chogoria School	80.34 62.31	148	9
Meru, Chuka Dispensary	79.84 49.18	132	7
Embu, Kevote Mission	79.66 51.69	154	2
Embu, D.C.	50.11 40.91	96	39

COMMUNICATIONS

As the map indicates roads are comparatively scarce and much of the country is accessible only on foot. The sparsely populated tsetse-ridden areas are penetrable only with great difficulty owing to the rankness of the grass cover. The Mount Kenya Forest Reserve is uninhabited except for occasional Wanderobo, and consequently trackless and almost impenetrable. Owing to the limited time available no attempt could be made to traverse the forested area except along the Ruguti River to a point about 12 miles upstream from the forest reserve boundary.

SURFACE EXPOSURES

The rocks of the area are on the whole sufficiently well-exposed to determine broadly the lithological boundaries. The phonolites and trachytes lying above the kenytes in the Mount Kenya succession could not be accurately delineated however, owing partly to the general paucity of outcrop in that part of the area. On the peneplain Basement System outcrops are scarce owing to the deep granular soil cover, especially above the softer schists and weakly granitized rocks which are consequently not much in evidence, even along the main river courses.

PREVIOUS GEOLOGICAL WORK AND PROSPECTING

As early as 1912 the area attracted the attention of prospectors. During that year Messrs. A. Gamble and W. G. Parker pegged claims on the south-west flank of Kierra Ridge to exploit the mica pegmatites occurring there and in January, 1914, Parker also pegged claims for mica in the Koutheni Location near the Kazita River in the north-eastern corner of the area. The latter claims were apparently never worked. Parker after entering into a partnership agreement with Messrs. Newland Tarlton and Co., with respect to all his claims and leases during 1914, eventually relinquished all rights to them in 1917. They finally abandoned the claims and all rights in January, 1920. In the meantime, however, Government had obtained permission from them to reopen the Kierra prospects and to win mica. Operations began in October, 1918, and continued until May, 1920. Details of production are given in a later section dealing with the economic aspects of the area.

Subsequently the prospects were offered out to tender for working but although a tender was accepted by Government in August, 1919, the deposits were not deemed workable and the titles were abandoned in December, 1921.

During 1942, owing to the great demand for this strategically vital mineral an area of approximately 500 square miles was closed by Government to prospecting, for the purpose of reserving it for mica production. The closed area fell wholly within the present quarter-degree sheet and included the Kierra workings. A prospector was sent by Government to reopen old mica workings and to prospect for mica in the remainder of the area. After inspection by the Government Geologist of the reopened workings and certain new workings in November, 1943, it was decided to cease prospecting. Since then no further work on mica has been done in the area.

Apart from the interest in the mica no records exist of geological work in the area previous to the visit of Dr. W. Pulfrey to the mica workings in September, 1942. The findings of his investigation are embodied in unpublished departmental reports, and a published paper (1946) which deals chiefly with the petrology and petrography of the basic rocks of Kierra. In November, 1942, the Government prospector while on a reconnaissance through the southern part of the present area collected a few specimens, two of which, from Kiburu Hill, are of interest since they were identified by Pulfrey with the basic rocks of Kierra, confirming his opinion of the probably wide extent of such rocks within the area. C. Ferguson, Esq., prospecting in the Tharaka country during 1945, submitted to the Department for identification a few specimens of the types of rock found there.

II—PHYSIOGRAPHY

1.—GENERAL

The district can be divided into two distinct physiographic units, the eastern slopes of Mount Kenya and the Basement System terrain.

Mount Kenya has a relatively flat profile and builds gradually up to its present summit elevation of 17,040 feet over a diameter of about fifty miles. The area mapped embraces the lower slopes of the mountain up to about 9,000 feet in its north-western part. The volcanic accumulation thins gradually eastward and the lowest flows are relatively thin and closely reflect the flat sub-Miocene peneplain landscape over which they spread widely and protected from erosion. The boundary of the lavas

forms a distinct and sometimes prominent escarpment varying from less than fifty to a few hundred feet in height. The boundary has a deeply serrate outline due to the many streams descending from the mountain that have cut gorges in the lava to expose the Basement System beneath. On all the larger streams these gorges are often several hundred feet in depth and bounded by tall precipices of the lava. A few lava outliers form elevated table-top features. Certain of the large subsidiary vents such as Ndua, Ithanguni and Rutundi (the last two lying just west of the area) are not excessively denuded and are very prominent features. A number of smaller cones of different ages also make conspicuous landmarks. Certain inliers of the Basement System form distinctive hills discerned without difficulty, especially those in the vicinity of Igoje and Kenyakin.

The Basement System has for the greater part been lowered well below the level of the sub-Miocene peneplain, now preserved intact only under the eastern-most flows of the Mount Kenya series, at an elevation of between 3,200 and 3,000 feet. A younger peneplain some hundreds of feet below the sub-Miocene surface is clearly recognizable. It has been preserved intact in the north-eastern quadrant of the area by a protective capping of plateau basalts of the Nyambeni episode. It is continuous with the vast almost featureless peneplain stretching east of the area and northwards over the Northern Frontier District. Dixey (1948, pp. 29, 31) observes that the post-Miocene surface "... in its relation to the older surface, is closely comparable with the end-Tertiary surface of Central and Southern Africa." In the northern part of the area, north of Mitunguu, it lies at about 3,200-3,000 feet; it adjoins the sub-Miocene surface here at a slightly lower elevation, so that the step from the older to the younger surface is not prominent. It falls, however, fairly rapidly both to the east and south-east at approximately 47 and 36 feet per mile respectively; its lowest elevation in the area, 2,200 feet on the narrow elevated outlier Kiangumba near the confluence of the Tana and Mutonga Rivers, is 800 feet below the general level of the sub-Miocene peneplain. The marked slope of the end-Tertiary peneplain in these directions, i.e. towards the Tana River, leads to the conclusion that the river was already in existence in the Pliocene and maintained its present position over a considerable period, serving as the local base level of erosion during the end-Tertiary planation. The Tana River has lowered its bed about 500 feet during Pleistocene and Recent times.

Much of the Basement System rock in the area, mainly the gneisses of granitic composition and the basic plutonics, resisted both cycles of erosion, and now form lines and groups of inselbergs rising from a fairly flat floor. Some of them such as Kierra, Kijegge and Kiagu rise upwards of 1,500 feet above the surrounding plain but do not attain to the level of the Cretaceous peneplain recognized north-east of the area on the tops of the Karissia Hills and Matthews Range (Shackleton, 1946, p. 2).

A small plain about 400 feet lower than the end-Tertiary peneplain, covered with a thin deposit of gravel, near the Thingishu River south-east of Lansa Hill, appears to mark the youngest erosion cycle.

2.—DRAINAGE

The drainage pattern is determined chiefly by three factors: (1) the direction of slope of the Mount Kenya volcanic series; (2) the slope of the end-Tertiary peneplain; (3) the Basement System structures.

The slope of Mount Kenya has resulted in a radial pattern until the mountain streams debouch from the gorges in the lavas on to the Basement System floor. The Tana River, the recipient of all the drainage in the area, is a notable example of a strike stream having selected for its course within the area a series of relatively less resistant migmatitic gneisses confined between the resistant granitoid gneisses of the Mumoni Range on the east and the Kijegge Range on the west. The present Basement System drainage pattern is an adaptation between the initial south-east and east slope of the end-Tertiary peneplain and the strike of the formations which is between north and north-east over the greater part of the area. Thus most of the large rivers are partly transverse and partly strike streams.

The ubiquitously developed dip jointing of the Basement System strata has also had a marked effect on the stream fabric, often causing flow at right angles to the strike, an effect that is especially well-developed in the tributary streams. A notable example in a major stream is seen on the Tana River which describes a number of right-angled steps near the Mutonga confluence.

At the present time the drainage on the Basement System is in a state of maturity, attained probably before the Gamblian Pluvial Period of the Upper Pleistocene when the aggradation of most of the stream beds is considered to have taken place. Recent uplift has caused the removal to depths of over thirty feet of most of the material then deposited so that the streams now flow along steep-sided channels. Numerous rapids and low falls also resulted along all the main streams. The more prominent falls, however, of which there are many over one hundred feet in height in the Mount Kenya volcanics, were doubtless for the greater part carved previously during the lower Pleistocene. The most notable example on the Basement System terrain is the "Grand Falls" with a height of approximately sixty feet situated east of Kijegge on the Tana River. It has served as a most effective and far-reaching base level of erosion since above the fall the river is broad and sluggish for many miles while below it has excavated a deep narrow gorge along which the speed of flow is greatly increased.

III—GEOLOGICAL HISTORY OF THE AREA

In the table below the rock succession and the chief geological events in the evolution of the area are summarized:—

Age	Formations	Earth Movements and Climatic and Erosional Phases
Recent	Soils, Laterites, Calcretes .. U River gravels and sands. Lateritic ear)hs.	Re-excavation of river gravels. Gamblian Pluvial Period.
Pleistocene	M Gravel beds Thingishu river(?) Parasitic cones Mt. Kenya. L Nyambeni Volcanic Series, olivine basalts.	dry Kamasian Pluvial Period; local peneplanation(?). Laterite formation at times, erosion reaching stage of maturity. disturbance.
Pliocene	Mount Kenya volcanic series.	end-Tertiary peneplanation. disturbance.
Miocene		sub-Miocene peneplanation. disturbance.
?Cretaceous		peneplanation.
Pre-Cambrian(Archæan)	Basement system.	

The rocks of the area fall naturally into two distinct groups, those very ancient constituting the Basement System and the comparatively recent, Tertiary and later volcanics and subordinate sediments. The geological history of the area can be traced through the following chief phases:—

I.—DEPOSITION OF THE BASEMENT SYSTEM

During Archæan times vast successions of sediments had accumulated. These were of varied type the nature of which is now often obscure owing to later changes. A thick originally shaly series and one band of felspathic quartzite, however, are recognizable, but compared with other Basement System areas in Kenya the number of lithological types is limited; limestones in particular are not represented. Volcanic rocks found elsewhere, are also apparently absent or transformed beyond recognition.

2.—METAMORPHISM OF THE BASEMENT SYSTEM

Later in the Archæan powerful crustal adjustments caused the originally flat-lying strata to be uptilted, intensely contorted and folded. Under the influence of these deforming forces and with accession of heat and magmatic fluids from the earth's interior the sediments were converted to crystalline schists, gneisses and granulites, the greater part of the rocks developing a granitoid appearance and a granitic or near-granitic composition. Large masses of basic magma invaded the strata at some unknown stage in this great cycle of tectonism and metamorphism.

3.—EROSION BETWEEN THE ARCHÆAN AND THE TERTIARY PERIOD

In the period between the Archæan and Tertiary, erosion seems to have been the only process operating over the area, since no evidence of sedimentation, vulcanicity or intrusion exists. The region must have been denuded of many thousands of feet of rock during this long interval.

4.—SUB-MIOCENE PENEPLANATION AND MIOCENE SEDIMENTATION

The completion of formation of the sub-Miocene peneplain, which is the oldest erosion surface recognized in the immediate area, corresponds with the termination of a period of crustal stability following the end-Jurassic uplift. Sedimentation has taken place in channels on this surface at widespread localities over the Colony, at certain of which Miocene fossils have been discovered. The present area affords no evidence of such sedimentation.

5.—ERUPTION OF MOUNT KENYA

No evidence has as yet been adduced to date the inception of the Mount Kenya vulcanicity closely. In the present area the lowermost flows, except for basalts in the extreme north, are of kenyte—a lava type established as later than the Laikipia phonolitic plateau eruptions, which began in the late Miocene. The kenyte, however, on the northern side of the mountain (Shackleton, 1946, pp. 35 36) is underlain by phonolites and basalts so the age of initiation of the Mount Kenya flows is at present unknown. In the area mapped the kenytes, with the exception noted below, rest directly on a flat surface, presumably the sub-Miocene peneplain.

There is, however, evidence that the kenyte did not commence to flow before the peneplain was already well-eroded over the south-eastern quadrant of the area. The Uguleri kenyte outlier in this part of the area has at its extreme eastern end an elevation of 2,610 feet, which is about 400 feet lower than the sub-Miocene surface and 400 feet higher than the nearest point on the end-Tertiary surface. This suggests that eruption had not commenced before the late-Tertiary, though probably before the culmination of the end-Tertiary planation.

6.—THE END-TERTIARY PENEPLANATION

In the north-eastern quadrant of the area the end-Tertiary peneplain is a well-defined surface. It marks the end of a cycle of uplift and renewed planation during the later part of the Tertiary whereby the district was progressively lowered eastward and south-eastward several hundred feet below the level of the sub-Miocene peneplain, causing the formation of the prominent kenyte escarpment overlooking the end-Tertiary peneplain.

7.—THE PLEISTOCENE BASALT ERUPTIONS

Covering the end-Tertiary peneplain are thin flows of olivine basalts, which have emerged from numbers of cones, one or two within the area and the remainder scattered over the plains extending northwards to the foothills of the high Nyambeni volcanic range. These basalts are doubtless to be correlated with those covering the end-Tertiary peneplain to the north of Mount Kenya along the south side of the Uaso Nyiro River. (Shackleton, 1946, p. 5.) They are representative of a distinct eruptive period in the volcanic history of the Colony causing widespread extrusion

of basalt, and which is generally regarded as falling largely if not wholly within the lower Pleistocene period. The numerous parasitic cones on the northern slopes of Mount Kenya and the group of three named Karuie in the north-west part of the area probably belong to the same period. Basalt was erupted from them, and they are mostly in a well-preserved state and have been described by Shackleton (1946, p. 38) as "not later than lower or possibly middle Pleistocene in age".

8.—MIDDLE AND UPPER PLEISTOCENE EROSION AND DEPOSITION

On the northern side of the Thingishu River to the south-west of Lansa Hill lies a small plain covered with partly eroded, dark, poorly cemented gravels containing angular and sub-rounded pebbles predominantly of the basalts covering the end-Tertiary peneplain, which at the nearest point is 300 feet above the gravels. The erosion of this plain may be attributed to a cycle of uplift and planation possibly in the middle Pleistocene. No artefacts or fossil evidence were found, however, in the gravels.

Many of the rivers contain narrow deposits of crudely bedded, loosely cemented boulders, gravels and sands, probably accumulated during the Gambian Pluvial Period of the Upper Pleistocene when most of the rivers of Kenya received a load of detritus. Recent incutting has removed the greater part of these deposits.

IV—SUMMARY OF THE GEOLOGY

THE BASEMENT SYSTEM

The Basement System forms the floor on which lie all the remaining rocks of the area. It is composed of heterogeneous gneisses, granulites and schists, of varied and complex origin, as over a wide area of Kenya.

The present rocks represent an originally stratified, predominantly sedimentary, succession now converted to stratiform successions of well-banded gneisses with moderate to steep, mainly westward, inclination. Text-figure 1, indicates tentatively the conditions of their formation. Regional metamorphism and variable though intense granitization were the dominant processes. Considerable granitic injection has also taken place and pegmatites and aplites are abundant.

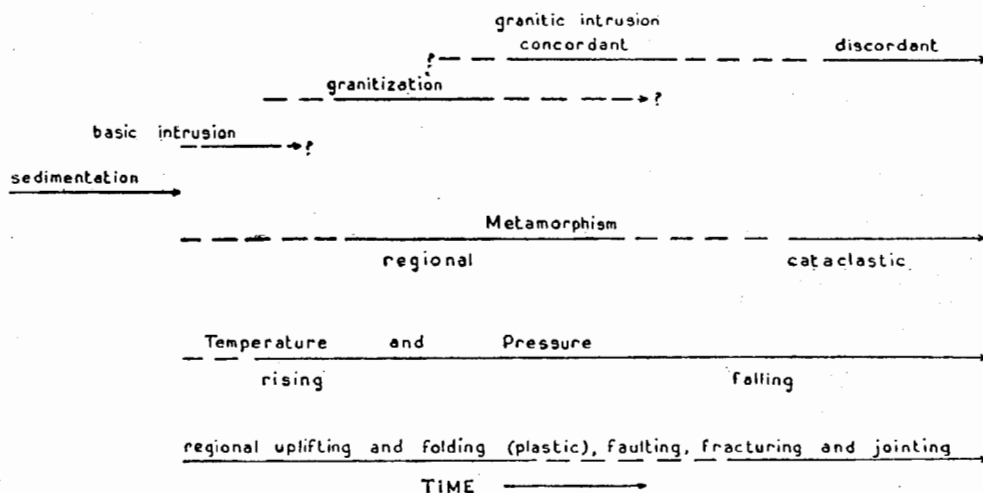


Fig. 1.—Conditions of formation of the Basement System.

At a certain stage in the tectonic-metamorphic cycle large masses of basic magma invaded the Basement System rocks, mainly as tabular-lenticular bodies. The bulk of the magma crystallized as various members of the gabbro clan, though separate intrusions of perknite also occur. Hypersthene is an essential mineral in most of the basic rocks. Surrounding the gabbroic and perknitic bodies up to distances of a

few miles there is also much hypersthene-bearing granitized rock, grading in composition from quartz-gabbro to granodiorite. Although the evidence collected is not conclusive it appears probable that they are granitized derivatives of the basic rocks. Together these hypersthenic rocks constitute a charnockite suite.

Minor intrusions of dioritic type are widespread but relatively rare.

THE MOUNT KENYA VOLCANIC SERIES

The western half of the area is covered by a succession of lava flows which have erupted from the central and subsidiary vents of Mount Kenya.

The succession falls into four main and a subsidiary fifth group according to age and lava type:—

- (5) Basalts of the parasitic craters.
- (4) Olivine basalts. Unknown thickness.
- (3) Finely porphyritic and dense phonolites. Up to more than 2,000 feet thick.
- (2) Kenytes up to over 3,000 feet thick.
- (1) Basalts with phonolite. Not thick.

(1) The lowermost flows are of olivine basalt which underlie the kenyte in the northern part of the area north of Kituri rest camp, and are themselves underlain by tuffs and agglomerates. They are accompanied by some dense phonolite. (2) Overlying the basalts in the north and resting elsewhere directly on the sub-Miocene peneplain are a succession of kenyte* flows gradually increasing from a negligible thickness across the northern limit of the area to an unknown value well over 3,000 feet across the southern part. Interbedded in this series are considerable thicknesses of ash and agglomerate and a few basalt flows of limited extent. (3) The kenytes are followed by eruptions of finely porphyritic or dense phonolites and subordinate ash beds having their maximum development along the central part of the lava area and attaining a total thickness of over 2,000 feet. (4) In the north-eastern part of the area the phonolites are overlain by flows of olivine-basalts. The extent of their distribution could not be determined as the densely forested area was not traversed. (5) Within the forest in this part of the area are a group of three small and well-preserved craters named Kiruini, representing the latest manifestation of vulcanism within the area. The basalts of (4) are thought to belong to an earlier period.

THE NYAMBENI VOLCANIC SERIES

Some miles north of the area volcanic accumulations build the Nyambeni mountains which cover a big area and rise many thousands of feet above the great flat expanses of the end-Tertiary peneplain. Extensive sheets of lava spread out on the surrounding plains from vents in the mountains and from numerous cones scattered over the plains, a few of which fall within the area. The greatly different stages of erosion seen in these cones perhaps indicate a protracted period of eruption. The basaltic sheets have a fairly large extent in the north-eastern part of the area, but a few widely separated outliers show that the flows originally stretched over most of the eastern half of the area to a distance of well over thirty miles south of the Nyambeni Range.

The flows consist of finely porphyritic and moderately vesicular olivine basalt, some of which has a markedly columnar structure.

PLEISTOCENE SEDIMENTS

Gravels of Pleistocene age on the small plain on the north side of the Thingishu River south-west of Lansa Hill consist chiefly of pebbles of Nyambeni basalt with less frequent Basement System and kenyte pebbles set in a sandy friable matrix. No good vertical exposures were found to show the thickness of the beds.

The remnants of apparently younger, torrential deposits, probably upper Pleistocene in age, occur in places along the Basement System streams.

* A strongly porphyritic type of phonolite.

V—PETROLOGY AND PETROGRAPHY

I.—BASEMENT SYSTEM

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

- (1) Schists.
- (2) Psammitic rocks.
 - (a) Plagioclase-hornblende gneisses.
 - (b) Quartzite.
 - (c) Other psammitic gneisses.
- (3) Migmatites.
- (4) Intrusives.
 - (a) Granites.
 - (b) Pegmatites and Aplites.
 - (c) Basic and ultra-basic intrusives; and
associated hypersthene rocks
 - (d) Minor intrusives.

} Charnockite suite

(1) SCHISTS

Schists are not abundantly exposed and always occur among migmatites. The dark colour of many migmatites shows their derivation from pelites, but although pelitic material often predominates in the dark bands of composite gneisses so that they closely resemble schists, the microscope usually shows considerable addition of alkali feldspar or reconstitution of the original feldspar and the typical micro-features of the migmatites. Non-migmatized schists are the most easily weathered and eroded rocks of the Basement System which accounts in part for their scarcity in outcrops, but the generally advanced stage of granitization over the area renders it improbable that much schist has been left unmodified especially since their structure makes them preeminently favourable for permeation by metasomatising fluids. No areas of schist of sufficient extent to be shown on the geological map were found.

A few specimens of the least granitized or possibly non-granitized schists were collected. They doubtless represent some of the rock types from which the migmatites originated. Specimen 44/153 is dark green-gray and soft, the dark minerals which are slightly predominant over the light, being primitive blue-green hornblende, subsidiary brown biotite and abundant iron hydrates. The light minerals are albite and a little potash feldspar and quartz. A similar schist 44/284 is composed of a confused imperfectly recrystallized aggregate of green and brown biotite, chlorite, iron hydrates, abundant clinozoisite-epidote, sphene and felsic minerals, quartz and kaolinized feldspars. The feldspar is partly of potash type. In 44/294 the dark minerals greatly predominate being chiefly green-brown biotite with deep blue-green hornblende and much iron dust. The most common felsic mineral is oligoclase, partly with subhedral porphyroblastic habit, accompanied by quartz and a small amount of potash feldspar. Epidote, apatite and sphene granules are abundant. Specimen 44/154 is representative of the more light coloured schists and is perfectly foliated in very thin alternating light and dark coloured layers. The colourless minerals, potash feldspar together with subordinate quartz and untwinned albite, form a fine-grained mosaic, and the dark minerals, deep blue-green hornblende and a small amount of green biotite and epidote, are segregated in folia. Sphene is an abundant accessory. A holo-leucocratic extremely fine-grained semi-schistose rock, 44/268, consists of thin folia of cryptocrystalline and microcrystalline quartz, with subordinate albite forming a few augen. The section is sparsely dusted with sericite and greenish biotite.

