



COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
SOUTH KITUI AREA

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

by

E. P. SAGGERSON, B.Sc., Ph.D., F.G.S.

Geologist

1957

PRINTED BY THE GOVERNMENT PRINTER, NAIROBI

Price: Sh. 12/50



COLONY AND PROTECTORATE OF KENYA

**GEOLOGY
OF THE
MERU-ISIOLO AREA**

(with coloured geological map)

EXPLANATION OF DEGREE SHEET 36, S.E. QUARTER

by

P. MASON, B.Sc.

Geologist

1955-

PRINTED BY THE GOVERNMENT PRINTER, NAIROBI

Price: Sh. 8

FOREWORD

The survey of the Meru-Isiolo area completes the geological mapping of a meridional strip of country about 35 miles in width and 175 miles in length in central Kenya, stretching from near Sultan Hamud in the south to the borders of the Northern Province. Accounts of the four quarter-degree areas south of Meru have already been published in previous reports—No. 17, Embu-Meru; No. 23, the country south-east of Embu; No. 14, the country west of Kitui township, and No. 25, south-east Machakos. The ground west of the Meru-Isiolo area was covered several years ago in Report No. 11 on the country between Nanyuki and Maralal, and the country to the south-east is described in forthcoming reports.

The southern part of the Meru-Isiolo area, with the north-eastern flanks of Mt. Kenya, the attractive township of Meru, and the fine chain of volcanic hills that forms the Nyambeni range, is one of the most pleasing districts in Kenya from the point of view of scenery. It seems, however, to have little to recommend it in connexion with valuable minerals. Apart from their value in restraining the run-off of rainwaters, and the provision of a few inferior building stones, the volcanic rocks appear unlikely to have any economic value, though it is possible that detailed search might reveal the presence of bleaching and fulling clays. On the other hand the volcanic rocks conceal beyond reach a large tract of ancient rocks that might well contain mineral deposits. The remnants of the old rocks that protrude from the lavas are, however, devoid of any suggestion of such occurrences.

Mr. Mason gives a preliminary account of the lavas of the volcanic succession. His work has shown that though the older and lower lavas on the Nyambeni hills are of calc-alkaline type, as is usual with Pleistocene basic lavas in Kenya, the lavas that form the younger upper part of the range are more alkaline in their affinities, and represent a reversion to the type of volcanic rocks that were so extensively poured out in middle Tertiary time. Reversion is not unknown in other parts of Kenya, but usually the latest more alkaline lavas are rhyolitic or trachytic in character rather than basaltic or felspathoidal.

Nairobi,

24th June, 1953.

WILLIAM PULFREY,

Chief Geologist.

CONTENTS

	PAGE
Abstract	
I—Introduction and General Information	1
II—Physiography—	
1. General	3
2. Drainage	5
III—Geological Succession, Correlation and Summary of Geology—	6
IV—Petrology and Petrography	10
1. Basement System	10
2. Post-Archæan rocks	15
V—Metamorphism and Granitization	20
VI—Structure	21
VII—Economic Geology	24
1. General	24
2. Building-stone	24
3. Water-supply	24
VIII—References	25

ILLUSTRATIONS

Fig. 1.—Physiographic sketch map	3
Fig. 2.—Distribution of Recent volcanic craters and vents	9
Fig. 3.—Structural map of the area	21
Fig. 4.—Geological cross-sections to illustrate the structural axis in the Basement System rocks near to Isiolo	22

MAP

Geological map of the Isiolo-Meru area (Degree sheet 36 S.E.): Scale 1:125,000 .. At end

ABSTRACT

The area described in this report is situated north-east of Mt. Kenya, being bounded by the Equator and 0° 30' N. latitude and by longitudes 37° 30' E. and 38° 00' E. It is approximately 1,225 square miles in extent.

Five major physiographical divisions are recognisable: (1) the lower north-eastern flanks of the Mt. Kenya volcanic pile; (2) the north-east to south-west Nyambeni volcanic range and its associated Basement System inliers on the south; (3) the up-standing monadnocks of Pre-cambrian rocks on the north-western boundary; (4) the prominent Basement System inlier of Mbokoro and (5) the Nyambeni lowlands, consisting of the lower and terminal lavas of both the Mt. Kenya and Nyambeni volcanic episodes, and surrounding the preceding divisions.