It is evident that the above examples of schist contain appreciable amounts of alkali feldspar and quartz and do not differ greatly in mineralogical composition from much of the migmatite. Where a distinction should be made between non-granitized schists and low-grade migmatitic rocks is, therefore, a matter of doubt. Whether or not, also, granitizing fluids had some influence on the composition of these apparently non-granitized schists cannot with certainty be determined.

(2) PSAMMITIC ROCKS

(a) *Plagioclase-hornblende Gneiss.*

A distinct class of gneiss was recognized, composed essentially of plagioclase and hornblende with quartz and biotite. The members of the class closely resemble migmatitic gneisses from which they can only be definitely distinguished under the microscope, but to what extent migmatization has influenced their composition is a matter of doubt. They are thought to contribute an appreciable part to the total rock succession but owing to the difficulty of field recognition their true importance is difficult to determine. Their origin could not be established with any degree of certainty but in view of the well-developed banding in the outcrops from which some of the specimens were taken they are considered to be, for a good part at least, derived from lime- and soda-bearing sediments. They have, however, a roughly dioritic composition and the possibility that some are meta-intrusives must be considered. Field relations offer no solution to any particular origin; certain specimens are from bands of composite gneiss while one is a xenolith in migmatite.

The hand specimens have heterogeneous textures. They are in general medium-grained and gneissose with rough foliation, but mottling and uneven distribution of the dark minerals is not uncommon. A few specimens are relatively fine-grained dark gneisses. Specimen 44/282 has a clearly defined linear structure.

Under the microscope the textures of these gneisses are similar but simpler on the whole than those of the common type of migmatite. They vary from medium- to fine-grained and are usually inequigranular and only mildly gneissose. An indefinite foliation of the felsic minerals is sometimes noted while the mafic minerals are often roughly segregated with good schistose orientation of the components. The dark minerals are sometimes seen to wrap round the plagioclase grains. Straining and rupturing of the plagioclase is ubiquitous and weak mylonitization is common with development of mortar structure. Plagioclase and subordinate quartz always make up between 50 per cent and 60 per cent of the volume of the rock. The plagioclase is fresh but often dusted with ferruginous material or crowded with minute chadacrysts of biotite or hornblende. Where determined the plagioclase was found to be andesine. Quartz is seldom present in large amount and forms small irregular grains often with sutured outlines. It occurs scattered throughout the slides but sometimes has a tendency to be concentrated in discontinuous layers. In slide 44/195 it has a late relationship to the plagioclase being inset between grains or in fractures in them, indicating the attainment of a considerable degree of mobility during the recrystallization of the rock or possibly the introduction of quartz from an external source. Potash feldspar is absent except in 44/223 which contains a trace. Hornblende is the chief dark mineral and has consistent features in all the slides examined. It is a dark green to medium blue-green strongly pleochroic variety, the blue colour being sometimes pronounced. The colour sometimes varies from grain to grain. In slide 44/192 the maximum extinction is 28° . It forms well-cleaved solid crystals but for the greater part the habit is rather ragged and wispy. A curious skeletal intergrowth with plagioclase, quartz and biotite is seen in 44/192 and 44/238, and parts of certain large crystals form a vermicular intergrowth with quartz. Poikilitic inclusion of apatite, sphene and iron ore grains is common. Biotite, pale brown, dark brown and green-brown, with irregular flaky habit is intimately intergrown with the hornblende but does not intensely replace it. Apatite and sphene in well-formed microlites are common while zircon is rare. Iron ore is a common accessory. A little epidote occurs in a few examples.

The approximate modes* of some representative examples of these gneisses are:—

	44/192	44/195	44/223	44/241	44/238
Plagioclase	53 (An ₃₈)	45 (An ₃₈)	35 (An ₃₅)	40 (And)	47 (An ₄₂)
Quartz	1	4	20	10	10
Potash feldspar	—	—	+	—	—
Hornblende	37	45	20	38	31
Biotite	8	5	20	10	10
Accessories	1	1	5	2	2

* Modes were estimated.

(b) *Quartzite.*

From the road between Embu and Runyengis in the south-western corner of the area, a conspicuous smooth-sided hill, Karue, is visible, built of beds of quartzite. The beds are a few hundred feet thick at Karue but thin northward and can be traced for only a mile in that direction before apparently merging into leucocratic granitoid gneiss.

Closely-spaced bedding joints are well-developed giving a slabby aspect to outcrops. The quartzite is predominantly pure with a light blue-gray colour, weathering white, and on freshly fractured surfaces has a fine-grained compact semi-glassy texture. Inter-banded with the purer quartzite are finely laminated sericite-rich quartz gneisses. In thin section the quartzite 44/203 is seen to consist of a fine-grained fairly equigranular mosaic of sutured highly strained quartz grains with moderate gneissose texture. A small percentage of minute iron ore grains are scattered throughout the section. A slide of the micaceous quartzite 33/304, shows fine foliation of sericite and quartz-rich layers. The quartz has uneven grain and has developed pronounced flow lenticles. Iron ore dust is again abundantly dispersed through the slide.

(c) *Other Psammitic Gneisses.*

A few specimens of other psammitic rocks were collected. These also resemble the migmatites in hand-specimens and their identity was disclosed only after the examination of thin sections. They illustrate further the diversity of rock types from which the greatly preponderating migmatitic rocks were derived. Specimen 44/228 is a coarse-grained muscovite-magnetite gneiss consisting of flakes of muscovite averaging 0.5 cm. with a subordinate amount of magnetite in subhedral grains up to a few millimeters in diameter. Specimen 44/283 is a sericite-sodic plagioclase-quartz-garnet rock; the plagioclase is untwinned and the garnet is an unusually pale pink, almost colourless variety. A slightly migmatized labradorite-quartz rock 44/283, represents a possibly common type of gneiss in the highly banded migmatitic facies exposed along the Tana River. It consists of medium labradorite and subordinate quartz together with minor amounts of epidote, orthoclase and garnet.

(3) MIGMATITES

By far the greater bulk of the rocks of the Basement System in the present area are much modified from their original composition by granitization. Great masses of rock of approximately dioritic to granitic composition have been produced from sediments and possibly volcanics of different types. Some of the basic intrusives are also regarded as having been extensively granitized.

THE PROCESSES OF GRANITIZATION

The following is a summary of the chief processes generally regarded as involved in the production of migmatites. It may be emphasized that although the end-products of each process can be sometimes distinguished they are generally closely interrelated and mutually continuous. Some migmatites have been regarded as produced on a regional scale by the *mechanical injection of magma* usually of granitic composition in layers and streaks along foliation planes (lit-par-lit injection), joints, and other channels in the country rock. Development by *magmatic soaking* of the host rock is, however, regarded in many regions as more important if not the principal migmatizing process.

Metasomatism, i.e. molecular exchange between the host rock and the permeating fluids, the final migmatite being composed partly of original and partly of added material, is a well-established phenomenon resulting from the magmatic soaking. Opinion is, however, divided as to the precise nature of the magmatic fluids—whether they are true magmatic melts, water-rich magmas or relatively dilute aqueous solutions. Turner (1949, p. 309), in a resumé of current opinion on the question, considers that migmatization itself is not the work of aqueous solutions, although in particular cases hydrothermal metamorphism and migmatization may be associated phenomena. He affirms the conclusion of Eskola (1939, p. 378) that if migmatization is to be classed

as a kind of metasomatism it is one in which a highly fluid water-saturated granitic magma itself acts as "carrier". With regard to the relation between granitization by percolating fluid magma and mechanical injection of granitic magma itself Turner quotes MacGregor and Wilson (1939, p. 209) who recognize complete gradation between two extreme cases, "at one extreme there may be complete continuity between the chemical metasomatism and (subsequent) mechanical penetration by magma, in which case the igneous melt simply flows into the enlarged pore spaces of the metasomatised rock. This would lead to lit-par-lit type of injection and similar phenomena. At the other extreme there may be a marked discontinuity between the two processes, particularly if the mechanical advance of the magma has been rapid and the energy content low; the country rocks will then be invaded by magma before they have suffered important modification by metasomatism. This in the case of normal intrusive rocks with clear contacts". A third process is also generally accepted as contributing to the formation of certain migmatites, that of *differential fusion*; synonymous terms are anatexis, palingenesis, ultrametamorphism. The results of this process are essentially the separation of granitic material by selective fusion of different rocks under deep-seated conditions, particularly at high temperature, which then crystallizes more or less in place or is injected into the surrounding or superimposed rock in the form of discontinuous streaks, lenses or veins of granite, aplite or pegmatite. Migmatites of this kind are essentially the same as the injection migmatites but instead of a juvenile magma a regenerated magma is postulated. The injected and granitizing magma of the first two classes of migmatites, however, probably in part represents regenerated magma formed by differential fusion at lower levels in the crust.

Aspects of Granitization in the Area.

Of the above processes granitic metasomatism seems to have played the dominating role in the area. Banding of the successions is a marked feature (Pl.Ia). It is especially well-developed in the thick series of migmatites lying between the Kijegge and Mumoni ranges, where there is a rapid and spectacular alternation of relatively lighter and darker layers over considerable thicknesses of the successions. By analogy with the Kitui region (Schoeman, 1948, p. 21), where much evidence exists to correlate such well-banded migmatites with interstratified pelitic schists, much of the migmatite of the present area is thought to be due to a nearly pseudomorphous replacement of previously existing structures. Such faithful reproduction is more reconcilable with the concept of metasomatism than with that of bulk addition of granitic material. As a corollary it is assumed that the rocks must have maintained an essentially solid state throughout the period of granitization.

As granitization advances there appears to be a general tendency for the banding to become less distinct with the relative increase of alkali feldspar, and the rocks progressively assume the aspect of granitic gneiss. Much of the migmatite of the area is in an advanced stage of granitization and its definite distinction from intrusive granitic gneiss is seldom possible, especially since granites injected as such during the granitization period are characteristically concordant with the foliation.

In the lower grade and well-banded migmatites a universal feature is the presence of often closely spaced and thin layers, lenses, streaks and less regular bodies of leucocratic granitic material in a relatively darker base, lying parallel with the banding. This feature may equally well be explained as due to segregation from the body of the rock, relatively more intense granitization along such planes or mechanical lit-par-lit type of injection. It is thus not possible, on the whole, to assess the importance of granitic injection in the formation of the migmatites but it is, nonetheless, thought to be considerable since some larger scale granitic intrusion has undoubtedly taken place. Whether or not much differential fusion also occurred as a result of excessive stress or elevated temperature is an equally difficult problem.

To whatever process or combination of processes it may be ascribed, migmatization has advanced to a high degree of completeness over the predominant part of the succession in the area, and except for the large basic intrusions, only relatively small amounts of the rocks shows no recognizable effects of granitization.

Structures of the Migmatites.

In the same way that the banding is preserved until a high degree of granitization is reached so granular structures seem to be preserved by mimetic crystallization of newly formed minerals, so that the gneissose or linear structure and grain size are probably also largely inherited from the parent rock. The granitization, however, proceeded under regional metamorphic conditions and a metamorphic fabric results regardless of previous structures. Where not notably disturbed by deformation the gneissosity and lineation parallel the stratification. Gneissosity is mostly of a mild degree but intense flattening of grains is common. In much of the rocks the directional impress is faint due apparently to a number of causes including the predominance of the granular minerals quartz and feldspar, the possible absence of a directional stress element during recrystallization, and granulation.

Owing to the intense confining pressures, high temperature and pervasion of magmatic fluids, much intense plastic deformation is seen. It is also probable that portions of the migmatite masses were rendered highly viscous, if not more mobile, by the advanced metasomatism or accession of much liquid magma, and movement in such masses may have been the cause of the extreme contortions and textural heterogeneity often observed in the area. An important factor which contributes to the great variety of textures is the recrystallization and redistribution of the mafic material causing conspicuous streaking, mottling, spotting, etc. Also the degree of coarseness is influenced by the variable concentration of volatiles during crystallization so that often within small masses of migmatite a large range in grain size is found.

Petrography.

Under the microscope the migmatites are in general characterized by a complex, extremely uneven-grained aliothiomorphic texture combining metamorphic and replacement phenomena in all grades of intensity. Replacement textures often yield clear evidence of the mineral paragenesis and are perhaps the most notable microscopic feature of the migmatites. The following is the most common order of formation of their minerals—mafic and accessory minerals, quartz and plagioclase, potash feldspar, myrmekite. In many slides, however, repeated generation of one or more of the minerals is seen, but always in much less amount than during the main period of crystallization. The place of the dark minerals in the sequence is variable; although mostly of early crystallization, biotite and hornblende enter into apparently contemporaneous intergrowths with plagioclase. In some slides, e.g. 44/270A, biotite forms interstitially between the felsic mineral grains and in 44/293 and 44/214 biotite replaces the plagioclase. In most of the thin sections quartz and plagioclase have crystallized more or less simultaneously and do not reveal evidence of mutual reaction. Occasionally, however, quartz replaces the plagioclase to a small degree as in 44/170; in 44/164 and 44/296 they seem mutually replacive, in the last example forming a complex interpenetration intergrowth.

The relationship of the potash feldspar to the quartz and plagioclase is most striking. It normally shows indisputable evidence of having formed later than the bulk of these minerals, and has for a great part been emplaced by reaction with them. The visible effects of this replacement are sometimes slight or indefinite but in most cases a variety of replacement phenomena are displayed, such as fine corrosional intergrowths around the borders of plagioclase grains, tongues, embayments, veinlets, etc. Frequently single grains and sometimes many grains of plagioclase in a thin section are corroded throughout by orthoclase, resulting in perthitic intergrowths difficult to distinguish from some types of exsolution antiperthite (also developed in certain of the migmatites). Often grains of plagioclase are completely mantled by microcline, and in slide 44/306 (see fig. 2B) a few crystals of plagioclase are clearly in an advanced stage of pseudomorphous replacement by microcline. This feature was also noted in other slides, though not so clearly, indicating that much of the potash feldspar replaces original plagioclase pseudomorphously. Although the potash feldspar replacement shows a selective affinity for plagioclase the quartz is also much replaced, sometimes to the extent where clusters of separate quartz grains with common optic

orientation embedded in microcline indicate advanced digestion of the quartz. In well over half the thin-sections examined myrmekite, an intergrowth of sodic plagioclase with vermicular quartz, is present, sometimes only as a grain or two in a slide but often abundant and constituting up to a few per cent of the rock. It encroaches on the earlier felspar in the form of fungoid grains, replacing chiefly the potash felspar. Its origin is not evident in the migmatites but it appears to accompany if not result from the reaction of the potash felspar with the plagioclase. No direct relation, however, seems to exist between either the amount of potash felspar present or the degree of intensity of its replacement, and the abundance of the myrmekite. Late sodic plagioclase formation is common, the plagioclase occurring in much the same interstitial and replacive habit as the potash felspar. It frequently forms borders round the earlier formed plagioclase and is distinguished from it by being clear, fresher and free of inclusions. Rarely, as in 44/271, three generations can be observed; the bulk of the plagioclase forms the largest crystals, which contain remnant units of an earlier generation, while late plagioclase is abundant, partly in the form of myrmekite. Potash felspar is also occasionally present in two distinct generations as in 44/173. A good number of thin sections exhibit a type of "mortar" structure in which the earlier crystal intergrowths are set in a base consisting of fine- to very fine-grained aggregates of quartz, plagioclase and orthoclase. The base material infills fractures and locally strongly corrodes the earlier material. It is not certain whether this texture is a result of protoclasis or cataclasis or whether it represents an invasion of granitic matter emplacing itself by metasomatism along grain interspaces and other channels. It may perhaps result from a combination of processes.

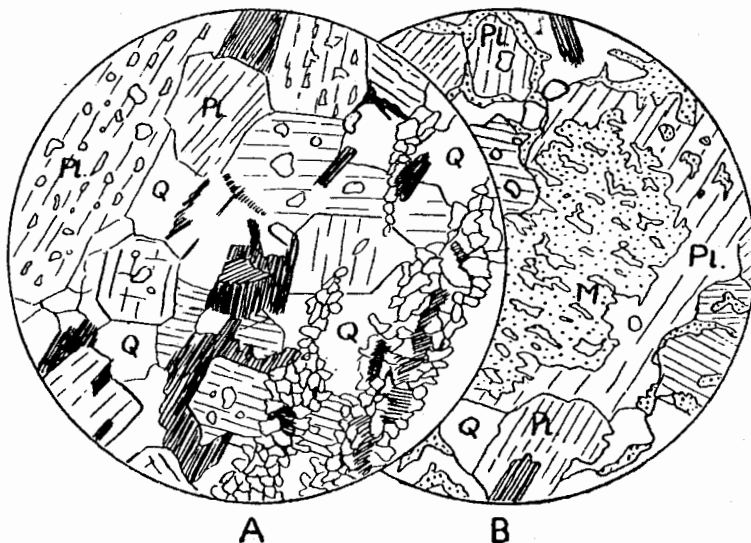


Fig. 2.—*Microscope Drawings.* (A) Hornblende-biotite-quartz-plagioclase migmatite. Specimen 44/199. Ordinary light $\times 26$. Pl = plagioclase, Q = quartz. A low-grade migmatite with little potash felspar and whose plagioclase is andesine-labradorite An_{50} . The plagioclase is unusually idiomorphic, but many sections of migmatite shows occasional development of crystal faces indicating unrestricted crystallization in a yielding, probably partly liquid, environment. The section also shows a characteristic of the migmatites, the often intense crowding of the felspar with small rounded and droplike grains of quartz. Crush and replacement veinlets such as those shown on the right-hand side of the drawing are commonly developed in the migmatites. Much of the biotite of the section is concentrated in such veinlets.

(B) Leucocratic biotite-bearing granitoid gneiss. Specimen 44/306. Ordinary light $\times 26$. Pl = plagioclase, microcline shown stippled. The replacive relationship of the potash felspar to the plagioclase is well shown. The large albite unit is in an advanced stage of replacement, the replaced area forming a perthitic intergrowth resembling ex-solution antiperthite.

At a stage when macroscopically the effects of granitization are not marked thin sections show complete reconstitution of the original felsic minerals to those of granitic assemblage; the replacement of the original dark minerals by their more alkaline counterparts, biotite and blue-green hornblende, seems to lag somewhat behind the replacement of the felsic minerals. As granitization advances, the rocks become progressively lighter in colour owing to increase in introduced alkali feldspar and possibly quartz, but there is nevertheless a strong tendency for the host rock to retain its colour index to a well-advanced stage of metasomatism. Thus melanocratic rocks form relatively dark migmatites and it is doubtful whether any of the more leucocratic granitoid migmatites were derived from dark schists or gneisses. As well as this largely inherent variation of the ratio of dark to light minerals there is marked variation in the ratio of the felsic minerals to each other. In more than half the specimens sliced plagioclase predominates over potash feldspar, but in a good number the reverse holds true, and either may be present to the near exclusion of the other. There is furthermore, no tendency towards a maintenance of average balance between the two, nor is the predominance of either to be correlated with the degree of completion of the granitization. Quartz makes up from a trace to almost half of the rock in individual specimens.

The plagioclase shows considerable range in composition even in the more intensely granitized rocks. In the lowest grade migmatites it is apparently unchanged or only slightly changed from its original composition and may be relatively calcic labradorite or andesine. With progression of the alkali metasomatism the plagioclase may fall anywhere within the oligoclase or albite range. Values from basic oligoclase An_{30} to albite An_7 were determined. Whereas the potash feldspar can be seen to make its place in part by replacement of the earlier formed minerals, no evidence was found except for the minor amounts of late plagioclase and myrmekite to indicate that the plagioclase formed in a similar way. The albitization of the original plagioclase thus presumably took place by total solution and crystallization under the influence of the pervading alkaline solutions, or the albite molecule entered the plagioclase in such manner as to be undetectable under the microscope. In this connexion the fact that occasionally the plagioclase grows with one or more straight crystal faces or, as in 44/271 and 44/199 (see fig. 2A), has a generally high degree of idiomorphism, indicates that in certain cases the plagioclase crystallized unrestrictedly in a yielding and probably partly liquid environment. In the examples where more than one generation of plagioclase is present it is all of identical or only slightly differing composition; the late additions of plagioclase and myrmekite are always of about the same composition as the chief generation of plagioclase, i.e. albite-oligoclase. In only one slide, 44/270A, does it show concentric zoning. In the slightly migmatized, relatively basic rocks, quartz and potash feldspar have entered along interstices and effect some replacement, but plagioclase was not found to accompany them. The plagioclase is mostly non-perthitic but in a good number of thin sections it is perthitic to a variable extent, sometimes affecting only a few grains in a section. When well-developed the perthite has a characteristic "checker-board" pattern made up of more or less rectangular blebs of potash feldspar lying with their longest axes parallel to the prismatic cleavage. By contrast with the potash feldspar the plagioclase is often heavily kaolinized and sericitized and crowded with small chadacrysts of epidote, biotite, iron hydrates, sometimes hornblende and other, undetermined, minerals.

The potash feldspar usually exhibits the cross-hatched twinning of microcline and is much more frequently perthitic than the plagioclase. All types of exsolution patterns are met with and the ratio of unmixed plagioclase varies markedly, in certain extreme cases being present in greater amount than the host orthoclase or microcline.

In addition to the irregular, lenticular, sutured, lobate, veinlike and other forms which the bulk of quartz assumes, a characteristic of the migmatites is the presence of numerous small droplike quartz grains scattered through both types of feldspars (see fig. 2A) and often included in the dark minerals and within larger units of quartz. Their mode of formation is not evident.

(4) INTRUSIVES

(a) *Granites.*

The granites apparently arose by the quiet and gradual upwelling of magma chiefly along foliation and stratification planes in the country rock which was itself undergoing granitization at elevated temperature, so that contacts are mostly gradational and indefinite. Even when clear-cut they show no border chilling, contact effects, or other phenomena diagnostic of intrusion. When, however, such granites are intruded in sheet, vein or lit-par-lit fashion into non-granitized or relatively non-granitized rocks there can be little doubt of their magmatic origin. In the present area, however, little of the country rock was found in this condition and granitic intrusion could only be inferred from such considerations as the following—the presence of leucocratic sheets and veins of varying thickness in melanocratic migmatites; the occurrence of sheets of homogeneous and relatively leucocratic rock from a few to several hundred feet thick forming prominent outcrops in the normal heterogeneous migmatitic assemblage; and by transgressive relationships. When also occurrences show distinct textural or structural features such as conspicuous porphyritic development, even grain, marked homogeneity, etc., not shared by the surrounding migmatites, an intrusive origin is postulated. In the area mapped the specimens regarded as orthogranites on some of the above grounds, revealed the same variability in the potash-soda ratio as the migmatites and showed no distinctive textural or mineralogical differences.

(b) *Pegmatites and Aplites.*

Pegmatites are abundant over the area as lenticular or wholly irregular segregations in migmatite, as anastomosing vein systems, as discontinuous roughly conformable sheets and as lit-par-lit injections. Individual bodies are sometimes large especially when in sheet form; one near the confluence of the Thingishu and Kazita rivers is over forty feet in thickness.

Many of the smaller bodies appear to be auto-segregations or replacements but the greater number are emplaced with sharp contacts and often discordant relation to the granitized country rock. The pegmatites must thus in greater part have succeeded the granitization and probably mark the final phase of the granitization-granite intrusion cycle. The emplacement of pegmatites within the basic intrusions, however, raises the question of whether a pegmatitic fluid segregated from the basic magma and whether more than one phase of pegmatitic intrusion is represented in the area. No conclusive evidence was found; in appearance, composition and mode of occurrence all the pegmatites seem to be closely allied.

The few slides made show that the pegmatites, like the migmatites and granites, include both potash and soda types; 44/111 and 44/126 consist entirely of microcline perthite and quartz while 44/239 represents a soda type, being composed of moderately antiperthitic albite, intimately intergrown with vermicular quartz. White and pale green mica is the commonest accessory mineral, present in considerable amount in certain veins. Biotite is often also present but is not so consistently developed as the white mica. Rarely hornblende is the dark mineral. Black iron and titaniferous ores have sporadic distribution. Other common pegmatite minerals such as tourmaline were not observed, indicating that the pegmatitic fluids were probably devoid of hyperfusibles other than water and small amounts of fluorine.

Aplites are common though not abundant. They are emplaced as thin veins in the same way as the pegmatites and often accompany them. To judge from the few specimens sliced they are also variable with regard to the relative proportions of the felsic minerals.

(c) *Basic and Ultra-basic Intrusives and Associated Hypersthenic Rocks. (Charnockite Suite.)*

(i) *Form and Distribution of the Intrusions.*—The basic rocks are strongly resistant to erosion and the large bodies form prominent ridges and conical hills mostly characterized by steep grassy slopes with a minimum of outcrop. They are consequently easily distinguishable from the jagged and cliffed forms of the other Basement System hills,

The concordance of the main north-south belt of basic intrusion with the broad structural plan of the area is evident on examination of the geological map. The belt extends from well southwards of the present area to Kambuti Hill a distance of at least thirty miles. Intrusion seems to have taken place selectively along a series of thinly laminated amphibole-rich schists, outcrops of which are exposed in the Mara River south of Munguni Hill and further southwards, adjoining the basic bodies on their eastern side. The disposition of the Mutharanga-Mwangandia body which parallels the main belt has also been controlled by the trend of the Basement System. The Kierra intrusion on the other hand appears to transgress at an angle of about thirty degrees across the general foliation of the migmatites, which is almost east to west on the south side of the ridge. The Kibagi-Kandogi bodies are emplaced in an area where the structures are intensely irregular but they are, however, also discordant to the average strike of the enclosing strata. The Chemala-Kamanyori body and the Kantaugu-Kiuguni body, situated south and east respectively of Kiagu Hill, are at right-angles to each other, apparently in conformity with large flexuring in the Basement System at this locality.

It was not possible to obtain much direct evidence of the dip of the intrusions owing to lack of undisturbed exposures. The few dip values recorded on the primary banding or secondary foliation indicate that they have about the same dip as the country rock, which varies between about 50° and vertical. If a dip of 60° , which is approximately the regional average, is assumed for the largest mass in the area, the Kierra body, then its thickness is upwards of nine thousand feet.

In the belts of basic intrusion between the larger bodies forming the prominent hills, the topography is flatter and intrusion has taken the form of complex stock-works, and the outcrop pattern is intensely irregular owing to intimate interfingering with the country rock. The total area of basic rock outcrop predominates in such areas. They are not differentiated on the map owing to the difficulty of mapping their complexities in the limited time available. The chief areas are between the hills Kanyanyi, Kilimakieru and Kambuyi; between Kareni Hill and Munguni Hill and between Kampongo and Mbirika Hill. In a relatively well-exposed transverse section across the Kiburu body, a few miles north of the Kiburu trigonometrical beacon, the main body is flanked over a short length on its eastern side by numbers of closely spaced thin sheets of gabbro interleaved in hornblende schists. Such lit-par-lit type of injection possibly flanks some of the other gabbro bodies although exposures are generally too poor to determine whether this is so.

Surrounding the basic intrusions a considerable proportion of the regionally metamorphosed gneisses are hypersthene-bearing and grade in composition from quartz gabbros through diorites to granodiorites. Liberally dispersed among them are small bodies of basic rock of tabular or irregular form, which are thought to represent remnants of originally much larger masses reduced in size by partial conversion to hypersthene hybrids.

(ii) *Description of the Constituent Minerals.*—The mineral assemblage of the plutonic rocks is essentially similar to that of the charnockites described by Groves (1935) from the northern part of Uganda and of charnockites in India and many other parts of the world.

In a suite of rocks of this nature where the origin of certain minerals is a matter of doubt, and where several processes have been active in their formation, it is difficult to sub-divide the minerals into those of primary and those of secondary origin. The primary minerals listed below are those which are considered to have crystallized directly from a magmatic melt or to have been formed by peritectic reaction before final solidification. Among the secondary minerals are included those thought to have been formed by reaction in the solid state by the action of solutions from the magma itself and those developed by recrystallization and granitization. The *primary minerals* are—olivine, hypersthene, augite, hornblende, basic plagioclase and intermediate plagioclase in part, spinel in part, and also in part: quartz, potash feldspar, biotite, iron pyroxene, apatite and perhaps sphene. The secondary minerals include—plagioclase, quartz

and orthoclase in part; hypersthene, monoclinic pyroxene, spinel and hornblende in part; uraltite, sodic-hornblende, tremolite, actinolite, anthophyllite, epidote, talc, bowlingite, antigorite, biotite in part, muscovite, sericite, chlorites; and in part iron ores and apatite, and probably sphene and zircon.

A description of the individual minerals is given below.

The *olivine* content varies from less than 1 per cent to about 15 per cent in the olivine-bearing rocks. The crystals usually measure less than 1 mm. but occasionally are found to attain more than 2 mm. in cross-section. They are usually anhedral but subhedral grains showing one or more crystal faces also occur. They are colourless or very pale green, optically negative with optic axial angle from 75° – 85° , corresponding to a range $Fa_{26-46} Fo_{74-54}$.

The olivine is almost invariably completely surrounded by hypersthene, though rarely augite grows against it (fig. 3A). It is usually partially decomposed with the characteristic lining of cracks by iron ore and yellow or green bowlingite. Similar crystals are often completely replaced by the progress of such alteration. Fine-grained intergrowths of iron ore also result from reaction at the contact of olivine and hypersthene.

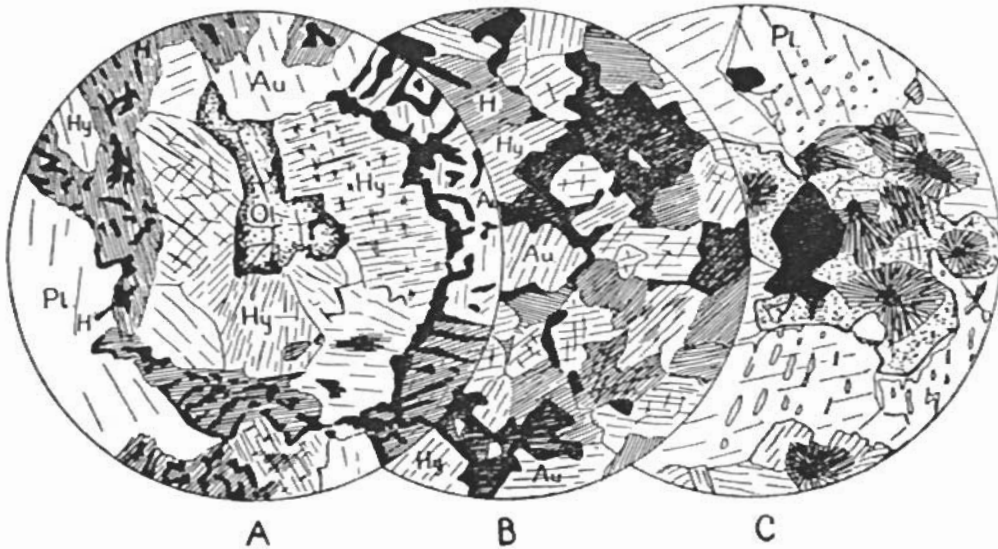


Fig. 3.—Microscope drawings. A. Olivine hornblende pleonaste norite. Specimen 44/93. Ordinary light $\times 26$. Ol = olivine, Hy = hypersthene, Au = augite, pleonaste shown black, Pl = plagioclase. The drawing shows well-developed reaction zoning of the dark minerals around a grain of olivine. The dactylic habit of the pleonaste is typical in almost all the spinel-bearing types. On the right side of the drawing the host mineral is a pale green monoclinic pyroxene and on the left it is intergrown with its more usual host, pale green hornblende, which in this case is partly brownish.

B. Hornblende hypersthene pyroxenite. Specimen 44/133. Ordinary light $\times 26$. Au = augite, Hy = hypersthene, pleonaste shown black. The pleonaste in this section occurs associated with the pyroxene in granular fashion. The latter is intensely replaced by uraltite hornblende.

C. Augite hypersthene biotite hornblende quartz-diorite (migmatitic charnockite). Specimen 44/278. Ordinary light $\times 26$. Pl = plagioclase, Hy = hypersthene, Au = augite. The radial growth of the biotite around iron ore grains is characteristic of the charnockitic migmatites. The pyroxene and plagioclase (medium andesine) is extensively replaced by biotite, blue green sodic hornblende and orthoclase.

The *hypersthene* is variable in colour from almost colourless with barely discernible pleochroism to pink with strong pleochroism. A progressive variation in composition might be expected in a rock series of this nature, ranging from pale magnesia-rich hypersthene in the ultra-basic and basic members to darker iron-rich hypersthene in the intermediate and acid varieties. Some indication of such variation was found; the ultra-basic and basic rocks usually carry a pale to almost colourless hypersthene whereas the intermediate and acid types have a more strongly pleochroic type. There are, however, many exceptions. Estimation of the value of the optic angle gives some indication of the variability in composition. The optic angle is usually about 60° , indicating about 40 per cent FeSiO_3 , but values up to about 85° (20 per cent FeSiO_3) were found, as in slide 44/124 of hornblende websterite from Inandago Hill. In the present thin sections the hypersthene always has negative optical character but Pulfrey (1946, p. 10) found the orthorhombic pyroxene in a hornblende websterite from Kierra Ridge to be optically positive enstatite.

The hypersthene has the characteristic pleochroism X pink, sometimes brownish pink or yellow, Z pale green, occasionally bluish green. Some varieties are almost colourless. It normally has straight extinction, but extinctions of a few degrees and even up to 17 degrees measured from a prominent cleavage have been noted. There is no indication that the anomalous extinction is due to cleavage inherited from monoclinic pyroxene (Sen Gupta, 1916, p. cxxi) or from former amphibole (Groves, 1935, p. 191). It may possibly depend on the development of cleavages other than the usual prismatic ones, to which cause Washington (1916, p. 331) has ascribed the oblique extinction of the hypersthene in a hornblende-hypersthene from the charnockite suite of Pammal Hill, Pallavaram; or it may merely be due to the simple, though seldom quoted fact, that orthorhombic crystals show extinction inclined to the cleavage in all sections which cut the three crystallographic axes (Johannsen, 1937, III, p. 212).

None of the ortho-pyroxene appears to have a secondary origin as postulated in certain charnockite provinces, e.g. by Ghosh (1941, pp. 8-10) and Groves (1935, pp. 154-159).

The *monoclinic pyroxene* is augite, varying from colourless to faintly green. It is rarely faintly pleochroic in shades of green. In one thin section it has pleochroism Z pale-green—X very faintly pink. No definite correlation seems to exist between the colour and the composition of the rock. The extinction angles vary between 33° and 67° (the latter in a diorite) with the majority between 48° and 58° . Pulfrey (1946, p. 71) observed some degree of correlation between the presence of spinel and the extinction angles of the augite, finding that in spineliferous rocks extinction angles did not exceed 48° , whereas in the spinel-free rocks, extinctions, although not necessarily high, were not observed to be less than 48° . In the specimens collected from the same locality during the present examination, however, some exceptions to his findings were noted. In a spinel-bearing olivine bojiite, 44/89, the augite has $Z \wedge c 57^\circ$ and in a spinel-free olivine-bearing norite the extinction angle is 33° , implying that although excess alumina represented by spinel in some of the rocks can be assumed to have been taken up into the augite molecule in the spinel-free types, resulting in augites with higher extinction angles, factors other than alumina content also affect the value of the extinction angle. The soda content seems to influence the size of the extinction angle in the acid members of the series where extinctions are usually over 50° and often over 60° . Extinction angles over 60° indicate the presence of the acmite molecule, which is not present, however, in sufficiently high proportion to affect the colour or pleochroism of the augite.

Diallage parting on (100) is often developed and schiller structure is also encountered in ultra-basic and basic rocks. Both structures disappear as the rocks become more acid.

Green *spinel* occurs in some of the perknites, in almost all the olivine-bearing rocks and in about a third of the bytownite-bearing rocks, but is scarce in those containing basic labradorite and rare in the still more acid gabbros. It is not found in the diorites. It attains a maximum abundance of about 25 per cent in a pyroxenite, 44/133, from Kamakua Hill to the north-east of Kierra Ridge (cf. Pulfrey, 1946, p. 72).

The spinel is for the greater part included in the hornblende as small rounded grains or dactylic growths the latter being often complex. It seems to be the result of the reactive replacement of both hypersthene and augite by the hornblende, excess alumina, magnesia and iron from the pyroxenes separating as spinel, which is probably the ordinary magnesia-iron type, pleonaste (cf. Pulfrey, 1946, p. 84). It is notable that the host hornblende is always of pale green or pale brown type whereas in the spinel-free basic rocks the hornblende is usually a deeper green. The pale colours of the hornblende enclosing spinel are taken to indicate a lower iron and alumina content, resulting from the formation of the spinel. In many grains the spinel almost equals the host hornblende in amount. The composite hornblende-spinel grains in addition to growing inwards into the pyroxene also occasionally appear to grow outward into the plagioclase, indicating that reaction with the plagioclase may also have contributed to the formation of the spinel. Often around the edges of these grains narrow rims of more intense intergrowth have formed against the plagioclase, of such extreme fineness that the two minerals overlap and it is impossible to distinguish them.

Hornblende-spinel intergrowths around olivine are described by Stewart (1946, pp. 472, 484, 492) in the troctolites and other olivine-bearing rocks of the Belhelvie gabbroic complex, Aberdeenshire, and are compared with similar intergrowths in allivalites and associated rocks from County Galway (Wager, 1932, pp. 59, 60). Stewart considered the intergrowths to be the result of late-stage magmatic processes taking place after the main consolidation of the rocks. Harker (1939, p. 306) ascribes them to magmatic, as distinct from metamorphic, reactions.

The spinel also forms grains and intergrowths in the pyroxene but to a much less extent than in hornblende and may have originated by precipitation of excess alumina from the pyroxenes. Ghosh (1941, p. 13) advocates a similar origin for pleonaste enclosed in hypersthene, diopside and amphibole in eclogites of the charnockite province of the Bastar States and Jeypore. It also very rarely occurs as scattered small grains in plagioclase, and then only in certain rocks in which the pyroxenes and hornblende occur in the same way. In certain of the perknites it is in relatively coarse-grained, anhedral forms measuring up to 1 mm. In 44/133 (see fig. 3B), a hornblende hypersthene pyroxenite, it constitutes about one-quarter of the thin section, intergrown with the pyroxene in granular fashion and apparently of simultaneous crystallization. An augite hornblendite, 44/137, consisting of coarse plates of hornblende with poikilitic grains of augite also has numerous rounded grains of included spinel.

A few smaller grains also lie in the augite but usually have a narrow reaction corona of hornblende surrounding them. In the hornblendite the spinel can be regarded as a reaction mineral liberated during the amphibolization of a pyroxenite, but there is no indication that the spinel has separated from the pyroxene in the pyroxenite 44/133.

Hornblende.—In the basic and ultra-basic members the hornblende mostly has a clear reaction relationship to the pyroxene. This is seen in the zoning of the dark mineral groups, hornblende surrounding the pyroxene as granular aggregates or as well-developed coronal growths. The hornblende also occurs without showing any reaction relationships and is intergrown with the plagioclase and pyroxenes in clean cut granular fashion. All stages of the pyroxene replacement are seen. The hornblende has a strong predilection for the augite but also replaces the hypersthene, which, however, is most commonly altered to tremolite. Often the whole face of a pyroxene crystal shows the commencement of the replacement in numerous minute patches, which increase in size progressively until the whole crystal is converted to hornblende.

The pyroxene cleavage is often perfectly preserved. To what extent this replacement is due to primary magmatic reaction, or to metamorphic action, is doubtful. The greater part of the hornblende is probably primary but there is often evidence, such as veinlets or films of hornblende in the plagioclase connecting with patches of hornblende in the pyroxenes, to indicate that much of it may be a late-stage product formed after the main consolidation of the rocks. Uralitic hornblende also replaces the tremolite which itself is evidently a late-stage replacement of the pyroxenes. Since under stress the gabbros convert to plagioclase-amphibolites, it is not certain to what extent the hornblende is a metamorphic mineral in some of the rocks which otherwise show stress effects.

The proportion of hornblende present in the rocks is extremely variable. It is often the predominant dark constituent even in the ultra-basic members and is occasionally the sole dark mineral. About half the rocks with plagioclase An_{50-75} have hornblende as the dominant mafic mineral. Only rarely it is entirely absent. In the diorites and quartz-diorites the hornblende again frequently predominates but it is to a large extent proxied by biotite.

In the perknites and olivine-bearing members of the series, the hornblende is predominantly a pale green variety pleochroic from pale yellowish green or very rarely pinkish yellow to darker neutral green or bluish green. It is sometimes exceptionally pale and only faintly pleochroic. Types with a brownish green or brown colour are also common especially in the perknites but do not appear in the intermediate and acid types. They show pleochroism, Z greenish brown or brown, Y pale brown, X pale lemon yellow or brownish yellow. More deeply coloured green varieties are also present in the perknites and olivine-bearing rocks, e.g. 44/147, an olivine-bearing hyperite, has a medium olive green hornblende and 44/113 a deep green type. In the rocks with plagioclase in the bytownite and labradorite range, excluding the perknites and olivine-bearing types, both pale and darker types of hornblende are present with darker types predominant. The darker hornblende is mostly a deep olive green colour but deep bluish green kinds also occur. In the diorites the primary hornblende is exclusively a deep olive green or bluish green colour.

Regardless of the degree of basicity, rocks which show the slightest sign of alkali metasomatism, presumably due to granitizing fluids or possibly in part to late alkaline residues from the basic magma itself, have developed a characteristic *blue sodic hornblende*. It appears to be a sensitive indicator of alkali reaction in these rocks, e.g. 44/140, a hornblende-bearing gabbro with acid bytownite, has numerous veinlets infilled with alkali felspar, calcite and the blue hornblende traversing the thin section. It definitely precedes the formation of the associated alkali minerals, biotite and potash felspar. It occurs in the first stages as filmy and wispy material along plagioclase grain borders and replaces to a slight extent the outer edges of the primary hornblende and pyroxene. In the rocks with plagioclase An_{60-50} almost half the slides show some replacement by blue hornblende. In 44/218, a biotite-bearing hornblende gabbro, it is the only amphibole and does not seem to have developed from pyroxene or hornblende of earlier crystallization. In the diorite class with plagioclase An_{50-40} examples which are quartz-free and show no indication of the presence of the potassic minerals, orthoclase, biotite or muscovite, do, however, contain blue hornblende. The primary hornblende is the deep green type. In the diorites containing quartz, biotite and a little replacive potash felspar, the replacive effects of the soda hornblende are more intense than in the gabbros, indicating that the soda hornblende increases *pari-passu* with the other minerals indicative of alkali enrichment. In some rocks such as 44/267, a hypersthene augite hornblende biotite-bearing diorite, and 44/223, a hornblende biotite quart-diorite, the hornblende is entirely of the soda type. In the granodiorites although hypersthene or augite are still present biotite tends to take the place of the hornblende; hornblende occurs in most examples but is sometimes absent, biotite only accompanying the pyroxene.

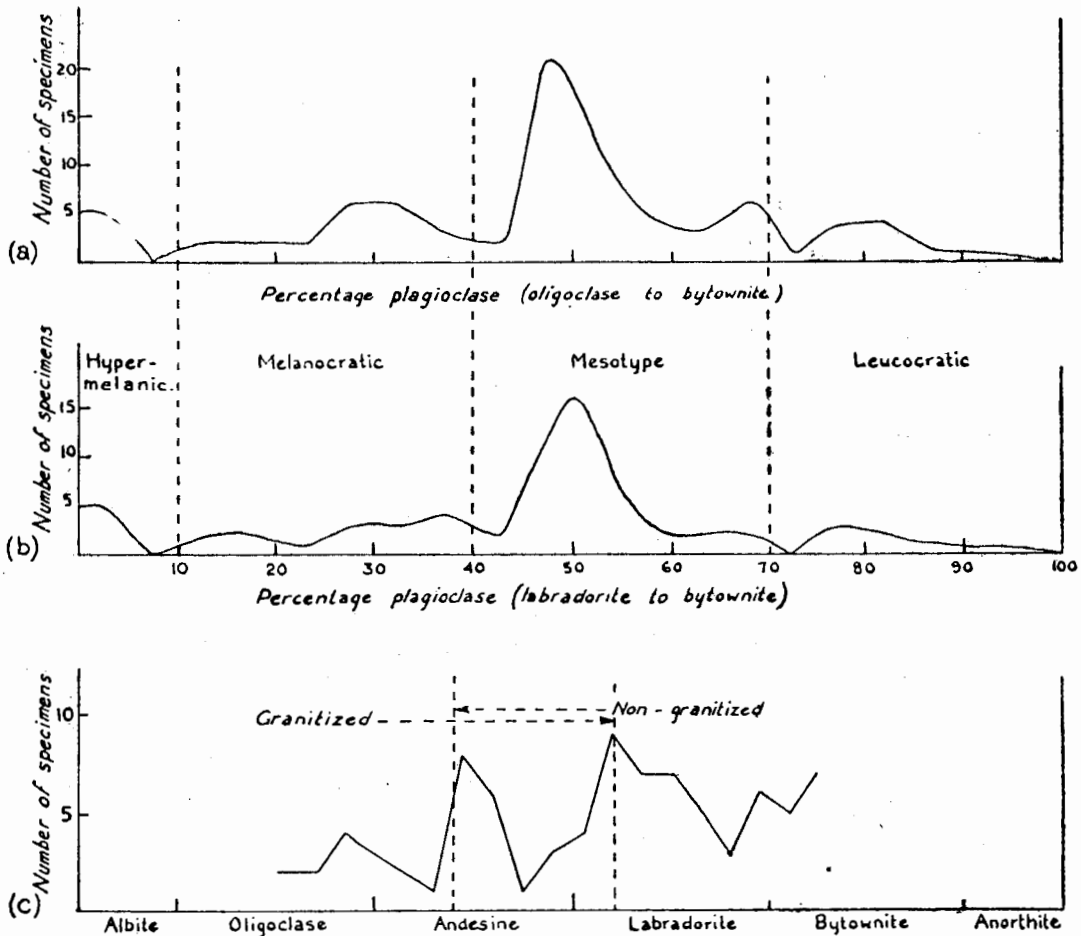


Fig 4.—Colour index and plagioclase-type frequency diagram of the basic intrusions and associated charnockites.