The exposed rocks in the area may be divided into two broad groups: (1) the variably banded and metasomatized psammitic and pelitic gneisses, with associated granitoid gneisses and pegmatitic veins and bands, which comprise the Basement System, and (2) the comparatively young series of eruptive rocks of the Mt. Kenya and Nyambeni volcanic episodes, consisting essentially of basaltic and phonolitic rocks, which it is believed were extruded during great crustal movements associated with the formation of the Rift Valley.

GEOLOGY OF THE MERU-ISIOLO AREA

I—INTRODUCTION AND GENERAL INFORMATION

The Meru-Isiolo area as defined for this report is the south-eastern quarter of Degree Sheet 36 (Kenya) and is bounded by the parallels 0° and $0^{\circ} 30' N.$ and by longitudes $37^{\circ} 30'$ and $38^{\circ} E.$ It covers approximately 1,225 square miles. About three-quarters of the area consists of the Meru native reserve, whilst the greater portion of the remainder forms part of the Northern Province. A small area of the Mt. Kenya forest reserve occupies the south-west corner, extending north-eastward from the higher slopes of the mountain down into the lowlands.

The primary reason for the geological mapping of the area was the supposed occurrence of a granitic intrusion on the southern slopes of the Nyambeni range, as had been indicated on the geological map of Kenya published in 1942. The presence of a granitic intrusion suggests the possibility of the occurrence of valuable minerals. A reconnaissance survey of the area was therefore undertaken between December, 1950, and April, 1951, in order to ascertain whether or not more detailed work and prospecting would be advisable. Examination of the supposed intrusion proved that it is an inlier of quartzo-felspathic biotite gneisses and granitoid gneisses of Precambrian age, surrounded by much more recent lavas and thick brown soils. The full extent of the inlier could not be determined in the time available owing to the thick forest which covers that part of the area.

Maps.—The topography of the geological map is based on the Meru Sheet (East Africa, zone H, E.A.F. No. 1617, scale 1:125,000) printed in 1944. The map was found to be very accurate, two-thirds of it having been compiled from aerial photographs and the remaining third by plane-table survey. Consequently little alteration was necessary, although many local native names have been added to previously unnamed topographical features.

The mapping of the geology was done mainly by means of the plane-table, although aerial photographs were of great assistance. Cyclometer traverses were occasionally necessary. The boundary of the Mt. Kenya forest reserve was mapped from aerial photographs.

Population.—A mixed and varied population is found in the area, the Meru being by far the most numerous although other tribes are represented. At Isiolo and north of the reserve a mixed population of de-tribalized Turkana, nomadic Borana and Somali are present, while to the south of the reserve are found the people of Tharaka, considered to be intermixed Meru, Embu and Kamba.

Rainfall.—The following table illustrates the distribution of the rainfall. The distribution is directly controlled by the prevailing south-easterly winds, the highest figure being recorded on the eastern and south-eastern side of the Nyambeni range, with a decrease in quantity to the north and north-west. At Meru the rainfall is still high due to high elevation. North and north-west of the Nyambeni range the quantity decreases gradually to 20 in. per year, this being the annual record at Isiolo. There are no figures available for the lowlands east of the Nyambeni range but it is probable that they receive less than 20 in. of rainfall per annum.

RAINFALL IN THE MERU-ISIOLO DISTRICT

Station	Annual total for 1950 inches	Average total inches	No. of rainy days in 1950	No. of years recorded
Beresford Memorial Hospital, Maua ..	88.88*	90.37	100 plus	19
Kivieni	69.17	67.50	80	13
D.C. Meru Township	64.04	51.82	114	37
Methodist Missionary Society, Meru ..	69.53	48.51	134	19
Forest Station, Kenya Forest Reserve ..	56.51	—	101	1
Miatheni	62.50	55.61	93	10
Lava	43.54	—	59	1
Oringo Farm Kanjai	44.80	36.73	54	9
Muthara	29.70	28.40	71	2
Isiolo	19.09	21.39	62	20

*1947, latest recorded data.