The *plagioclase* has a considerable range both in composition and in the percentage contained in any rock. Its composition was determined in seventy-six of the specimens sliced and found to range from acid bytownite to medium oligoclase. The graph Fig. 4c shows the relation between the anorthite-albite ratio of the plagioclase and the number of determinations. In Fig. 4a & b the estimated plagioclase content at intervals of 5 per cent is plotted against the number of specimens within the specific plagioclase ranges. The graphs show that all gradations from anorthositic and leucocratic acid types to hypermelanic grades exist and that the majority of the rocks are mesotype.

The composition of the plagioclase appears to be constant in individual specimens and in no instance is it noticeably zoned. This is to be expected in the basic and intermediate rocks in which the plagioclase presumably crystallized directly from a magma without undergoing such mechanical or chemical modification during subsequent metamorphic or metasomatic processes. In the rocks, however, which exhibit the effects of granitization and have become enriched in the alkali minerals, although the plagioclase may range from sodic oligoclase to andesine, its composition is constant in the individual specimens. The range in composition and repeated generation met with in individual specimens of the acid and sub-acid charnockites, described by Ghosh (1941, pp. 11, 12, 34) in the Bastar States, India, was not observed in the present suite.

Secondary plagioclase with the interstitial and replacive habit of the potassic feldspar was not positively identified, and it is thought that any accessions of soda were consumed in the formation of the sodic amphibole or taken up into the plagioclase molecule. A little secondary plagioclase was released in the epidotization of the primary plagioclase in certain of the epidote-bearing rocks. Small amounts may also appear together with biotite, blue hornblende, iron ore and quartz in the replacement of the dark minerals or the plagioclase. Late crystallized myrmekitic growths of quartz with sodic plagioclase such as are described from many charnockite suites, and are characteristic in general of the migmatic granitoid gneisses, have not developed even in the hypersthene-bearing grandodiorites containing abundant alkali feldspar.

The plagioclase is usually well-twinned in the basic and intermediate rocks although often a good proportion of the grains in any particular slide are feebly twinned or untwinned. In the sub-acid rocks twinning is as a rule weakly developed and the plagioclase is often difficult to distinguish from the quartz and orthoclase. Stress effects although usually not intense are commonly seen in the complication, confusion or destruction of the twinning. In a few specimens the plagioclase grains have resolved partially or completely under stress to fine-grained mosaic aggregates of untwinned grains.

The plagioclase is generally fresh. In a few examples appreciable amounts of clinozoisite-epidote have resulted from hydrothermal and reaction effects. The epidote forms narrow coronas round the dark minerals or occurs intergrown with hornblende in the outer zones of the mafic aggregates. It has in part obviously formed by the reaction between the plagioclase and dark minerals but in certain cases, e.g. 44/123 a hornblende-bearing gabbro, and 44/131 hornblende augite diorite, the epidote in addition to occurring as coronal growths around the dark minerals intensely replaces and forms peripheral chains around the plagioclase grains. In the intermediate and sub-acid grades small amounts of sericite have sometimes formed.

Inclusions of finely divided hornblende are common in the plagioclase and in some examples are intensely crowded. Hypersthene and augite rarely occur in the same way. The hornblende inclusions are often associated with microlites of a colourless mineral with moderate relief, weak birefringence and prismatic habit. The dark colour of the plagioclase in many hand specimens is evidently due to a high content of ferruginous dust. In the biotite-bearing types minute biotite fragments are sometimes also included in the plagioclase.

As a rule the plagioclase is of later crystallization than the dark minerals in the basic and intermediate rocks but is sometimes partly contemporaneous with both the pyroxenes and the hornblende, plagioclase grains being included in them or grains of the former occurring in interstitial fashion and moulded by the plagioclase. The secondary minerals blue hornblende, biotite, muscovite, potassic feldspar, apatite, sphene and iron ore (in part), quartz and epidote show undoubted replacement relations to the plagioclase.

Quartz first appears in the acid gabbros containing sodic labradorite and is present in about one-third of the specimens of this class, varying from a few per cent to about 30 per cent of the rocks. Except in one instance, slide 44/201, it is accompanied by biotite, small amounts of potash feldspar and blue hornblende. Well over half the slides of the diorites contain quartz in greatly variable amount.

The fact that the quartz makes its appearance in the basic rocks, sometimes in large amount, at the same stage as the alkali minerals, suggests its introduction during granitization as opposed to direct crystallization from a differentiated portion of the original basic magma or late-stage addition from a silica-alkali-rich residuum. This supposition is supported by the fact that the diorites considered to be normal differentiates of the gabbroic magma are quartz-free, indicating that at least to the diorite stage of differentiation, the magma did not reach a stage of over-saturation in silica. Furthermore in the diorites, as in the gabbros, quartz always appears together

with biotite, potash feldspar and blue-green hornblende. The great variability in quartz content also points to an extraneous source. In the acid diorites and granodiorites the quartz is assumed to have a migmatitic origin.

The quartz exhibits similar petrographic features in all the classes. In the acid gabbros and basic diorites it is clearly of later crystallization than the plagioclase, forming for the greater part as interstitial, lenticular and lobate grains and as short discontinuous veinlets. It also mildly replaces the plagioclase. Small granules are often closely associated with the secondary blue-green hornblende and biotite in the replacement of the dark minerals and plagioclase, and in fracture veinlets. Quartz also commonly forms small symplektitic growths with these minerals and occasionally with iron oxide. In the sub-acid and acid rocks it is sometimes indefinitely segregated into gneissose folia of sutured grains. Much of it exhibits strain polarization which becomes intense in certain of the acid charnockitic gneisses.

The quartz is not noticeably blue in hand-specimen and under the microscope is seen to be free of the minute acicular inclusions regarded as the cause of the characteristic blue colour of the quartz in many charnockitic rocks.

The poikilitic occurrence of the quartz as tiny droplets and fusiform grains in plagioclase and also in the dark minerals, such as is characteristic of the migmatitic gneisses of the area and, in fact, of migmatitic gneisses in general, is well-developed in the present suite, including the quartz-gabbros. In 44/122, a hypersthene granodiorite, the greater part of the quartz occurs in this form. In a quartz-gabbro, 44/244, some grains of plagioclase contain showers of unusually small quartz droplets and simulate micropertthite. In the present rocks these droplets seem to be due to the all-pervading penetration of silica-bearing fluids.

Potash feldspar first appears in small amounts in one or two sections of the basic rocks, but whereas the orthoclase-bearing rocks invariably contain some biotite, biotite often occurs in orthoclase-free types, and it is assumed that on the influx of potassic fluids biotite is first formed preferentially.

In the gabbros and diorites, the early potassic feldspar crystallizes as thin interstitial shreds and as fracture veinlets in the plagioclase, corroding the latter in fine to extremely fine intergrowths, which, in later stages of replacement often penetrate the whole body of the crystal, forming pseudo-antiperthite. As the amount of potash increases relatively large grains of orthoclase are formed. In the acid diorites and granodiorites orthoclase may constitute up to 15 per cent of the rock, and in these types microcline twinning is sometimes feebly developed. Some exsolution anti-perthite has also been formed, as in 44/108, in which a large crystal of plagioclase shows "checker-board" inclusions of orthoclase orientated parallel with the prismatic cleavage.

The *biotite* percentage varies from a trace to 20. It is not present in the perknites or the basic rocks with bytownite plagioclase. One specimen 44/206, an augitic bojiite with calcic labradorite, contains a small percentage of biotite together with traces of replacive alkali feldspar. In the class with plagioclase An_{60-50} about one-third of the rocks contain biotite varying from a trace to about 7 per cent. It makes its appearance together with marked amounts of quartz which itself seems to be an introduced mineral of late crystallization. A little potash feldspar usually accompanies it but is not always present. The biotite is invariably accompanied by some of the blue soda hornblende. In the diorite class biotite appears in well over half the rocks sliced. The granodiorites always contain biotite up to a maximum of about one-fifth of the rock.

In all the rocks sliced the biotite has a replacive relationship to the other dark minerals but in a number of cases seems to be partly of primary crystallization, e.g. 44/144, an augite hypersthene diorite, contains about 5 per cent biotite in clean-cut flakes intergrown with the pyroxene and of earlier crystallization than the plagioclase. In 44/213 a large plate of biotite has poikilitic inclusions of augite.

The colour of the biotite varies from pale shades of brown to dark brown or faintly greenish dark brown. The secondary biotite occurs in much the same manner as the soda hornblende in the early stages of its replacement, that is, thin films or

veinlets in the plagioclase grains and replacing the dark minerals in complex fashion. It develops preferentially round ore grains in radial or coronal form (see fig. 3c) growing into the surrounding minerals. It also replaces the dark minerals in complex and delicate symplektitic growths. It is often intimately intergrown with its congener the blue hornblende. Large skeletal or symplektitic plates sometimes develop in the plagioclase.

Tremolite.—The pyroxenes are commonly replaced by a fibrous, colourless or faintly green amphibole, probably tremolite, with maximum extinction of about 18° . Hypersthene is much more readily replaced than the augite, which is usually directly replaced by hornblende. All stages of replacement are met with, the tremolite sometimes transmuting all the orthorhombic pyroxene in a rock. Fine-grained iron ore is often abundantly precipitated during the change. Similar alteration of the orthopyroxenes and olivine to the colourless amphibole cummingtonite, in the Belhelvie gabbroic complex (Stewart, 1946, pp. 477, 478), is regarded as having preceded the formation of green uraltic hornblende. This order also appears to be the rule in the present rocks, e.g. in 44/123 which distinctly shows the replacement of tremolite by green uraltite. Green borders of aluminous hornblende developed round the cummingtonite at Belhelvie when in contact with the plagioclase are attributed to reaction with the anorthite molecule of the felspar (ibid, p. 483). The green hornblende round the tremolite of the present rocks may also be in part due to a similar reaction, especially in the case of thin rims of finely felted acicular crystals as are sometimes seen.

The tremolite is much altered to a colourless or pale green chloritic mineral with weak birefringence and, sometimes, aggregate polarisation.

The following are the subsidiary and accessory minerals: *Anthophyllite* is associated with tremolite in a few of the ultra-basic rocks. *Actinolite* is rare and when present occurs intergrown with tremolite or in coronal fringes round the dark minerals. *Epidote* is an uncommon mineral but forms in appreciable amounts in some of the rocks of all groups. It has developed as a reaction product between the plagioclase and mafic minerals or by hydrothermal alteration of the plagioclase. *Talc* is found only in the highly altered rocks of the basic group in which it occasionally becomes abundant. *Iron ore* is the most abundant accessory. In addition to the oxides, pyrite and pyrrhotite sometimes occur in small amount as disseminated grains or as veinlet infillings. Chalcopyrite rarely accompanies them. Much iron oxide has resulted from secondary changes such as the serpentinization of the olivine, conversion of the pyroxene to tremolite, etc. *Calcite* is common in small amount in almost all the rock types. *Bowlingite* of yellow or brown colour is the characteristic alteration product of the olivine. *Muscovite* occurs rarely in small amount, with symplektitic habit in certain of the migmatitic types. *Sericite*. The felspars are occasionally slightly sericitised. *Apatite* is a normal accessory of the basic rocks but shows a marked increase in the migmatized rocks. *Sphene* is very rare, and was noted only in a few of the diorites and granodiorites. *Zircon* occurs only in the diorites and granodiorites and is evidently a granitization product.

(iii) *Description of the Chief Petrological Types. Classification*.—The basic and ultrabasic rocks are divided for the purpose of description into the groups given below. The nomenclature employed for specific identification is based on the comprehensive mineralogical classification, suggested by Pulfrey (1946, p. 69)*.

A.—Basic and Ultra-basic Group.

1 (a) Perknites.

(b) Altered equivalents of the melanocratic types.

2 Olivine-bearing types.

* References to specimens with numbers prefixed by VIII or V in the following pages are quoted from this paper.

- 3 Gabbroic types, including norites, hyperites, gabbros and bojites*.
- 4 Anorthosites and anorthositic types.
- 5 Quartz-bearing gabbros.

B.—*Intermediate Group.*

- 1 Diorites.
- 2 Quartz-diorites.

C.—*Sub-acid Group.*

- 1 Granodiorites.

1 (a) *Perknites.*

The graph, fig. 4 (b), depicting the relationship between the colour index and the number of specimens sliced, indicates that the majority of the rocks in the main basic bodies are mesotype, maintaining a fairly even balance between light and dark minerals. The figure is misleading, however, to the extent that relatively fewer specimens were collected from the large and distinct concentrations of predominantly ultramafic grade. The largest mass forms the line of cones between Inandago and Mikuiki, north of the Kierra Ridge. The thick body building the prominent conical hills Chemala, Lansa and Chamanyori to the south of Kiagu Hill on which the trigonometrical beacon is situated is also largely composed of melanocratic grades. Ultra-mafic patches, streaks, lenses, bands and irregular bodies also occur in the gabbros.

Thin sections show considerable variation in the relative proportions of the minerals. It was found that the greater number are hornblende websterites. A notable feature is the absence of peridotitic types although many of the gabbros are olivine-bearing.

The *hornblende websterites* are dark grey or green grey, of variable grain size, with a tendency to the development of coarse patches in which some stout crystals measure up to a few centimetres.

Thin sections show simple intergrowths of fairly equidimensional anhedral and subhedral crystals of pyroxene with the hornblende forming usually interstitial plates or replacing the pyroxene in patchy fashion. The pyroxene is fresh or slightly replaced by tremolite and sometimes by secondary uraltic hornblende, as in 44/136. The hornblende in general is medium to dark green, sometimes brownish green or brown. Accessory plagioclase is found in some rocks as interstitial or poikilitic grains. Small grains of magnetite and occasionally sulphide are a minor accessory. Spinel was not found in the present slides but is recorded in specimens VIII 5 and VIII 23.

Volumetric modes of representative specimens are as follows:—

	VIII 5	VIII 7	VIII 8	VIII 23	V 13	44/124	44/136
Plagioclase	0.9	—	6.2	5.9	5.6	—	1
Hypersthene	37.8	49.6	37.3	23.5	30.4	34	35
Augite	22.9	41.3	50.2	39.0	56.0	60	44
Hornblende	13.6	5.1	2.6	21.1	6.5	5	20
Tremolite	—	—	1.8	—	—	—	—
Spinel	24.6	—	—	8.8	—	—	—
Ores	0.2	4.0	1.7	1.5	0.7	1	+
Total	100.0	100.0	99.8	99.8	99.2	100	100

* The term bojite (Johannsen, 1937, Vol. III, p. 227) is employed for gabbros containing hornblende in excess of the other mafic minerals.

Specimens VIII 5-8 were taken from the southern slope of Kierra Ridge, VIII 23 and 44/136 on Nyandatu Hill; VIII 13 on Kiburu Hill: 44/124 on the east slope of Inandago Hill.

Augitic Hypersthene.—One specimen only, 44/125, in which hypersthene is the chief mafic mineral was found during the present survey, and one in the previous examination, VIII 6. Their textures are similar to those of the websterites. The orthorhombic pyroxene in 44/125 is a pale magnesian type, optically negative with $2V=85^\circ$. In VIII 6 a small percentage of enstatite accompanies the hypersthene. A fair proportion of pleonaste is also found in this rock as scattered grains and aggregates and occasionally as dactylic growths in hornblende.

The modes of the two rocks are:—

	VIII.6	44/125
Plagioclase	0.1 ..	—
Hypersthene	33.0 ..	80
Enstatite	3.9 ..	—
Augite	16.2 ..	14
Hornblende	29.1 ..	5
Spinel	13.8 ..	—
Tremolite	— ..	+
Apatite	0.5 ..	—
Magnetite	1.2 ..	1
Chromite?	0.1 ..	—
	99.9 ..	100.0

VIII.6 a coarse melanocratic clot in norite from the southern slope of the Kierra Ridge.

44/125 from the west slope of Inandago Hill.

Hypersthenic pyroxenite.—Rocks in which monoclinic pyroxene predominates are also as uncommon as the hypersthenites. Only two examples were found. Specimen VIII.19 is medium-grained and crudely banded and contains a small percentage of pale brown hornblende. Specimen 44/133 is finer-grained and also contains a small amount of brown hornblende. The hypersthene is slightly tremolitized and the augite ($Z_{Ac} 41^\circ$, $2V 75^\circ$) is in an early stage of replacement by the uraltic hornblende. Pleonaste occurs abundantly as anhedral grains and clusters. (See fig. 3B) A small percentage of sulphide grains, probably pyrrhotite, form nuclei for the spinel growth.

The modes of the two specimens are:—

	VIII.19	44/133
Hypersthene	18.2 ..	5
Augite	74.9 ..	60
Hornblende	2.0 ..	10
Tremolite	3.8 ..	+
Spinel	— ..	23
Secondary Hornblende	— ..	+
Ore	0.8 ..	2
	99.7 ..	100.0

VIII.19 on Inandago Hill to the east of Kierra Ridge.

44/133 on Kamakua Hill, on the north-east side of the Kierra Ridge.

Pyroxenic hornblendites are on the whole of extreme coarseness, stout prismatic crystals of hornblende measuring up to 2 inches in length in some specimens. They are considerably coarser than the pyroxenites and occur as irregular segregations especially in the ultra-mafic zone between Inandago and Mikuiyi. The largest body found in the

area forms a low outcrop about 50 yards in diameter about one mile south-east of Kampongo Hill. It appears to have pipe form and is intruded in granitoid migmatitic gneisses. Although coarse felspar or quartz is not associated with it this occurrence suggests a pegmatitic affinity, possibly representing the crystallization of a water-rich residual fraction of the basic magma. The hornblendites in general, by virtue of their superior coarseness, indicate the influence of hyperfusibles.

A thin section 44/130 shows the coarse hornblende crystals to be intensely poikilitic containing a good proportion of small anhedra, originally pyroxene, but now completely tremolitized and chloritized. Slide 44/137 reveals a similar texture but the minerals are less altered and the pyroxene is coarser. The augite, however, is slightly tremolitized and intensely replaced by hornblende and by a few large patches of calcite. The latter slide also contains abundant rounded grains of spinel and numerous grains of pyrrhotite.

These two specimens have estimated compositions:—

	44/137	44/130
Plagioclase	+	—
Hypersthene	1	—
Augite	34	—
Hornblende	50	60
Tremolite (+ chlorite)	—	40 (after pyroxene)
Pleonaste	10	—
Ore	2	+
Calcite	3	—

44/137 from the crest of Mikuiyi Hill.

44/130 from the intrusion 1 mile south-east of Kampongo Hill.

1 (b) *Altered Equivalents of the Melanocratic Types.*

The late-stage presumably magmatic changes by which the orthorhombic pyroxene is replaced by tremolite, and the pyroxenes and primary hornblende are converted to uraltic hornblende, are seen in an advanced or complete stage in the rocks of this category.

Patches of the altered rocks are found in many parts of the basic masses. One large area of about 200 yards diameter, between Munguni and Mariene Hill was traversed indicating that locally considerable masses of the basic rocks have been so altered. This type of alteration is commonly met with in basic plutonics and has been described in great detail by Stewart in the Belhelvie gabbroic complex, Aberdeenshire (1946, pp. 477-585). In the Uganda charnockite suites, Groves (1935, p. 180) records the amphibolization of the pyroxene as the commonest and also the lowest grade mineralogical change.

The following examples are described to show the characteristics of these altered rocks in the area. In fairly advanced stages of amphibolization they often retain a close resemblance to the unaltered types. Specimen 44/245 is an example of this type, in which the dark minerals have been entirely replaced by uraltic hornblende with much subordinate tremolite and the plagioclase has been largely epidotized. A similar specimen, 44/229, is macroscopically a fine-grained amphibole gneiss, but reveals its origin under the microscope and is seen to consist of predominantly pale green bladed uraltite replacing the completely tremolitized pyroxene pseudomorphs, the plagioclase being again heavily replaced by epidote. The slide also contains a few flakes of talc. An altered pyroxenite, 44/197, has a finely mottled texture and a light grey colour due to the abundance of the colourless tremolite, the mottles being plates of primary green hornblende. The thin section consists of about 70 per cent of fibrous tremolite and anthophyllite blades with random orientation and 30 per cent of extremely ragged plates of hornblende. Another example 44/261C taken from a melanocratic layer in banded gabbro, light yellow-green in hand specimen, is entirely composed of colourless

amphibole, partly as pseudomorphs of pyroxene, altering to pale green chlorite. Complete chloritization has taken place in 44/247, a green, soft, finely flaky rock in which the original texture has been wholly obliterated, the sole mineral being a penninite chlorite. In 44/285, megascopically a light grey soft flaky rock, talc has formed abundantly in addition to the other secondary minerals. The rock is composed predominantly of aggregates of talc, needles of tremolite, abundant pale green chlorite, much secondary iron ore and an abnormally high percentage of accessory apatite in large anhedral grains. The derivation from pyroxenite is established by a large pseudomorph clearly showing original pyroxene cleavages and schiller structure.

2. The Olivine-bearing Types.

Olivine was found as a subsidiary mineral in many parts of the basic masses except those situated northwards of Kanyani Hill. The Inandago-Mikuiyi ultra-mafic body is also notably free of olivine.

A series of closely spaced traverse specimens taken on the north-western flank of the Kierra Ridge show that the olivine-bearing rocks occur in bands, about a third of the specimens being olivine-bearing. The exposures were not sufficiently complete to determine the nature of the banding, whether rapidly or broadly alternating, sharply transitional or gradational. Two more series of samples, taken on the southern slopes of the ridge further to the east, did not yield any olivine-bearing specimens, showing that, in addition to the transverse banding, olivine is also localized within certain parts of the individual bodies.

In the field the olivine-bearing rocks are indistinguishable from the olivine-free gabbros. In thin section, textures are fairly simply granular, the most marked feature being the corona structures of the dark minerals. Although also well featured in the gabbroic types such structures are sometimes absent, whereas it appears to be the rule in the olivine rocks. Anhedral grains of olivine, usually small but ranging up to 1.5 mm. in one thin section, are cloaked with hypersthene and occasionally by augite. The pyroxene in turn is surrounded by coronal hornblende, always a pale green type, intergrown with pleonaste, mostly in complex vermicular form. The pleonaste is also intergrown with augite to a much less extent and occasionally with hypersthene. The plagioclase ranges in composition from bytownite An_{76} to sodic-labradorite An_{33} . In certain slides the plagioclase has an ophitic relationship to the dark minerals, grains of plagioclase being partly or completely enclosed in them. The olivine is partly converted to yellow or brown bowlingite, green antigorite and opaque iron ore. Primary ore in small amounts and very rarely apatite are accessory. Tremolite and carbonates sometimes slightly replace the dark minerals which are on the whole, however, quite fresh.

Olivine occurs in most of the gabbroic mineral associations including the anorthositic and melanocratic grades and varies from about 1 per cent to 15 per cent, as the following estimated volumetric modes indicate:—

	44/92	44/243	44/156	44/147	44/286	44/43	44/292	44/101	44/99	44/89	44/100
Plagioclase	15	35	40	45	48	50	50	53	55	58	80
Olivine	2	15	14	7	5	6	2	2	1	2	1
Hypersthene	39	35	1	20	25	23	7	24	17	6	10
Augite	8	10	40	23	—	1	33	2	5	9	—
Hornblende	25	3	5	5	14	12	7	12	13	17	5
Pleonaste	11	2	+	—	8	7	1	7	9	8	4
Iron ore	+	+	+	+	+	1	+	+	+	+	+

3. The Gabbroic Types.

The majority of the basic rocks are gabbros. They are usually medium-grained and fairly equigranular with subordinate coarser and finer types. Porphyritic development of either the pyroxene, hornblende or plagioclase is rare. As indicated previously the majority have a mesotype colour index, with the light and the dark minerals evenly distributed, but owing to the prevalent dark colour of the plagioclase many,

PLATE I

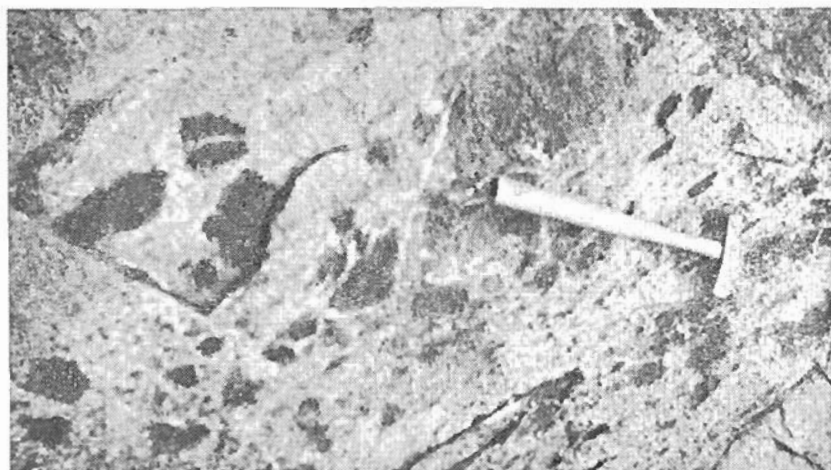


(a) Highly banded migmatite in a tributary of the Tana River a few miles south-west of Kiburu Hill.

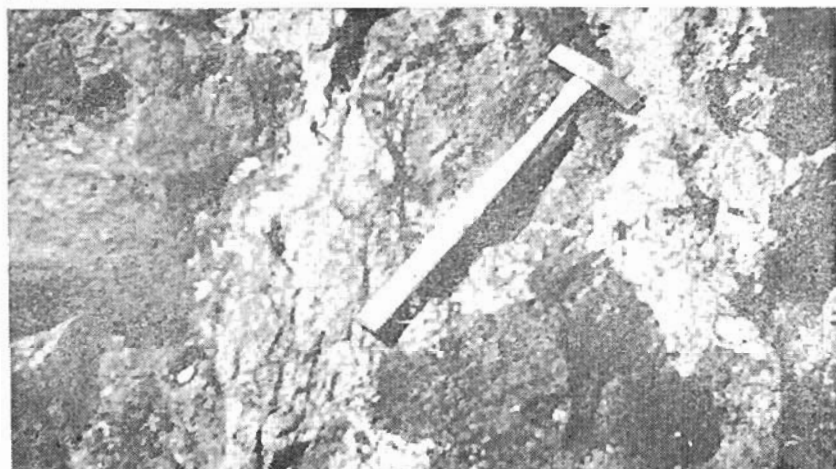


(b) Coarsely porphyritic kenyte exposed about 1 mile west of Chambagori Hill.

PLATE II



(a) An outcrop at the base of Kierra ridge on the north-eastern side. The dark material, apparently in a state of partial digestion, is charnockitic diorite in a base of more leucocratic biotite-hornblende granitoid gneiss, the two types constituting a migmatitic series.



(b) A similar example to (a) seen in a small gully on the Kiburu-Nsavini ridge near the Mutonga River. In this case the dark rock is a hypersthene quartz-gabbro.

even those of anorthositic grade, are dark grey in hand-specimen. In types with a light-coloured felspar mottled and spotted textures may be developed. On weathering the dark mineral aggregates stand out as knots and the melanocratic types are often deeply pitted owing to the erosion of the plagioclase. Banding is usually broad and not well-defined but conspicuously and thinly banded exposures are sometimes observed, the bands tending to extremes of ultramafic and anorthositic composition. A metamorphic directional texture is rarely developed. A few of the gneissose specimens are cited in the following descriptions.

The gabbro group can be divided into several types according to the proportions of mafic mineral present. The various types are not sharply defined one from another, and many intergradational types exist, especially between the norites and bojites where often the hypersthene and hornblende are present in about equal amount. Of the thirty rocks sectioned, thirteen are bojites in which hornblende predominates over other mafics, eight are norites, five are hyperites and four are gabbros, showing that, as with the perknites, hornblende-rich types are the most abundant. The plagioclase ranges from about medium bytownite to acid labradorite and dividing the rocks on the basis of the plagioclase type, viz., An ≥ 70 , An 70-60, An 60-50, about equal number are represented in each class. In each of the classes bojites predominate but are still more prevalent in the acid labradorite class. Such an increase points to the bojites as members of a magmatic series, hornblende increasing with the degree of acidity of the plagioclase. It is interesting to note in this connexion that the olivine-bearing rocks are mostly norites and that of the eleven specimens sliced not a single example of bojite is represented, again demonstrating the magmatic origin of the greater part of the hornblende in these basic rocks. The number of norite specimens remains about constant in each of the plagioclase ranges but normal gabbros were not found in the acid-labradorite range indicating that augite tends to disappear selectively in favour of the hornblende, hypersthene being more resistant to replacement by hornblende.

Bojites are of two types, those containing pyroxene and those which are pyroxene-free. Of these, the former types are the most common. Either hypersthene or augite alone may be present or both may accompany the hornblende. Two specimens 44/102 and 44/106 of hypersthene biotite were collected. Both are from the north-eastern flank of Kierra Ridge and differ in degree of coarseness, the former having a coarse even-grained texture while the latter is relatively fine-grained. Although both are rich in plagioclase they are dark grey, owing to its dark colour. They have a similar micro-texture, the plagioclase having partly platy, inequigranular habit, and the hornblende a zonal distribution round hypersthene cores and scattered in fine-grained form throughout the plagioclase. A small amount of pleonaste is intergrown with the hornblende. The plagioclase exhibits strong optical strain and distortion indicating subjection to moderately intense stress conditions.

The visual estimations of these two rocks are:—

		44/102		44/106
Plagioclase		50 (An ₇₂)		75 (An ₆₄)
Hypersthene		22		12
Hornblende		25		13
Pleonaste		3		+
Iron ore		+		+

Hyperitic bojites.—In two specimens 44/105 and 44/115, from the southern slope of Kierra Ridge, both orthorhombic and monoclinic pyroxene are present. The former is dark grey and medium-grained with dark grey felspar. The latter has a fine-grained granulitic structure and the felspar is a lighter grey colour. The slide of 44/105 shows a more inequigranular texture than 44/115 in which the minerals have crystallized as a simple even-grained mosaic. The medium green hornblende of both has a partially reactive relationship to the pyroxene in the mafic clots but pyroxene and hornblende crystals are also abundantly dispersed in the leucocratic areas. The hornblende intensely replaces the augite in 44/105 and in the other rock the hypersthene is partly converted to tremolite and chlorite (bastite). A few chlorite veinlets also traverse this section.

The approximate composition of these specimens is:—

	44/105	44/115
Plagioclase	67 (An ₈₀) ..	55 (An ₆₅)
Hypersthene	2 ..	8
Augite	10 ..	2
Hornblende	21 ..	35
Tremolite	+	+
Chlorite	—	+
Iron ore	+	+

Augite bojites.—In some of the rocks monoclinic pyroxene only was found to accompany the hornblende. The two specimens selected for description differ markedly in texture. Specimen 44/145, collected from a small hill to the north-east of Mikuiyi Hill near the Mutonga River, is like the hornblendites described previously—a coarse-grained dark rock in hand-specimen, seen in thin section to consist of large plates of yellow green hornblende up to more than 1 cm. in length, enclosing abundant small grains of pale green augite and subhedral crystals of clear plagioclase. The other specimen 44/206A is dark grey and fine-grained with a semi-schistose microtexture and is composed of deep green hornblende and subordinate augite together with finely granular plagioclase, abundant iron ore granules and traces of biotite.

The compositions of the two specimens are estimated to be:—

	44/145	4/206A
Plagioclase	20 (An ₅₈) ..	48 (An ₆₅)
Augite	25 ..	19
Hornblende	55 ..	27
Biotite	— ..	1
Iron ore	+	5
Apatite	—	—

Pyroxene-free bojites.—In a number of cases pyroxene was found to be altogether absent. They then resemble in composition some of the plagioclase-amphibolites but since they have been found within the basic bodies their identity is not open to doubt. Their most notable occurrence is a body in the north-eastern part of the area building the two conical inselbergs Kantaugu and Kiuguni. In the other gabbroic masses they are sometimes developed in the extreme outer parts.

An anorthositic and a melanocratic example, 44/261A and 44/261B respectively, from Kantaugu Hill, both have bytownite plagioclase in irregular, inequigranular intergrowth with ragged clusters and blades of pale green hornblende. Abundant epidote clusters round the hornblende or is disseminated throughout the plagioclase. A specimen, 44/288, from near the western edge of the Kiburu-Munguni body exhibits the same features and probably has a similar origin. The plagioclase except in 44/261A shows intense strain and partial recrystallization with production of finer-grained sutured aggregates and is intensely crowded with hornblende and epidote microlites. Despite the strain, however, it has not apparently suffered much chemical modification, being bytownite in all three examples. The hornblende is also strongly poikilitic and appears to have originated by the total recrystallization of earlier mafic minerals, none of the original structures remaining. It seems, therefore, that in this part of the area, the intrusions were subjected to different physical conditions during, or more probably after crystallization, than applied over the rest of the area, leading to the exclusive production of hornblende with epidote in place of the usual dark mineral assemblage.

The modal composition of the rocks quoted is:—

	44/261A	44/261B	44/288
Plagioclase	85 (An ₇₄)	30 (An ₇₄)	46 (An ₇₅)
Hornblende	10	57	52
Epidote	5	13	1
Ore	+	+	1

Norites are a fairly common type, especially in the main Kierra mass. The hand-specimens are all dark grey, medium-grained rocks with the felspar mostly dark grey and sometimes light grey. Specimen 44/94 is the only example with a faintly gneissose texture.

The thin sections all have much the same texture. The plagioclase is always well-twinned and as a rule is in fairly simple, partly prismatic and partly granular form. In some of the slides it is strongly dusted with iron oxides and contains prismatic microlites of hornblende, usually crystallographically aligned parallel to the prismatic cleavage. Stress conditions have complicated the twinning and caused slight recrystallization but only in one specimen, 44/94, has any appreciable deformation taken place. In this rock the dark minerals are roughly foliated and the plagioclase grains have pronounced gneissic elongation. Reaction rims of hornblende around the pyroxene are well-developed in every slide, and as in the *bojites* a good proportion of the hornblende is scattered in fine-grained form in the plagioclase. In most sections green spinel is intergrown with the hornblende in vermicular manner. The intergrowths are sometimes extremely fine and intricate as in 44/98. The hornblende is a pale green variety except in the few spinel-free rocks where it is a darker green. Subordinate amounts of augite are present in a few of the slides often exhibiting intense replacement by the hornblende. The hypersthene is occasionally slightly converted to fibrous tremolite. Anhedronal iron ore granules and apatite are very scarce accessories.

The following approximations to the volumetric modes shows the range of composition of the *norites*:—

	44/96	44/95	44/98	44/112	44/94	44/119	44/90	44/41
Plagioclase	68(An ₇₄)	65(An ₆₀)	58(An ₅₃)	57(An ₆₈)	55(An ₅₄)	50(An ₇₄)	35(An ₅₁)	22(An ₆₈)
Hypersthene	13	14	17	22	22	35	30	42
Augite	—	—	3	—	5	5	2	—
Hornblende	15	16	12	21	11	10	18	20
Pleonaste	4	5	10	—	7	—	15	16
Ore	+	—	+	+	—	+	—	—

Hyperites.—Rocks in which orthorhombic and monoclinic pyroxene are present in balanced amount are relatively scarce. They vary much in appearance; 44/128 is dark and coarse-grained with dark felspar; 44/129 and 44/276 are grey and medium-grained with a lighter coloured felspar; 44/127 is fine-grained and yellowish grey with resinous yellow grey felspar and 44/143 is dark grey and still more fine-grained.

In thin section 44/143 has a fine-grained granulitic texture with average grain size 0.5 mm. The hornblende, a strongly pleochroic olive-brown variety, occurs in the same granular form as the pyroxene. The minerals of 44/129 have crystallized in a simple mosaic intergrowth and a small amount of hornblende replaces the pyroxene. Secondary changes in 44/276 have converted much of the hypersthene to tremolite, and green uraltic hornblende replaces the augite and primary hornblende and forms narrow rims around the tremolitized hypersthene grains. In 44/128 the augite although not obviously replacing the hypersthene has a zonal distribution round it. A weak but definite directional texture is developed in 44/127. The slide is free of hornblende. In 44/143 and 44/128 abundant small iron ore anhedra are intergrown with the dark minerals.

Visual estimations of these slides give:—

	44/276	44/127	44/129	44/143	44/128
Plagioclase	53 (An ₆₄)	50	48 (An ₆₁)	48 (An ₆₀)	15 (An ₅₄)
Hypersthene	10	21	26	10	48
Augite	20	24	23	16	32
Hornblende	3	—	3	22	5
Tremolite	6	—	—	—	—
Uralite	8	—	—	—	—
Iron Ore	—	5	—	4	+

Gabbros (sensu stricto) like the hyperites are relatively uncommon. Megascopically 44/113 and 44/114, collected on the southern slope of the Kierra Ridge, are dark coarse-grained and massive, with pyroxene crystals up to more than 1 cm. in length. Specimen 44/36 from the crest of Inandago Hill has a similar but not so coarse-grained texture. On Kambuyi Hill, situated about four miles south-east of Kiagu beacon, the basic rock in general is noticeably gneissose. The gabbro specimens 44/150 and 44/151 are dark grey and finer-grained than the example cited above and both have a porphyritic texture with occasional stout units of pyroxene up to about a centimetre in length.

The two rocks from Kierra Ridge show in thin section even-granularity of the unstrained, well-twinned plagioclase and the dark minerals. The hornblende, a deep green type, partly mantles and replaces the pyroxene but is for the greater part in clean-cut granular association with it. The Inandago Hill specimen 44/123 has the same texture but secondary reactions have extensively converted the primary mafic minerals to uralitic hornblende and the subordinate hypersthene has been entirely changed to fibrous tremolite. Epidote has also formed as borders around the dark minerals in contact with plagioclase and as veinlets in the plagioclase. Slide 44/150, of one of the Kambuyi Hill gabbros, shows well-developed foliation of the dark minerals and gneissose deformation of the plagioclase crystals. The augite of this slide is strongly replaced by deep green hornblende, partly in coronas. Uralitic alteration and chloritization has affected most of the primary dark mineral. In one chloritized area, vermicular growths of iron ore have developed. Numerous veinlets carrying chlorite, uralite and calcite cut across the slide and the plagioclase shows traces of peripheral corrosion by alkali feldspar. Slide 44/151 reveals similar features; the texture is coarser, however, and not so clearly directional. In both rocks, iron ore in small anhedral grains is an abundant accessory.

These gabbros have approximately the following compositions:—

	44/123	44/151	44/113	44/150	44/114
Plagioclase	58 (An ₇₀)	50 (An ₆₄)	47 (An ₇₁)	40 (An ₇₁)	25 (An ₅₈)
Augite	21	32	31	30	37
Hypersthene	—	—	3	—	9
Hornblende	18	13	18	26	29
Epidote	3	—	—	—	—
Iron Ore	+	5	1	4	+

4. The Anorthosites and anorthositic types.

Anorthositic types constitute a minor proportion of the basic assemblage and no large concentrations or thick bands were noted anywhere in the intrusions. When composed of the prevailing dark grey plagioclase, however, they are difficult to identify in the field and anorthositic types may be more common than field inspection would suggest. A few specimens only taken from thin bands in the gabbro, were collected. Only three of these are true anorthosites with less than 10 per cent of mafic minerals.

Similarly to the gabbros the anorthosites are variable in appearance and texture. The plagioclase is white in 44/261A, light grey in 44/100 and 44/103 and dark grey in 44/106, 44/116 and 44/118, imparting a deceptively basic appearance. The anorthositic bojites 44/216A, 44/106 and the olivine-bearing anorthositic norite 44/100 have been described in previous sections. The remaining three specimens 44/103, 44/116, 44/118 are all fine-grained compact rocks.

The thin section of 44/103 shows it to have an inequigranular allotriomorphic texture with plagioclase twinning narrow and confused. 44/116 has a much simpler even-grained texture. The pyroxene has been completely replaced by uralitic hornblende and chlorite but the primary deep green hornblende is much less altered. Epidote resulting from reaction of the dark minerals with the plagioclase forms veinlets and

thin films outlining the plagioclase grains. In 44/118 these secondary changes have not been so intense and some hypersthene still remains while the dark green primary hornblende is comparatively fresh. A small amount of iron ore has been precipitated during tremolitic alteration of the hypersthene.

The approximate modes of these rocks are:—

	44/103	44/116	44/118
Plagioclase	93	85 (An ₅₇)	90 (An ₆₈)
Hypersthene	5	—	3
Hornblende	2	8	4
Tremolite	+	4	3
Epidote	—	3	—
Iron Ore	+	+	+

5. *Quartz-bearing gabbros.*

The quartz gabbros are characterized by a variable quartz content together with one or more of the minerals denoting alkali enrichment—blue sodic hornblende, biotite or potash feldspar.

Specimen 44/201, collected from a small outcrop about one mile north of the Thingishu River and south-west of Kambuyi Hill, is a dark grey fine-grained rock with the same appearance as the normal gabbroic types except that it has a faintly gneissose structure. Under the microscope it has much the same simple granular texture of many of the gabbros but a mild directional impress is left on the minerals. Quartz forms about a quarter of the area of the slide, intergrown with the plagioclase as interstitial grains of irregular, often elongated shapes. Small spherical units are frequently contained in the plagioclase. The quartz is of later crystallization than the plagioclase and appears to replace it slightly. The dark minerals are fresh and comprise predominant pale green augite, subordinate strongly pleochroic hypersthene and a few small crystals of deep green hornblende. Abundant iron ore anhedral grains are scattered throughout the slide and apatite forms numerous tiny euhedral crystals.

Specimen 44/280 from a low tor named Kanaituli, about three miles north of Kibagi Ridge, is a medium-grained mesotype gneiss. It is associated with heterogeneous banded migmatitic granitoid gneisses, many of them hypersthene-bearing. In this section the plagioclase has an even-grained granular texture without appreciable gneissose deformation but the dark minerals are imperfectly foliated. A small amount of quartz is present interstitially and as included droplets in the plagioclase. The dark minerals, unaltered as in the previous specimen, are hypersthene, augite and dark green hornblende in granular intergrowth. The hornblende also shows indefinite reaction zoning round the pyroxene. Anhedral iron ore grains are again numerous and apatite is a common accessory. Potash feldspar has penetrated along interstitial channels corroding the plagioclase grain borders in delicate intergrowths, sometimes penetrating deep into the body of the grains.

Specimen 44/205 is a dark grey fine-grained gneiss which together with 44/206 occurs in a series of variable banded gneisses exposed near the Thingishu River about two miles south-west of Kambuyi Hill. The slide shows the rock to have a semi-gneissose granulitic texture with parallel orientation of the mafic minerals. The quartz is not intergrown with the plagioclase in such an intimate manner as in the above two slides but tends to be segregated in layers of fluxional grains parallel to the schistosity. In this slide the effects wrought by secondary solutions are clear. The primary deep green hornblende, pale green augite and a few flakes of biotite were first converted to tremolite and chlorite, and later alkali-rich solutions travelling along grain boundaries and in small fissures have deposited by reaction small amounts of biotite and pale blue soda hornblende together with quartz and a little epidote. Primary iron ore is abundant and much has also been evolved from the secondary changes,

Specimen 44/206 is a leucocratic uneven-grained gneiss with a typically migmatitic appearance. The thin section gives the impression that quartz in large amount invaded the original rock mechanically and to much less extent by digestion of the plagioclase, resulting in an unusually complex intergrowth. Quartz drops are again abundantly dispersed through the plagioclase. The secondary changes have as before led to the formation of tremolite and chlorite leaving only vestiges of the original pyroxene, and to the development of small amounts of biotite in coronal growths round ore grains and as skeletal flakes in the plagioclase. Traces of blue hornblende replace the tremolite. Small apatite prisms are particularly abundant in this slide, and anhedral iron ore grains are again quite numerous.

Specimen 44/244 is a dark grey, medium-grained, massive rock indistinguishable from the uncontaminated normal basic rocks and was collected on Mwangandia tor to the east of Mariene Hill near the track leading to Chokirigi. Under the microscope it exhibits the usual gabbroic texture, with quartz infiltrating among the plagioclase. The deep green primary hornblende displays a partially coronal attitude towards the augite and hypersthene, both of which are intensely altered to tremolite and chlorite. Blue hornblende replaces the dark minerals along a shear zone traversing the slide and biotite forms a few incipient growths.