Vegetation and Agriculture.—Dense, impenetrable forests are mainly confined to the higher altitudes of approximately 5,500 ft. and above. Below the forests and extending down to about 3,500 ft. the land supports a dense native population subsisting, in the higher and wetter areas, on the cultivation of banana, beans and potatoes, while with decreasing altitude, and consequently less rainfall, maize and millet gradually become the dominant crops. Soil erosion is advanced generally throughout the area, due mainly to grazing malpractice, although this problem is being energetically tackled by the Department of Agriculture. Below 3,500 ft. the rainfall is too small for intensive cultivation and the natives depend almost entirely on animal husbandry. Pasture, where present, is very poor and sparse, while the natural vegetation consists of short, stunted, thorny scrub bush and coarse grass.

Communications.—As the map indicates, the area is comparatively well supplied with roads and tracks, although in the Nyambeni range they are in a rather poor state of repair. Roads are scarce across the lowlands and consequently much of the country is accessible only on foot. The forests are thick and difficult to penetrate and even along the forest tracks no exposures were found, due to a thick cover of soil and humus.

Rock Exposures.—Exposures to enable the accurate mapping of geological boundaries are, on the whole, poor throughout the area. In the Nyambeni Hills the boundaries of the Basement System rocks and the later extrusives, and the junction of the various types of eruptive rocks of the upper Nyambeni Volcanic Series, are obscured and hidden by the natural vegetation, by native cultivation and by thick cover of soil and volcanic dust. At lower levels the contact between the Archæan rocks and later volcanic rocks is obscured by recent sandy deposits, derived from the Basement System inliers, and black cotton soil.

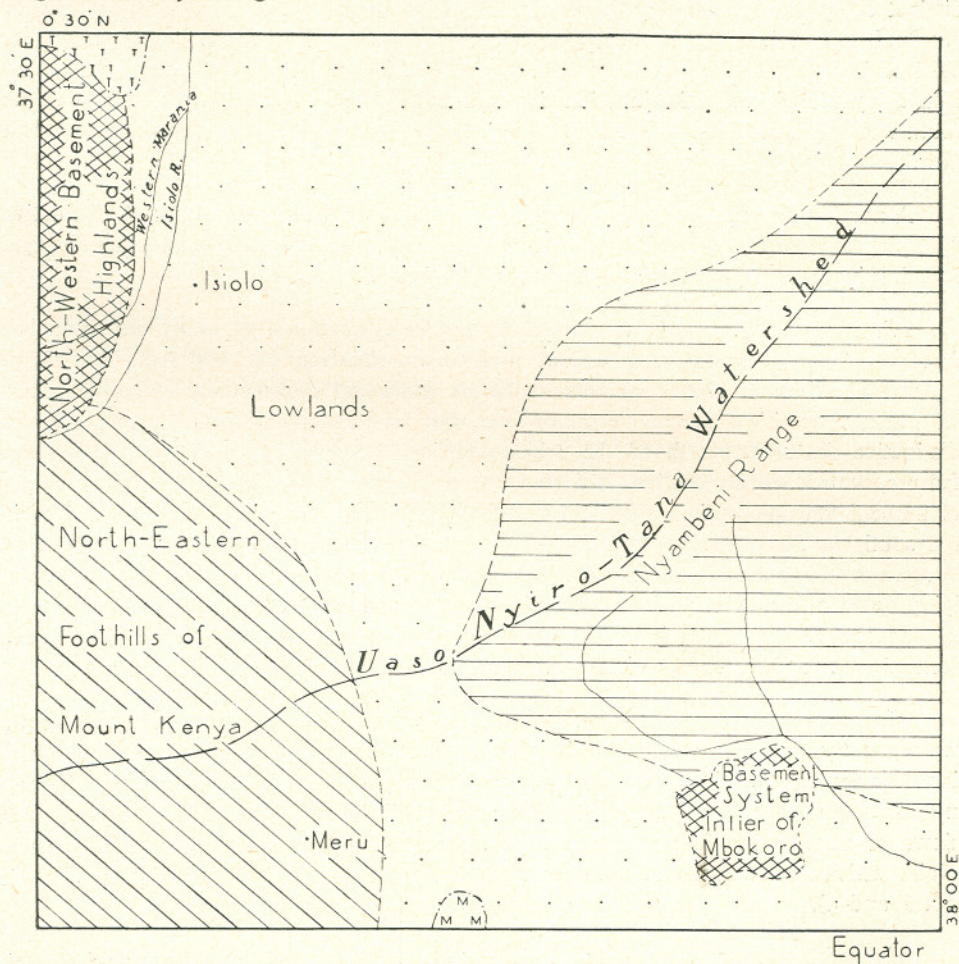
Previous Geological Work.—Few reports of previous geological work in this area have been found. In 1914 Parkinson passed through the area en route to the Northern Frontier District (Parkinson, 1920*) and in his report described a gneiss inlier 11 miles north-east of Meru (op. cit. p. 24; the hill mentioned is now known as Gwathini, not Oringo). Parkinson also noted the basalts in the vicinity of Isiolo. In 1930 the results of a general soil survey were published by D. S. Gracie (1930, p. 47), and in 1936 G. Milne produced a memoir and provisional soil map of East Africa compiled from records.