The estimated modes of these specimens are:—

	44/201	44/280	44/205	44/206	44/244
Plagioclase	35 (An ₅₅)	45 (An ₅₄)	55 (An ₅₈)	48 (An ₅₄)	60 (An ₅₀)
Orthoclase	—	—	2	—	—
Quartz	25	5	3	36	8
Hypersthene	10	+	13	—	+
Augite	26	24	9	—	+
Hornblende	1	20	15	—	13
Blue sodic Hornblende	—	+	—	+	+
Biotite	—	3	—	1	+
Tremolite and chlorite	—	+	—	10	17
Epidote	—	+	—	—	—
Apatite	+	+	+	+	+
Iron Ore	3	3	3	4	2

Origin of the Quartz-bearing Gabbros.

The origin of these rocks is involved with the question of the source of the quartz and the alkaline fluids which have deposited the small amounts of blue soda hornblende, biotite and potash felspar. Two possibilities are considered; firstly the conceivable formation of an acid residue segregated during the consolidation of the basic bodies, and secondly addition or metasomatism in the course of the regional granitization. Either hypothesis seems equally tenable theoretically since only in two of the rocks is quartz a major constituent and the secondary alkali minerals are always present in minor amount. When the field relations are considered, however, the evidence is more strongly in favour of a migmatitic origin. The rocks are not an integral part of the basic masses but occur near them in the regional migmatitic fields in which the basic bodies probably represent non-granitized remnants. They are in addition, closely associated with dioritic and granodioritic charnockitic gneisses most probably of hybrid origin.

B.—Intermediate Group.

1. *Diorites.*—Under this heading are included the types with plagioclase in the andesine range. Most were found in close proximity to the Kierra Ridge. One specimen 44/117 was collected on the crest of the ridge about one mile east of the trigonometrical beacon. This specimen and another, 44/138, from a small tor one mile north-east of Mikuiyi Hill, to the north of the ridge, are of anorthositic grade. They are medium-grained and dark grey owing to the dark colour of the plagioclase. In thin section,

the texture is seen to be allotriomorphic with weak schistose arrangement of the dark minerals, which in 44/217 are slightly tremolitized hypersthene and medium green hornblende, while those of 44/138 are slightly uralitized hornblende, completely tremolitized hypersthene and numerous small iron ore grains.

Specimens 44/109, 44/120 and 44/121 are all from the Kierra Ridge on its southern side. They are associated with rocks of quartz-dioritic composition described below and their relation to the basic rocks of the ridge itself is not certain. In appearance they closely resemble the dark gabbroic types but are differentiated by a gneissose texture which in the slides is seen as a mild but definite directional orientation and elongation of the plagioclase grains, and imperfect foliation of the mafic minerals. The primary mafic minerals are hypersthene, augite and medium green hornblende in granular, crudely reactional intergrowth, together with relatively abundant ore mineral comprising magnetite and rare sulphide. Apatite is a scarce accessory except in 44/121 where small euhedral prisms are common. The usual secondary alteration is seen, slight in 44/109 and 44/121 where the hypersthene is partly replaced by tremolite, and intense in 44/120 in which the hypersthene is completely tremolitized and the augite and hornblende are weakly uralitized. Two specimens, 44/140 and 44/142, from the base of the ridge on its northern side, are practically identical in appearance, microscopic characters and field associations with those on the southern side of the ridge.

A low hill on the peneplain between Inandago and Kampongo yielded a specimen 44/131 of dioritic composition, of which the relation to the country-rock could not be established owing to lack of outcrop. It can, however, safely be regarded as intrusive since a marked porphyritic texture is developed, with sharply idiomorphic plenocrysts of augite up to a centimetre in length scattered in a fine-grained dark matrix. In thin section the rock is seen to consist of fine-grained equigranular plagioclase, pale augite, medium green hornblende and a little accessory iron ore. The plagioclase is heavily epidotized in certain patches and traces of interstitial orthoclase were noted.

The approximate composition of the diorites is:—

	44/117	44/138	44/109	44/120	44/121	44/140	44/142	44/131
Plagioclase	88(An ₄₈)	85(An ₄₀)	50(An ₄₃)	52(An ₄₀)	58(An ₄₀)	53(An ₃₄)	55(An ₄₈)	50(An ₃₈)
Hypersthene	8	—	22	+	23	—	6	—
Augite	—	—	16	9	—	43	4	25
Hornblende	4	2	7	23	12	2	35	20
Tremolite	+	11	+	12	5	—	—	+
Iron Ore	+	2	5	4	2	2	+	+
Apatite	—	—	—	+	+	—	—	—
Epidote	—	—	—	—	—	—	—	5

2. Quartz-diorites.

Most of the specimens of quartz-diorites were collected from the granitization complexes surrounding the basic intrusions and appear to be an integral part of them. They mostly occur near the basic intrusions and with very rare exceptions were not found at distances exceeding two miles from their edges.

The specimens have fairly constant characteristics when the wide area over which they were collected is considered. There is no indication in thin section that they are not all of similar origin.

Most of the representative samples, like the diorites, were again collected near the base of the Kierra Ridge both on its northern and southern side. A few of these, 44/107, 44/135 and 44/144 are selected as embodying the typical features of these rocks in this locality. They are without exception grey or dark grey with a medium- to fine-grain. Their moderately gneissose texture, clear under the microscope, is not easily discernible in hand specimen. The quartz though abundant in 44/135 is only with difficulty detected since it has the same grey colour as the felspar. In thin section the texture is somewhat variable; 44/107 has a fine-grained allotriomorphic texture with barely appreciable directional tendency, the quartz forming irregular grains

between the feldspars; in 44/144 the texture is fine-grained equigranular with a high percentage of its dark minerals in semi-schistose alignment; 44/135 has finely granulated crush zones running across an even-grained non-gneissose fabric. In the former two slides the primary dark minerals are unaltered hypersthene and augite; slide 44/144 has a few clear-cut flakes of biotite intergrown with the pyroxene and 44/107 a little yellow-green hornblende. The augite has in general a slightly deeper green colour in the quartz-diorites than in the basic rocks. Measurements of the maximum extinction angles of the augite in the three slides quoted gave values of 57°, 65°, 67°, probably indicating a high soda content. A thin vein in 44/144 contains a small amount of secondary blue hornblende. The last slide 44/135 shows the normal secondary alteration effects whereby the hypersthene was converted to fibrous tremolite, and blue hornblende forms interstitial films, vein infillings and kelyphitic borders round the augite grains and tremolite pseudomorphs. Small anhedral iron ore grains and minute apatites are fairly abundant accessories.

About two miles north of Kierra trigonometrical beacon two specimens, 44/267 and 44/269, were taken from the heterogeneous hybrid gneisses of that area which revealed a quartz-dioritic composition under the microscope. The hand-specimens have a more definitely hybrid appearance than the quartz-diorites near the Kierra Ridge but in common with them have a dark grey colour. In both the specimens the grain size is very uneven, relatively coarser and finer patches having random distribution. A strongly gneissose texture is developed in 44/269 which in addition to the usual dark minerals contains numerous schistose plates of biotite. Both specimens have in thin section a pronouncedly gneissose fine-grained allotriomorphic texture but show no foliation of the dark constituents. The quartz has the usual interstitial habit in 44/267 and in 44/269 forms small sutured fluxional grains and droplets scattered through the slide. Hypersthene is the predominant mafic mineral accompanied by some augite in 44/267. Primary hornblende has not formed. Changes due to alkali metasomatism are well-developed. Orthoclase is present in appreciable amount as interstitial films, grains, and fine corrosion intergrowths with the plagioclases, giving an antiperthitic aspect to many of the latter in 44/269. Small ragged and skeletal flakes of the biotite and kelyphitic borders round iron ore grains are abundant. A small amount of blue hornblende occurs together with the biotite in 44/267. Small granules of quartz are often intergrown with the biotite and blue hornblende. Many of the pyroxene grains have sieve structure and contain minute apatites and fusiform quartz grainlets, suggesting a certain amount of recrystallization during the granitization which evidently gave these rocks their final form.

The five slides gave approximate modes:—

	44/125	44/107	44/144	44/267	44/269
Plagioclase	35 (An ₃₁)	88 (An ₃₈)	53 (An ₄₅)	60	67
Orthoclase	—	—	+	1	5
Quartz	20	3	+	+	8
Hypersthene	+	5	9	24	12
Augite	10	2	32	6	—
Hornblende	—	1	—	—	—
Blue hornblende	7	—	+	2	—
Biotite	—	—	5	2	5
Tremolite	27	—	—	+	—
Iron Ore	1	1	1	5	3
Apatite	+	+	+	+	—

The area between the basic bodies forming the ridges Kibagi and Kandogi seems to be largely composed of composite gneisses of dioritic and granodioritic composition, most of them hypersthene-bearing. Three of the specimens from that area are hypersthene quartz diorites, viz. 44/277, 44/278, 44/279. They are a dark grey colour; 44/277 and 44/279 are fine-grained and homogenous, the latter strongly gneissose, but

44/278 has a patchy heterogeneity of grain size indicating its migmatitic origin. In thin section they are seen to be allotriomorphic and fine-grained with weak foliation, the quartz again crystallizing in the interstices between the other mineral grains and being enclosed poikilitically in them. All three are mesotype; the primary dark minerals being hypersthene, augite and deep green hornblende. The orthoclase, biotite and blue soda hornblende have formed in the usual way, the replacement of the dark minerals by blue hornblende being intense in 44/277. Iron ore and apatite are again common accessories, mostly as poikilitic grains in the mafics.

Other examples at widely separated localities are identified by more or less the same composition and general features as the above specimens. The universal dark grey colour of the quartz-diorites in general is remarkable despite the often high proportion of felsic minerals; a feature which makes their certain recognition in the field impossible. A few other examples may be referred to since they show characters not seen in the above examples. Instead of the usual allotriomorphic crystallization of the felspar, 44/210 and 44/216 have the plagioclase with hypidiomorphic platy habit, while 44/274 has an unusually strong gneissose fabric with the abundant quartz segregated in folia. The replacement effect of the quartz and late alkali minerals are particularly well developed in 44/210. Biotite is uncommonly abundant in 44/274 and in addition to the apatite there are many tiny grains of sphene.

The estimated modes of the above slides are given to demonstrate more fully the variation in mineralogy of these types:—

	44/277	44/278	44/279	44/210	44/216	44/274
Plagioclase ..	51 (An ₄₀)	52 (An ₄₃)	50 (An ₄₃)	69 (An ₄₇)	68 (An ₄₃)	53 (An ₃₄)
Orthoclase ..	3	3	+	+	+	2
Quartz ..	1	1	+	1	7	17
Hypersthene ..	8	16	16	6	5	1
Augite ..	7	23	20	15	13	—
Hornblende ..	28	1	12	2	2	20
Blue hornblende ..	+	+	—	+	1	—
Biotite ..	1	3	+	5	3	6
Tremolite ..	—	—	—	—	+	—
Ore ..	1	1	2	2	1	1
Apatite ..	+	+	+	+	+	+

C.—Sub-acid Group.

1. *Granodiorites*.—Under this heading are included rocks in which the plagioclase falls within the oligoclase range. They all contain hypersthene. Migmatitic granitoid gneisses of granodioritic composition abound in the region but were not found to be hypersthene-bearing. Hypersthene evidently gives place to hornblende and biotite in the later stages of granitization. The few hypersthene granodiorites discovered during the mapping all occur close to the basic bodies amongst the hypersthene quartz-gabbros, diorites and quartz-diorites, and may reasonably be assumed to have a common genesis. They do not differ from the quartz-diorites of the preceding section in any significant respect except perhaps in having a lower dark mineral content and a more consistent, though not higher, quartz-content than some of the quartz-diorites. The number of specimens collected, only three in number, are insufficient, however to draw any general distinctions. Their scarcity is in marked contrast to the abundance of the quartz-diorites. No rocks approaching the composition of true granitic charnockite appear to be represented in the area.

Two of the specimens, 44/108 and 44/141, are appreciably lighter in colour than the quartz-diorites but 44/122 is again dark grey. They are all finely equigranular sugary rocks, and 44/141 has a faint directional texture visible microscopically, the felsic minerals forming a mosaic with an indefinite directional arrangement. Orthoclase

is almost absent in 44/141, and forms fine corrosional intergrowths or orientated blebs and fibres in the plagioclase of 44/122. In the remaining slide where it is of late crystallization, forming veinlets and irregular small grains between the plagioclase, it constitutes about 15 per cent of the section. Cross-hatch twinning is weakly developed in some of the larger grains. Most of the plagioclase grains are finely anti-perthitic and sometimes almost cryptoperthitic, though a few large plates have a relatively coarse "checker-board" perthitic pattern. As in the quartz gabbros and quartz diorites, quartz droplets are again abundantly scattered through the plagioclase. In 44/108 a few grains of strongly pleochroic hypersthene have narrow blue amphibole borders. One or two iron ore grains are surrounded by radial growths of biotite which also forms a few flakes in the plagioclase. In 44/141 the hypersthene is replaced by small amounts of biotite and rimmed by deep green hornblende which also grows around ore grains and occurs as rare blades in the felsic minerals. The hypersthene also displays the same symplektitic intergrowth with quartz that is seen in the case of the pyroxenes and hornblende of many of the diorites and quartz-diorites. In 44/122 the original(?) hypersthene is entirely converted to indefinite aggregates of colourless chlorite and ferruginous dust surrounded by kelyphitic borders of deep green chlorite, chloritized biotite and fibrous green amphibole. In some grains vestiges of the original alteration product, tremolite, still remain. In part of the slide the felspar is heavily kaolinitized and sericitized with release of finely divided calcite. One large mafic crystal has been converted to an aggregate of biotite, albite, calcite, chlorite, kaolinite and sericite. Iron ore in the form of anhedral grains is an abundant accessory in all three slides while small apatites are also common. 44/108 contains a small grain of zircon.

These rocks give estimated modes :—

		44/108	44/122	44/141
Plagioclase		65 (An ₂₅)	70 (An ₂₀)	76 (An ₂₇)
Orthoclase		15	+	+
Quartz		15	20	16
Hypersthene		4	8 (altered)	1
Augite		—	—	—
Hornblende		+	—	6
Biotite		+	1	+
Iron Ore		1	1	1
Apatite		+	+	+

(iv) *Origin*.—Since the classical account of Sir Thomas Holland on the Charnockite Series of Southern India in 1900 several regions of charnockite development have been mapped in various parts of the world. Diverse opinions on their origin have been advanced but the consensus of opinion is that their origin is involved, broadly speaking, in the deep-seated metamorphism of originally igneous rock series. Assimilation of aluminous sediments by a basic magma followed by differentiation is called upon to explain certain occurrences.

Groves (1935) has convincingly demonstrated that the Uganda charnockites are products of deep-seated metamorphism of a series of normal plutonic rocks ranging in composition from normal granite to olivine-gabbro. Rocks of charnockitic affinity (norites, enderbites and charnockites) in western Greenland are interpreted by Ramberg (1949, pp. 35-47) in the same way, i.e. as granulitic facies developed by the ultra-metamorphism of gneisses belonging to amphibolite and epidote-amphibolite facies. A radically different theory was formulated by Ghosh (1941, p. 2 *et seq.*) for the Charnockite Series of Bastar State and Western Jeypore. A complete series ranging from ultra-basic to acid members is represented there and was considered to be derived by metamorphism and progressive granitization of originally impure calcareous sediments, rich in iron and magnesium. In the present suite the intermediate and sub-acid members are also thought to be products of progressive granitization, the parent

rocks being the basic intrusions. The evolution of the suite is considered in the following pages but in view of the absence of chemical or accurate microscope data the theories advanced must necessarily be tentative. The question falls naturally into two distinct divisions—firstly the origin of the ultra-basic and basic series and secondly the formation of the intermediate and sub-acid rocks.

Both field and microscope evidence leave no doubt that the basic series are intrusives, the variations in composition being due to differentiation at depth and *in situ*. It must be admitted that the prime evidence of intrusion, the presence of undoubted intrusive contact, is extremely scarce. The instance noted above of closely spaced intrusion of gabbroic sheets in relatively non-granitized schist is exceptional. One reason for lack of contacts is possibly the paucity of exposures at the bases of the hills along which the borders of the bodies are usually located. The chief reason, however, appears to be the obscuring and blurring of contacts by granitization.

Under the microscope the crystallization of the non-granitized intrusions is seen to have taken place in normal magmatic order. Reaction zoning is often perfectly featured in the dark mineral clots especially in those with olivine cores (fig. 3A). It is evident that the following examples of coronal structure accord with Bowen's Reaction Principle (the order of formation is shown from left to right with the core mineral on the extreme left):—

- (1) Olivine – (Magnetite) – hypersthene (sometimes with spinel) – ($\pm$ tremolite) – hornblende with spinel.
- (2) Olivine – (magnetite) – augite (sometimes with spinel) – hornblende with spinel.
- (3) Hypersthene – (Magnetite) – augite – hornblende – $\left\{ \begin{array}{l} \text{magnetite} \\ \text{tremolite} \end{array} \right\}$
- (4) Hypersthene – ($\pm$ tremolite) – hornblende.
- (5) Hypersthene ($\pm$ spinel) – augite and spinel – hornblende and spinel.
- (6) Hypersthene (sometimes with a little spinel) – hornblende with spinel.
- (7) Augite (sometimes with spinel) – hornblende with spinel.
- (8) Iron ore – hornblende.

The occurrence of spinel mainly as a result of the reactive replacement of pyroxene by hornblende, that is as a late mineral in the reaction series, is a problematical feature since spinel is a notable high temperature mineral. Bowen, (1928, p. 277 *et seq.*) in a discussion on the question of the reactive crystallization of spinel in magmas indicates that spinel may form in the course of crystallization of ultra-basic rocks but that it normally disappears with falling temperature unless accumulated in quantity or protected from resorption by cloaking with other silicates. He indicates that in corona structures it would be expected to surround olivine and in turn be rimmed by pyroxene. Since in the present rocks it is released in the replacement of pyroxene by hornblende an abnormally high alumina content must be postulated for the pyroxene, and consequently for the basic magma. As pointed out by Pulfrey (1946, p. 84) this leads to the conception of incorporation of sedimentary material, probably at levels far below the locus of emplacement of the magma. A similar conclusion has been reached by Prider (1940, pp. 378-9) in connexion with the constitution of spinel-olivine-hypersthene xenoliths in granitic gneisses in Western Australia. With regard to the apparently sporadic nature of the development of spinel in the Kierra body, Pulfrey observes (*loc. cit.* p. 84) that it may be explained by irregular distribution of stoped material, followed by restrained diffusion and convection. The distribution of spinel is also irregular in the other basic bodies in the area.

In some parts of the basic masses banding of an undoubtedly primary type is developed. Exposures proved, however, to be generally unsatisfactory for detailed study, chiefly owing to their scarcity and the thick oxidation coatings that cover most of them. Since also the banding is chiefly due to segregation of the mafic and felsic components, the prevailing dark colour of the plagioclase tends to render it indistinct on relatively fresh exposures. On the whole, therefore, the banding is not conspicuous

and it is not considered to have been notably developed over any great thickness of the rocks. The dominantly perknitic bodies in the Inandago-Mikuiyi zone are not noticeably banded. On a broad scale, however, in the larger gabbroic masses the layering is unmistakable and highly banded outcrops (or more usually boulders little removed from outcrop) are occasionally met with. The bands have variable thickness, ranging from less than one inch to several feet, taking the form of thin layers of near anorthositic or perknitic type enclosed in thick layers of intermediate colour index. The individual layers usually have sharp transitions. No definite instance was found of gradation (upwards) of a melanocratic band into one of more leucocratic grade, which is a feature of gravity-stratified bodies such as the Skaergaard intrusion (Wager and Deer, 1939, pp. 135, 136). Despite the above criterion being apparently not applicable, however, the banding is otherwise essentially similar to that of many gabbro intrusions for which some form of fractional crystallization and gravitative crystal settling is postulated. In addition to the visible banding of light and dark mineral associations "cryptic" layering with respect to variation in the olivine and pleonaste content, and in the anorthite ratio of the plagioclase, is also revealed in thin sections of serial specimens taken transversely across the Kierra body. In a discussion on the question of banding in gabbros, Bowen advances an hypothesis of auto-intrusion (1941, pp. 168, 169) by which especially extreme types of banding may be explained. Pulfrey (1946, p. 86) discounts the general validity of this hypothesis in connexion with the banding of the Kierra body. He observes that "with such intrusion at least local swirling of the bands and patches of intricate veining might be expected, but most commonly the banding appears even and continuous. Bands certainly wedge out, thicken and thin, and waver gently, but the general evenness, if due to intrusion, would presuppose a degree of load or compression for which there is no other evidence". Auto-intrusion, however, could explain other features such as thin bands or ribbons or irregular patches of relatively leucocratic material occasionally noted in the gabbros.

Differentiation within the larger gabbroic masses, in the course of crystallization, has evidently produced a composition range extending from perknites as the basic, to diorites as the most acid end-member, the latter constituting a relatively inconsiderable proportion. The distinct perknitic intrusions (page 52) and the porphyritic diorite (page 73) show that differentiation at depth before intrusion has produced almost the same range in composition. It is not thought that the bulk of the intermediate and acid charnockites are magmatic differentiates since the field and microscope evidence points to a migmatitic origin. It is difficult, however, to draw a certain distinction between the magmatic and migmatitic groups. The most probable dividing line in the gabbro class is where quartz together with one or more of the alkali minerals first makes its appearance. In the diorites this means of distinction is not so applicable since many examples free of quartz or alkali minerals appear from their field associates to have a migmatitic origin. All the quartz-diorites and granodiorites are considered to be migmatites.

There is much evidence to relate the intermediate and sub-acid chadnockites with the basic intrusives. Their spatial relation to the latter is most striking and leaves no doubt that there is some connexion between them. The presence of hypersthene, on which their identity rests, was not noted elsewhere in the area, denoting that the general conditions during metamorphism were not at any time conducive to the formation of hypersthene. This mineral is the ultimate product of the chain of metamorphic changes in the mafic minerals of the Uganda charnockites (Groves, 1935, p. 195 *et seq.*). Ghosh (1941, pp. 44-48) claims a secondary origin for the hypersthene (chiefly after diopside) in practically all types of charnockite in the areas he mapped. If it were regarded as having formed in a similar purely metamorphic manner in the present area, it would be expected to show a wider distribution and have a less definite relation to the basic intrusions. There is furthermore no indication in the thin sections that hypersthene is derived from any mafic mineral other than olivine by normal reaction processes.

The charnockites occur amongst the common biotite- and hornblende-bearing migmatites and are intimately associated with them. Where the gneisses are well-banded the hypersthene types occur inter-banded with them and in the structurally more irregular gneisses they are interdigitated in complex fashion. Although it is not definitely proved, they are probably also gradational into the biotite-hornblende migmatites. Often over small areas or across limited breadths of banded gneiss several charnockitic types are found together, closely associated with non-hypersthene gneiss. They are so closely similar texturally that the charnockites can be definitely distinguished only in thin section. Their chief distinguishing feature in the field is probably a relatively darker colour than their hypersthene-free associates. The intimate association of these intermediate and sub-acid charnockites with normal migmatites and their definite spatial relation to the basic intrusions inevitably points to their derivation from the latter by granitization. There is, however, not much direct evidence of granitic metasomatism of the basic rocks over much of their exposures, but basic bodies were encountered in places, enveloped in more acid charnockite. These basic residuals are bands, lenses, or quite irregular bodies of variable size. (Plate II). The intermediate types, however, which greatly predominate among the hybrid charnockites, are dominantly mesotype and apart from their commonly developed gneissose texture, resemble the gabbros, and the transition of the basic types into more acid varieties would not necessarily involve much change in appearance. If replacement *in situ*, which is the dominant mode of the granitization in the region, be assumed as the method of acidification of the basic rocks, then the latter must have had an originally far greater mass than now, their limits corresponding more or less with the outer boundary of the present charnockitic hybrids. It is doubtful whether the often well-banded character of the charnockites can be inherited from the gabbros since the latter are seldom so clearly banded. Redistribution of felsic and mafic material possibly by metamorphic segregation may be responsible for intensification of original banding. Whether or not one is dealing with the replacement of large and continuous masses of basic rock or with a great number of small closely-spaced bodies, perhaps of concordant sheet form, is not possible to say. It is easier to believe that the latter alternative was largely the case since a much greater surface area would be exposed to the metasomatizing agents. On the other hand under deep-seated conditions basic and ultra-basic rocks tend to be emplaced as bodies of relatively simple shape and not to form complicated intrusions. Basic rock is normally, at least in the Basement System of East Africa, resistant to granitization as is evinced by the numerous pre-anatectic thin meta-dolerite sheets noted in most of the areas mapped. It, therefore, seems improbable that any large body of the dimensions required in the present instance could be completely penetrated by granitization, as indeed appears to be the case in the area mapped.

In a consideration of the origin of these rocks where large volumes of basic magma invade meta-sediments the possibility of assimilation must be considered. Basic magma is not usually associated with large scale assimilation but examples have been studied where it has taken place to at least a limited degree (Shand, 1943, pp. 102-103). In addition a large mass of augite-monzonite is considered by Reynolds (1934) to have originated by differential fusion of greywacke and shale by ultra-basic magma. With regard to the present area this aspect must remain an open question since no definite field evidence can be adduced. Where two such diverse rock types as the gabbro and the meta-sediments are concerned it might be expected that some definite criteria of assimilation would be found. The evidence on the whole, however, is more easily reconcilable with the idea of genesis by granitization of the associated basic intrusives.

The thin-sections as indicated in preceding sections (pp. 37-40) show many textural and mineralogical features which can best be interpreted as due to granitization. Ghosh (1941) finds much the same features in his intermediate to acid charnockites which he concludes are granitization products. To summarize the evidence for the present area the microscope indicates that the following changes produced the compositions in the charnockites ranging from quartz-gabbro to granodiorite: (a) the progressive albitization of plagioclase; (b) addition of quartz in variable and sometimes large

proportion; (c) progressive increase in one or more of the alkali minerals—blue-green soda hornblende, biotite, potash feldspar—often with clear replacement of earlier minerals; (d) increase of apatite and appearance of sphene; (e) occasional sericitization of the plagioclase and rare formation of muscovite. Hypersthene persists throughout the sequence of granitization but appears to become unstable in advanced stages, accounting for the scarcity of hypersthene granodiorites and the absence of true granitic charnockites. Its derivation from the original hypersthene of the basic rocks is a reasonable postulate, but to what extent it is a remnant or a (reworked) recrystallization product in the migmatitic charnockites is extremely uncertain.

(v) *Metamorphism*.—Since the basic and ultrabasic rocks occur in a regionally metamorphosed environment of intermediate grade some evidence of their metamorphism might be expected. For the greater part, however, metamorphic effects are slight or absent. Stress phenomena are frequently developed but are seldom of sufficient intensity, except in the cases noted below, to modify to any extent the original igneous structures or mineralogical composition. Primary corona structures are preserved and the minerals evidently crystallized in normal magmatic order, and undoubted metamorphic reaction between the component minerals was not noted. The plagioclase shows most clearly what stress effects there are in the bending, complication or destruction of the twinning lamellæ. Parts of the crystals are often resolved to fine-grained mosaic aggregates, but concurrent breakdown of the plagioclase molecule was not definitely established except in rare examples such as 44/315 described below, which, however, exhibits the most extreme stress effects seen in the basic group. It is nevertheless possible that some of the hornblende-rich andesine-bearing types were originally of gabbroic composition and contained a more basic plagioclase. The clarity of the plagioclase, absence of zoning, and the often abundant inclusion of mafic microlites also indicate some degree of recrystallization. The presence of olivine, a most unusual mineral in regional metamorphic facies, points, however, to the absence of excessive stress. It is not confined to the central parts of the masses but also occurs in their outer portions. Garnet, which is a common metamorphic reaction product between the mafic minerals and plagioclase of many basic rocks, was not formed.

In the outer zones of the intrusions where metamorphism is much more evident, the above observations do not entirely apply. It appears, therefore, that the massive perknites and gabbros had great rigidity and could consequently offer effective resistance to the metamorphic stresses. A remarkable exception is the Kantaugu-Kiuguni mass which apparently consists entirely of rocks of the plagioclase-amphibolite facies. Directional textures become developed in the peripheral zones and mineral reconstitution takes place to varying extent. The ultimate products are plagioclase-amphibole gneisses. The thin sections 44/261A, 44/261B (from the Kantaugu-Kiuguni mass) and 44/288 show late stages in the conversion of the gabbro. They are slightly gneissose rocks composed of bytownite plagioclase and green hornblende with some epidote and accessory magnetite. It is surprising to find in them a plagioclase more basic than the usual labradorite of the gabbros—if their intrusive identity was less certain derivation from lime-rich sediment would be strongly suggested. The plagioclase is intensely recrystallized except in 44/261A and the original dark mineral structures are completely obliterated. The last stage is represented by 44/315 which has well-developed schistose orientation of the amphibole while the plagioclase, except for a few large intensely strained remnants, is recrystallized in fine-grained aggregates. Epidote and rutile are abundantly developed. The plagioclase is more acid than in the previous examples, indicating breakdown of the molecule during the reconstitution of the rock. Intermediate stages in the transition from gabbro to plagioclase-amphibolite are probably represented by the hornblendization of the pyroxene and the sporadic development of epidote. The hornblende, however, has a variable origin in these rocks; the evidence cited on page 22 indicates a primary magmatic origin for at least a good part of it. Other evidence discussed previously suggests that some is a deuteric product. Except for the distinctive pale green and brownish varieties and the migmatitic blue-green hornblende, the evidence as a whole is sufficient to ascribe a particular origin to much

of the amphibole so that the degree of hornblendization produced by metamorphism cannot be assessed with any certainty.

Partial to complete chloritization or serpentization has occurred over parts of the ultra-basic and basic masses, with the formation of minerals such as chlorite, antigorite, tremolite, urallite, epidote and apatite. In addition talc sometimes forms in quantity. These rocks are probably magmatic alterations of hydrothermal type since they are not pronouncedly gneissic.

The migmatitic charnockitic gneisses possess the same intermediate degree of regional metamorphism as the common migmatitic gneisses.

(vi) *Age of the Intrusions*.—The age of the intrusions must be deduced from indirect evidence since they are entirely emplaced in a succession of Archæan rocks.

The bulk of the rocks apparently does not share the same degree of metamorphism as the surrounding strata. This phenomenon was, however, also encountered in the pre-tectonic, pre-granitization basic sills in the Archæan rocks of the Mwapwa area, Tanganyika, which are in all stages of alteration comprising "types hardly distinguishable from ordinary dolerites to others that through recrystallization and mineral reactions have lost all traces of the original minerals and the original ophitic structures" (Temperley, 1938, p. 32). The latter are closely akin to the present plagioclase-amphibolites. If unaltered cores can be left in relatively small bodies of dolerite in a region of intense tectonism then the lack of directional recrystallization in the present much larger basic bodies does not necessarily indicate intrusion subsequent to the main period of regional tectonism. The development of the primary banding in the gabbros moreover implies an original much less steep dip, i.e. intrusion before the main folding and uptilting of the region. The intermediate and sub-acid charnockites are of the same metamorphic grade as the regional assemblage. If the concept of their derivation from the basic rocks by granitization is tenable then the latter are pre-granitization in age.

It is concluded that the basic intrusions are of great age, corresponding with some level in the Archæan.

D.—*Minor Intrusives*.

Thin veins, ribbons and less regular bodies of dense dark grey intrusives have sporadic and rather rare distribution over the area. The following types were distinguished.

(a) *Meta-diorite-porphyrates*, are much the commonest type. In hand specimen they are dense to fine-grained and of dark grey colour. A directional fabric had usually been imposed to greater or lesser degree on the original granular texture indicating intrusion prior to the regional metamorphism. Porphyritic development was not noted except in 44/217 and 44/220 where clusters of hornblende, biotite, iron ore and plagioclase seem to have resulted from the breakdown of earlier mafic phenocrysts. The felsic minerals are usually subordinate although sometimes about equally abundant as the mafic minerals. Blue-green and green hornblende is the predominant dark constituent, while brown biotite is subordinate but often abundant as in 44/200. It is occasionally absent as in 44/297. Iron ore granules are liberally dispersed through the slides and sometimes nearly equal the hornblende in amount. Plagioclase is the chief colourless mineral with composition about medium andesine (determined as An_{44} in 44/291) and is usually accompanied by minor amounts of quartz. Traces of orthoclase were detected in 44/217. In the same slide considerable portions are occupied by large areas of muscovite(?) highly altered to a colourless chlorite in which the dark minerals lie embedded. Rounded grains of apatite and rare sphene are accessory.

(b) *Diorite-porphyrite*.—This is an exceedingly scarce type; only one specimen was collected. In contrast to the above meta-porphyrates it is conspicuously porphyritic with well-formed plagioclase phenocrysts up to 2 cm. in length sparsely set in a dense dark grey matrix. In thin section it has a granular texture with no suggestion of orientation and consists of needles of hornblende seriate up to 1 mm. in length

with about an equal amount of light brown biotite intergrown with abundant iron ore microlites. The plagioclase is basic oligoclase to medium andesine and is subordinate to the mafic minerals. It occurs in laths, prisms and granules ranging from 0.5 mm. down to groundmass size. Quartz was not found. The only accessory is apatite.

2. POST-ARCHÆAN

(1) (a) *Basalts and Phonolites.*

North-east of Nkubu the lowermost flows of the Mount Kenya cycle are basalts and microporphyrific phonolites. They do not build up to a thickness exceeding a few hundred feet and of that thickness a considerable part is composed of ash beds. Along the Mariara River to the north of Kaongo ashy agglomerates are exposed and it is doubtful whether they are of Kenya age or belong to the Nyambeni volcanics which in this part of the country lie in juxtaposition with the Kenya lavas. The basalts of both periods also have close field and microscopic resemblance and since they often occur together here their mutual boundary is uncertain.

In hand specimen the *basalts* are dark grey with sparse phenocrysts of deep green olivine and black pyroxene, seriate up to more than one centimetre and set in a dense base. Some flows are comparatively lighter grey in colour containing in addition to the mafic phenocrysts scarce prisms of plagioclase up to about 2 cm. in length. Vesiculation is usually poor and when present vesicles are small and sparsely distributed. Under the microscope the specimens show variation of texture and mineralogy. They are all microporphyrific the phenocrysts normally forming only a small part of the rock. Olivine is the most abundant of the phenocrysts and is usually accompanied by a lesser amount of pale grey augite, both minerals being well-resorbed by the groundmass. In certain of the more leucocratic types seriate laths of plagioclase up to about a millimetre in length are also formed. Subhedral magnetite grains and rare apatite crystals also have porphyritic development. In the groundmass the dark minerals predominate except in the few plagioclase-rich types such as 44/254 and 44/263. Often the groundmass is exceedingly fine-grained. Augite is the preponderant dark mineral with either a pale greenish or grey colour and sometimes a strong purplish tinge due to its titania content. Olivine is much subordinate since most of it has formed as phenocrysts. In any particular slide the plagioclase has part lath and part granular form. Iron ore granules and dust usually compose a high percentage of the groundmass. Zeolite is often abundant forming an interstitial base and replacing the plagioclase and dark minerals, which are commonly also heavily chloritized. The olivine is characteristically altered to red and brown iron hydrates. The tiny spherical ovoid or irregularly shaped vesicles are infilled with zeolite, chlorite and carbonate.

The *phonolites* of this group are highly microporphyrific, phenocrysts sometimes making up about one-half of the rock. They are seriate up to a maximum of a few millimetres in length. Anorthoclase predominates but in 44/265 the phenocryst feldspar is seen to range in composition between anorthoclase and albite. Pale green or purplish augite, and olivine to a lesser extent, also form numerous euhedral phenocrysts. Many small apatite and magnetite crystals are also coarser than the groundmass. The very fine-grained groundmass consists of predominant feldspar, in lath and granular form, abundant ægirine-augite and iron dust, subsidiary kataphorite and rare cossyrite. The base is apparently analcite.

(b) *Kenytes.*

The name *kenyte* was proposed by Gregory for the porphyritic rock which appeared to him to form the central plug of Mount Kenya and which also composes much of the lava of the alpine zone of the mountain. He described and defined the rock (1921, pp. 146, 147) but as pointed out by Campbell-Smith (1931, p. 242) there was some confusion since he made no mention of the presence of nepheline phenocrysts which are an important constituent.

In the area *kenytes* with interbedded tuffs and agglomerates are accumulated to a total thickness of at least 3,000 feet on the south-eastern slope of the mountain. The lowermost flows are extensive and probably originally covered the greater part of

the area, as evidenced by their outliers. These earliest flows are relatively thin as can be seen along the eastern boundary which forms the escarpment overlooking the Basement System and do not much modify the flat sub-Miocene landscape over which they spread. The later flows form a series of broad inconspicuous steps giving a gradual ascent of the country westwards.

The kenyte, despite the large area it covers, shows remarkably consistent features. It is typically markedly porphyritic; in many exposures phenocrysts compose about half the rock. The lower flows are generally more closely porphyritic and a noticeable diminution in phenocryst size takes place upwards through the succession. In a number of flows the felspar phenocrysts average over one-half inch and occasionally (Plate 1b) many are over two inches in length. The felspar is anorthoclase and the amount crystallized as phenocrysts greatly predominates over that in the groundmass. It forms well-shaped to perfectly idiomorphic crystals of stout prismatic, often rhomboid habit or less commonly with tabular and rarely lath form. Its shape is perhaps the best macroscopic distinction between the kenytes and other coarsely porphyritic phonolites, such as the Kapiti type, in which the anorthoclase favours a platy habit. Especially in the lowermost flows the phenocrysts show pronounced flow orientation. In fresh specimens the anorthoclase crystals are grey with a glistening lustre and prominent cleavage, and on weathering stand out sharply white against the dark grey base. Greasy-looking grey-green nepheline phenocrysts are always present; normally in lesser amount but sometimes nearly equal to the felspar. They form smaller crystals which though often euhedral are mostly rounded by resorption. Occasionally comparatively thin crystals of pyroxene and olivine can be distinguished. Vesicles are normally absent or of microscopic size but in a few exposures small ovoid amygdaloids of porcellaneous white material were noted.

Thin sections reveal that the kenyte is also strongly microporphyritic, the smaller phenocrysts being seriate down to groundmass size. The abundant felsic micropheocrysts are accompanied by numerous small well-shaped crystals of augite and olivine. The augite is a pale grey variety, sometimes slightly greenish grey, with maximum extinction of 64° , and rarely has external purplish grey zones indicating increased titania content before crystallization ceased. The presence of olivine is doubtful in certain of the slides but it was identified in most of them as a fayalitic type. It has altered rather easily to green antigorite and iron hydrates. Iron ore is a common accessory in the phenocrysts often in well-shaped isometric units and is probably magnetite. Colourless apatite in idiomorphic crystals is also a characteristic accessory. The outlines of the phenocryst crystals are seldom as perfect as the hand-specimens suggest since some degree of peripheral resorption by the groundmass is a rule, often resulting in digestion of large parts of certain phenocrysts. Nepheline has generally proved the least resistant; in a few slides many relict hexagonal and rectangular shapes of totally resorbed nepheline are preserved by coronas of dark minerals which used these early crystals as nuclei for crystallization. A common feature especially of the felspar phenocrysts is marginal intergrowth with groundmass material often taking the form of a leucocratic or dark halo. Rhythmic growth is occasionally revealed by the inclusion of concentric zones of ferruginous granules though zoning with regard to chemical variation was not seen. Inclusion of grains of apatite and dark minerals in the felspar and nepheline phenocrysts is common.

The groundmass is characteristically extremely fine-grained, in most specimens averaging less than 0.05 mm. and is sometimes in part cryptocrystalline. The texture is granular, intergranular or semi-fluxional. The light and dark minerals are mostly present in about equal amount. Felspar, probably anorthoclase, is the chief felsic mineral, occurring for the greater part in needle shapes but in certain slides has granular habit. Nepheline is always subordinate to the felspar but is often abundant presenting typical square, oblong and hexagonal forms. The dark minerals show variable proportions; most commonly ægerine-augite and coesite are about equal in amount though either may predominate. Kataphorite is normally present as scarce, lavender-brown, strongly pleochroic plates of relatively larger size. It becomes more abundant in some slides

equalling the first named minerals and in 44/235 and 44/257 is slightly predominant. The ægerine-augite which sometimes has a strongly purplish tint, has variable soda content and often cluster-growths show zoning, the core crystals being paler green and the outer crystals deep green and strongly pleochroic, but extinction angles indicate that ægerine has not formed. The cossyrite, almost opaque except in very thin sections or under concentrated illumination, has pleochroism from black to ruby-red, red-brown or deep reddish purple. In amounts it bears an inverse relation to the iron ore, being abundant when the iron ore is scarce and when the latter is abundant, e.g. 44/194 and 44/257, cossyrite is almost absent. It is only rarely, however, that iron ore is abundant. Olivine is occasionally present in small quantity in the groundmass. The base is isotropic or feebly anisotropic and is tentatively identified as analcite. In a few slides such as 44/194 analcite, natrolite, and other zeolites form in irregular patches replacing the feldspar and other minerals. Zeolite is the chief vesicle infilling together with carbonates and chlorites. Chloritization of the groundmass minerals is sometimes intense. The phenocryst anorthoclase and nepheline is often much replaced by analcite and zeolites. Slide 44/235 contains in the groundmass considerable amounts of an unidentified brown, strongly absorbent, flaky mineral with straight extinction, which is possibly a type of brown mica.

Ash accumulations are often exposed along streams and road cuttings. Some are quarried for building stone around the missions and trading centres. Normally they are bedded deposits containing abundant lava and pumice inclusions of all sizes and fragments of feldspars, nepheline and dark minerals, in a fine-grained matrix. They weather easily and acquire a highly cellular structure and a light cream, grey, fawn, brown or red colour. Under the microscope the chief inclusions are seen to be fragments of the surrounding lavas and pumiceous material. Rounded grains of glass, sometimes clear and often saturated with iron hydrates are very common. Anorthoclase and nepheline fragments are abundant and plagioclase, augite, ægerine-augite, ægerine, biotite, quartz, apatite and magnetite were also recorded. The base consists of amorphous, probably partly glassy material, heavily impregnated with indefinite ferruginous material. Zeolites are abundant both in the groundmass and inclusions while the whole is usually strongly stained with iron solutions.

Two flows of basalt were found in the kenyte succession. Specimen 44/289 from a sheet exposed at the bridge crossing of the main Embu-Meru road at the Nithi River is finely microporphyritic with fresh phenocrysts of olivine, augite and plagioclase, seriate up to about 0.5 mm., in a groundmass with basaltic texture composed of plagioclase, augite, iron ore and a small percentage of olivine. Where the road crosses the Kithenu River a specimen (44/187) of a finely porphyritic basalt was collected. The phenocrysts with maximum size of about 3 mm. are well-twinned slender prisms of of labradorite An_{60} and small crystals of pale green olivine and augite. The groundmass is comparatively coarse with intergranular texture and contains plagioclase, grey, purplish-grey and greenish-grey augite, olivine, iron ore and accessory epidote. A small amount of orthoclase(?) has crystallized interstitially.

(c) *Finely Porphyritic and Dense Phonolites.*

The kenytes are overlain by a succession of finely porphyritic and dense phonolites which reaches its maximum thickness of at least 2,000 feet in the central part of the lava-covered area.

The phonolites are essentially similar in mineralogy to the kenytes but do not have conspicuous porphyritic texture, the phenocrysts rarely exceeding an average size of a few millimetres. In certain places the change from kenyte to dense phonolite is abrupt but in other sections the change is more gradational, the flows becoming successively less coarsely porphyritic upwards.

Some flows are intensely microporphyritic, phenocrysts constituting at least one-third of the volume. Many of the phonolite beds, however, are completely lacking in phenocrysts. As with the kenytes, anorthoclase, occasionally showing fine cross-hatched twinning, is the chief phenocryst mineral. Nepheline in variable but always subordinate

amount accompanies it. Augite forms the most abundant mafic phenocrysts; it is either pale grey or a purple grey titaniferous type, the latter often strongly pleochroic as in 44/184 with X purple grey, Y pale yellow, and Z purple grey, $Z\lambda c 66^\circ$. Olivine is slightly subordinate to augite. Iron ore and apatite also form small phenocrysts. The groundmass is generally much more coarse-grained than in the kenytes—in the latter the average grain size is consistently about 0.05 mm., the present phonolites average from 0.1 to 0.5 mm. Inter-granular and granular textures are commonest but many specimens have strong trachytic alignment of the anorthoclase laths. The groundmass usually contains about equal proportions of light and dark minerals. Anorthoclase is again the chief felsic constituent accompanied by subordinate nepheline, which can be identified by its euhedral forms. Slide 44/181 contains one small crystal of plagioclase. In a number of specimens, e.g. 44/165, 44/166, 44/179, nepheline is apparently completely absent indicating saturation in silica. The dark minerals are those of the kenytes. Aegerine-augite usually predominates and in 44/165 and 44/176 is the sole dark silicate. It is often associated with an appreciable proportion of ægerine. Cossyrite is subordinate or scarce and kataphorite is always much subsidiary. In 44/184 the kataphorite is accompanied by arfvedsonite with low extinction and weak pleochroism, pale yellow-green to medium purplish-brown. Iron ore is abundant only when cossyrite is scarce. A little epidote and sphene are accessory in 44/165. Analcite again forms the base, often accompanied by zeolites replacing portions of the groundmass and the phenocrysts. The dark minerals are sometimes altered to chlorite.

Tuff horizons intercalated with the phonolites are similar to those accompanying the kenytes.

(d) *Olivine Basalts.*

In the north-eastern part of the area exposures of black finely vesicular basalts were encountered. Their extent into the forested part of the area could not be determined.

In thin section they are finely and sparsely porphyritic containing chiefly clear plagioclase laths and stouter prisms up to a few millimetres in length, having a range between andesine An_{46} in 44/259 and labradorite An_{62} in 44/461. A few small euhedral fayalitic olivine and pale grey augite phenocrysts also occur in all the slides as well as some well-formed magnetite and apatite crystals. The matrix is very fine-grained and consists of indefinitely crystallized aggregates of dark semi-opaque material in which are set numerous plagioclase needles with strong fluxional arrangement, a small amount of pale green augite and chlorite(?) and much microlitic iron ore. The abundant tiny vesicles are for the greater part not infilled but some contain a little calcite and iron hydrates.

(e) *Basalts of the Crater Cones.*

A group of three well-preserved crater cones densely covered by vegetation and known as Kiruini represent the latest volcanic activity of the Kenya episode in the area. No representative specimens could be collected from them but they are doubtless of similar age to the numbers of young crater cones situated some miles to the north around Meru township and to those on the northern side of the mountain described by Shackleton (1946, pp. 37, 38). Olivine basalt was extruded from them.

(2) *The Nyambeni Volcanics.*

Within the area mapped the Nyambeni volcanics are represented by extensive sheets of basalt lying on the end-Tertiary peneplain and by a few residual outliers forming pedestal features due to the lowering by erosion of the surrounding Basement System country. The sheets are not thick and along their exposed edges were never seen to exceed one hundred feet and mostly are much thinner, often not more than twenty feet. They probably represent single flows except northwards towards the Nyambeni Range where the accumulation thickens and numbers of flows appear to be superimposed. These basalts were doubtless for the greater part erupted from central vents forming numerous cones, a few of which such as Chambogori, Kirindini

and Nkewene fall within the area. These are at widely different stages of erosion; Nkewene is a well-preserved horseshoe-shaped cinder crater while Chambogori and Kirindini are intensely denuded.

The western limit of the lavas for some miles south of Mkazie is indefinite. Also in the extreme north-eastern corner of the area the basalt is only the thinnest veneer on the peneplain and its extent is uncertain.

The basalts are similar in aspect over the whole area of exposure. They are often finely porphyritic with small insets of black augite, green-grey olivine and rare white plagioclase in a black aphanitic base. Sometimes mafic clots exceed a centimetre or two. An intensely vesicular structure is characteristic of most of the flows, the vesicles being mostly small and often completely irregular in shape. They are rarely infilled with carbonate, iron hydrates or zeolites. In thin section the basalts invariably have microporphyritic development. The phenocrysts usually constitute less than 20 per cent of the rock but in a few of the specimens make up as much as 50 per cent. They normally grade from a few millimetres to groundmass size. Olivine usually predominates except in the more felsic types such as 44/149, 44/155 and 44/233 where plagioclase is predominant. In a few slides, e.g. 44/248 and 44/255, except for a few small crystals of magnetite olivine is the exclusive phenocryst mineral. Augite is mostly subordinate and sometimes absent and only rarely predominates, as in 44/251. These minerals always form euhedral crystals though frequently resorbed by the groundmass. The augite is often zoned from grey to purplish grey outwards from the centre of the crystals due to increase in titania content. The plagioclase is occasionally strongly zoned; it was determined as medium labradorite An_{58} in both 44/234 and 44/263. Magnetite and rarely apatite also form tiny euhedral phenocrysts. The groundmass varies in fineness the average grain size being between about 0.1 and 0.5 mm. in different examples. An intergranular texture is commonest with frequently a semi-fluxional orientation of the plagioclase which is for the greater part in lath form. In 44/155 the augite has pronounced ophitic habit. The dark minerals mostly predominate though plagioclase is often present in balanced amount. Augite, grey or green-grey, and often markedly purple-grey, is normally the most abundant mafic mineral, accompanied by subsidiary olivine. Finely granular iron ore always makes up a considerable portion of the groundmass; in 44/234 it is partly acicular ilmenite(?). Melilite in minute slender prisms has partly taken the place of the plagioclase in 44/233 and completely in 44/255. In one or two of the slides zeolite has formed in appreciable amount in the base while in 44/155 probable potash feldspar occurs in the same way. Secondary changes are seen in most of the slides, the commonest being the intense replacement of the groundmass by amorphous ferruginous material and the conversion of the augite to chlorite. Much deuterite chlorite has also sometimes crystallized interstitially and in fracture veins. The olivine units characteristically have an alteration border of red iron hydrate or are completely converted to it. The vesicle infilling is calcite, zeolite and iron oxides and hydroxides.

The small outliers east and north of Munguni Hill are composed of a thin sheet of basalt of different type. It is the only basalt in the area with definite columnar structure and is furthermore distinguished by a considerable zeolite content estimated at almost one-tenth of the rock. It forms irregular patches in the groundmass and infills the numerous minute vesicles. Otherwise the basalt is again a highly microporphyritic plagioclase-olivine-titanaugite type.

3. SUPERFICIAL DEPOSITS

Pleistocene.

The most extensive Pleistocene deposit in the area, consisting of ill-sorted conglomerates and coarse gravels, lies on the small plain south-west of Lansa Hill. The pebbles, mostly sub-rounded and of variable size up to more than one foot in diameter, are chiefly of Nyambeni basalt with subordinate Basement System gneisses and Mount Kenya lava types. The matrix is dark grey, sandy, and somewhat friable. Closely similar deposits are exposed on the sides of the Kireria River channel north of Munguni Hill.

PLATE I

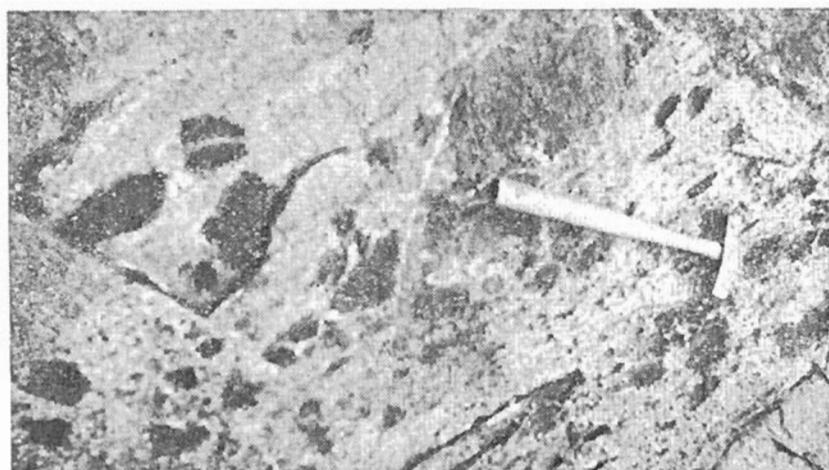


(a) Highly banded migmatite in a tributary of the Tana River a few miles south-west of Kiburu Hill.

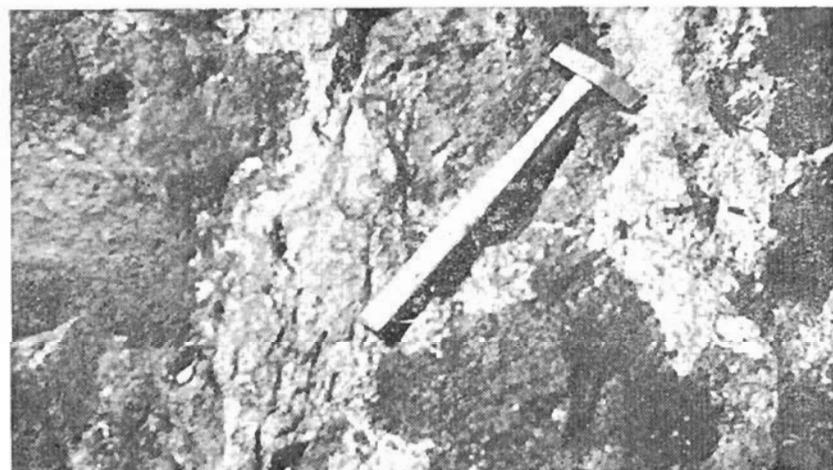


(b) Coarsely porphyritic kenyte exposed about 1 mile west of Chambagori Hill.

PLATE II



(a) An outcrop at the base of Kierra ridge on the north-eastern side. The dark material, apparently in a state of partial digestion, is charnockitic diorite in a base of more leucocratic biotite-hornblende granitoid gneiss, the two types constituting a migmatitic series.



(b) A similar example to (a) seen in a small gully on the Kiburu-Nsavini ridge near the Mutonga River. In this case the dark rock is a hypersthene quartz-gabbro.

Larger boulders up to several feet in diameter are included in this conglomerate and the matrix is considerably harder than in the first example. It is evidently an infilling of a former river-course which had cut its bed below the present stream level. No artefacts or fossil remains were found to give a clue to age but in comparison with the Gamblian Pluvial deposits cementation is more advanced and they are probably of an older, possibly mid-Pleistocene, age.

At intervals along most of the stream-courses ill-sorted sediments are exposed, sometimes with thicknesses of up to about thirty feet. They are probably the result of the torrential conditions during the Gamblian Pluvial period of the upper Pleistocene. Recent rejuvenescence of the drainage has caused the removal of most of these deposits. They are in general loosely consolidated, crudely stratified boulder-beds, gravels and sands. They do not form big individual deposits anywhere in the area.

Recent.

The soils of the district vary according to the rainfall, the underlying formations and local drainage conditions. Deep soil and sub-soil has developed over the greater part of the Mount Kenya volcanics especially on the ash beds, owing to the good rainfall and their easily decomposed nature. The top soil is generally a medium to dark brown loam grading downwards into a redder more clayey subsoil. The latter often tends to become lateritic when it is popularly designated "murram". Limestone often separates in considerable quantity dispersed through the rotted rock. It also compacts in more or less distinct thin layers a foot or two below the surface. Banks of hard cellular lateritic ironstone a few feet thick are sporadically exposed, usually near streams.

The Basement System is mantled by the usual pale reddish or brownish sandy and granular soils produced by semi-arid weathering conditions. They are of immature type and contain much quartz, feldspar and mafic material. Black cotton soil is only developed in a few marshy localities. Laterite formation is seldom of more than partial or incipient degree.

VI—METAMORPHISM

The metamorphic rocks of the area denote in their mineral constitution and structures an intermediate degree of regional metamorphism. Applying the depth-zone classification (Harker, 1939) to the relatively non-granitized schists of semi-calcareous argillaceous type the mineral association is that of the calc-hornblende-schists (*loc. cit.* pp. 262, 263) which Harker regards as equivalent in grade to the garnet zone schists of purer argillaceous composition. In a small percentage of the migmatitic gneisses garnet in fine-grained form is abundant. Minerals indicative of higher metamorphic grades are not developed.

VII—STRUCTURES

Major Structures.

In common with all areas of the Basement System mapped in the Colony the dominant aspect of the structure is its broadly stratiform disposition. There can be no doubt that tremendously thick tabular successions were involved in intense crustal compression. The prevailing strikes, roughly between north to south and north-east to south-west, indicate application of forces normal to these directions. The general dip is between 30° and vertical, averaging about 60°. Whether this implies simple tilting or close steep-angled folding was not possible to determine since distinctive marker horizons were not found, nor is there any recognizable repetition of strata. In the almost contiguous area to the north-west, between Nanyuki and Maralal, Shackleton (1946, pp. 26 and 27) cites evidence, based on the disposition of limestones and other distinctive psammites, which strongly suggests major isoclinal folding. The dips are predominantly westward but reversal of dip was sometimes encountered indicating folding, but the folds seem to fade along their axes within distances of a few miles. Over the central part of the area large-scale transverse folding or more probably

disruption and rotation has taken place. The general strike of the strata, more or less east-west, is here almost at right-angles to the regional strike. The resistant granitoid gneisses forming the inliers in the Mount Kenya volcanics again share the north-south strike of the strata to the east of the disruption area. The two broken lines shown on the map running in a roughly north-east to south-west direction between Kibagi and Kiburu ridges mark approximately the position of strong disconformity in this locality. The thickness of the strata in the Kijegge massif appears to be due to duplication by close folding. The right-angled bend made by the Chemala-Lansa and Kantangu-Kiuguni basic body in the north-eastern part of the area is repeated to a less distinct degree in the adjoining formations indicating a large, probably synclinal, flexure. It is not known whether the basic body is a concordant intrusion of post-folding date or whether it was itself involved in the flexing.

A few strike faults, probably of steeply dipping reversed type, are shown on the map, and possibly represent common type of faulting. During the main tectonism, however, the evidence points to a high degree of plasticity and lack of competence, adjustment by faulting, therefore, being subservient to folding. A feature which may indicate the presence of transverse faulting is the common tendency of the minor and some major streams to cut across the strata at right-angles over certain distances, but whether this merely indicates strongly developed jointing or whether some displacement has occurred is not certain. There is no evidence in any instance to indicate that any displacement could have been appreciable.

Minor Structures.

Although the broad structural plan is relatively simple, subsidiary deformation is generally intense. Deformation of plastic type can be seen in all stages of intensity involving extremely tight folding, plastic drag faulting, boudinage structures, ptigmatic veining and other typical features. In the course of granitization a more mobile, possibly fluid or partly fluid condition was attained accounting for the wholly unsystematic, extremely heterogeneous structure sometimes observed.

Jointing and Cleavage.

Jointing and cleavage is on the whole prominently developed. It was not possible to effect detailed measurements but certain types have wide and consistent development.

Cleavage (? jointing) parallel to the foliation is the most consistently developed and when closely spaced imparts flaggy and slabby structures. Jointing more or less normal to the strike and also to the foliation is very prominent and may have an important influence on stream directions as pointed out above. Strike jointing nearly at right angles to the foliation is frequently developed. It may also be inclined at variable angles to the foliation. Where a linear fabric is prominent, jointing, generally inclined steeply to the foliation, is often developed parallel to the axis of lineation.

The basic rock masses are too poorly exposed to give sufficient evidence of jointing or cleavage by which their place in the tectonic history of the Basement System can be deduced.

The jointing and cleavage is regarded as a late-tectonic feature resulting from conditions of declining temperature and regional pressure.

Lineation.

Lineation is commonly seen but is seldom prominent. Over the area as a whole it dips at variable but mostly steep angles consistently in a north to north-west direction, with but few exceptions, when the dip is southward. Such consistency indicates that the regional folding has a northward plunge. This applies over a wide extent since both in the Maralal area (Shackleton, 1946, p. 25) lying to the north-east and the west Kitui area (Schoeman, 1948, p. 24) to the south, i.e. over a north-south distance of over 200 miles, similar conditions are found.

The lineation is expressed on foliation planes mainly by orientated elongation of quartz and felspar grains and alignment of the long axes of mafic minerals. Often on primary foliation planes a secondary foliation of light and dark minerals is developed. Linear grooves and ridges resembling slickensides are an occasional manifestation of the lineation. As in the case of other structures no detailed study was made and other types of lineation are probably also represented. Since it seems to have a definite relation to the major folding it was probably concomitant and was probably imposed when the rock was in a plastic state.

VIII—ECONOMIC GEOLOGY

1. MICA

The following account is based on an unpublished departmental report by Dr. W. Pulfrey prepared after an investigation of the Kierra area during September, 1942, and November, 1943.

Interest in mica was first taken in this area in September, 1912, when Messrs. A. Gamble and W. C. Parker pegged claims on the south-east flank of Kierra Ridge. In January, 1914, two blocks of claims were also pegged by Parker in the Koutheni location near the Kazita River in the north-east corner of the area. In June of the same year a prospecting licence was granted over an area of five square miles on the north bank of the Kazita River which included a portion of the original claims. The licence was allowed to lapse without any mica being produced.

The claim held by Gamble on Kierra was abandoned in May, 1914, while Parker after entering into an agreement with Newland Tarlton and Co., Ltd., eventually ceded all his rights to them. The claims and all rights were finally abandoned by this company in January, 1920.

In the meantime, however, as a result of strong representations from the Ministry of Munitions in Britain, Government had itself obtained permission from Messrs. Newland Tarlton to reopen the Kierra prospects and to win mica. Operations began in October, 1918, and continued until May, 1919.

Subsequent to this the prospects were offered out to tender for working but although a tender was accepted, no further work was done and the claims were finally abandoned in December, 1921.

During the Parker-Newland Tarlton operations seven claims were eventually held on the flanks of Kierra and a considerable amount of excavation was carried out. By May, 1914 an opencast 50 feet by 25 feet and 18 feet in depth had been excavated and a mica pegmatite eight feet in width at surface and 25 feet in width at depth had been exposed. Several other pegmatites had been cut into by small opencasts. Details are not available of the underground workings, but it was stated that on the largest vein a shaft had been sunk to 140 feet depth where sinking ceased owing to the pinching out of the vein.

The overall cost of production was approximately Sh. 4.11 per lb. of mica, whilst the receipts were approximately Sh. 3.53 and Sh. 1.86 per lb. for the first and third consignments respectively. It appears that four shipments of cut mica were made, viz. :—

Number	Date	Weight of Mica	Value Realised
		lb.	£ s. cts.
1	June, 1914	3,010½	536 15 2
2	Sept., 1914	409	No record.
3	Dec., 1914	787	78 10 9
4	Feb., 1917	1,023	Estimated value Rs. 1,279 (approx. £85).

These consignments were graded as follows:—

Size Grade	First Consignment	Third Consignment	Fourth Consignment
	<i>Weight per cent</i>	<i>Weight per cent</i>	<i>Weight per cent</i>
Specials	14.1	4.3	5.6
1	8.4	9.6	3.5
2	14.2	5.7	4.3
3	14.2	8.0	8.1
4	21.5	15.7	8.8
5	13.2	30.5	19.7
5½	14.5	16.2	27.0
6	—	—	—
7	—	9.7	3.2
Films or splittings	—	—	19.6
Total weight in lb.	3,010½	787	1,023

In comparison with the general trend of sorted mica products of the Colony these consignments show an undue proportion of large sizes. To infer from the prices then prevalent it appears that much inferior grade material was included.

During the official operations a number of new deposits were cut into mostly outside the previous claim area. The best yields were from deposits on the south-east flank of Kierra near Karaoki and Kaliani. Altogether 2,716½ lb. of cut mica were produced, 845 lb. being derived from the old workings. The approximate cost of production was Sh. 12.2 per lb.

Two consignments of mica were eventually forwarded to Britain of which the details are as follows:—

Number	Date	Weight in lb.	Value Realised			
			Total		Per lb.	
1	Dec., 1919	2,082½	73	1	4	Sh. 0.6
2	Feb., 1920	634½	33	10	8	Sh. 0.9

Size Grade	First Consignment	Second Consignment
	<i>Weight per cent</i>	<i>Weight per cent</i>
Special	—	0.6
A1	—	0.8
1/2	—	7.3
2	—	—
2/4	8.2	—
3	—	—
3/4	6.5	—
4	14.7	—
4/5	—	20.0
5	12.1	39.1
6	52.6	10.9
Films	5.8	21.3

This mica was mainly of brown spotted type with small quantities of green and clear mica. The comments of the purchasing agent were concerned mainly with the excessive thinness and small size of plates, bad striation and softness.

In June, 1942, Government once more closed to prospecting an area of approximately 500 square miles which included the old Kierra workings. A prospector was sent soon after to reopen old workings and to prospect for mica over the remainder of the area. Some of the old workings were found and excavated but the mica in them was badly stained, thin, inelastic, soft, often vermiculitized and altogether valueless. New excavations mainly on the south-east flank of Kierra exposed pegmatites carrying mica of the same poor quality and it was decided to cease work in this area.

Over the quarter-degree sheet covered by the present report mica-bearing pegmatites have wide and fairly common distribution but no vein was observed bearing mica of good size or quality and in appreciable amount. More detailed search might, however, reveal workable material.

2. MINERALS OF THE NORITIC INTRUSIONS

A good number of differentiated noritic intrusions in various parts of the world, such as Sudbury in Canada, Insizwa in Cape Province, etc., contain mineral deposits, chiefly of nickel, chrome ore, copper and the platinoid metals. They have the form of crudely tabular deposits, situated at or near the base of the intrusions which are generally of laccolithic or lopolithic type, and thus occur in the most basic differentiates. The metals are carried chiefly in the primary sulphide minerals pyrrhotite, pentlandite and chalcopyrite with subsidiary niccolite and bornite, which occur as intense disseminations through the brecciated basic rocks and as vein infillings.

In Tanganyika Territory nickel-bearing minerals have been discovered in a number of distinct localities (Teale and Oates, 1943, p. 82). Nickeliferous magnetite occurs in disseminations and small lens-like concentrations in an ultrabasic rock (dunite) near Mwahanza, about 70 miles north-north-east of Dodoma, not far from the Great North Road. On the eastern shore of Lake Tanganyika, near Kungwe Bay, samples of noritic rocks with disseminations of pyrrhotite were found to contain about 0.5 per cent nickel. In the Duma River area, Serengeti Plains, indications of nickel were observed in association with silicified serpentine.

In the present intrusions indications of such mineralization were sought, especially in the ultramafic bodies situated between Inandago and Mikuiyi, but evidence of sulphide enrichment, gossans or copper and nickel "bloom" were not observed. Some of the freshly fractured rock has small and rare specks of pyrite, pyrrhotite and occasionally chalcopyrite, but not appreciably in excess of that normally found in igneous rocks. It is, however, not impossible that thorough prospecting might reveal concentrations of sulphides.

As such ores are normally located in the most basic portions of the intrusions prospecting should primarily be confined to the hills between Inandago and Mikuiyi. Samples of sands from gullies on the southern side of the Kierra Ridge were panned during the previous investigation in 1942 (Pulfrey, 1946) but proved to consist largely of magnetite and no platinum was found. The magnetite was also tested for nickel with negative results.

3. GENERAL

Apart from the mica, the pegmatites of the area are negligibly mineralized.

Other Basement System minerals such as kyanite, sillimanite, marble, graphite, etc., which are sometimes of economic importance were not found.

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