*References are given on p. 25.

II—PHYSIOGRAPHY

1. General

Physiographically five distinct units may be distinguished in the area: (1) the north-eastern slopes of Mt. Kenya, (2) the Nyambeni range, (3) the north-western Basement System monadnocks, (4) the Basement System inlier of Mbokoro, and (5) the Lowlands. These features, which are closely related to the rock formations, are shown diagrammatically in Fig. 1.



Areas where the end-Tertiary peneplain is recognisable



Areas where the sub-Miocene peneplain is recognisable

Scale

0 5 10 15 Miles

Fig. 1.—Physiographical sketch map of the Meru-Isiolo area.

Mt. Kenya.—The south-western part of the district lies at the foot of Mt. Kenya, a relatively recent though highly denuded volcano, whose summit elevation is 17,040 feet. The present area covers the lower north-eastern part of the mountain, extending from 4,500 ft. to 9,000 ft. in height, and since the flanks of the volcano have a comparatively flat profile the slopes are generally smooth. Some two miles east of the Meru-Embu road the terminal lavas of the upper Mt. Kenya basalt series form a distinct scarp-like feature approximately 400 ft. in height which, due to a number of youthful mountain streams cutting deep gorges through it, has developed a serrate outline. This feature becomes less distinct northwards until it finally peters out as the Kenya-Nyambeni volcanic junction is approached near Kovondi. In the extreme south-west another steep and distinct scarp is formed by the termination of a basalt flow.

A number of small parasitic cones, younger than the main volcano, form distinctive "pimples" on the lower foothills of Mt. Kenya. Examples of these features are Goriga, Matei, Kianondu, Njorivola, Kanyomba and Kathumbi.

The Nyambeni volcanic range is elongated in a north-east to south-west direction from the foothills of Mt. Kenya and rises to an elevation of 7,000 feet. The range consists of an accumulation of basic, alkaline basic and intermediate extrusive rocks, with many parasitic cones and vents of later date on the flanks forming prominent and distinctive features. North of the trigonometrical point of Mjogwe, a gentle scarp feature, with a serrate outline, is formed by the terminal alkaline lavas of the Upper Nyambeni volcanic series. This feature varies in height from a few hundred feet in the south to 50 ft. or so to the north, in which direction it gradually disappears. Erosion of the extrusive rocks in the south-east and south-west has uncovered underlying quartzo-felspathic gneisses of the Basement System, while on the southern flanks of the range, between Kithanga and Jeme, a marked scarp-like feature has been formed, due to the greater resistance to weathering of the metamorphic rocks.

The Basement System monadnocks of Lengishu and Lolmotoni, in the north-west, are the southern-most extensions of a discontinuous zone of mountains, which includes the Ngurie hills, Uaraguess and the Matthews range and trends approximately north-south (Shackleton, 1946, p. 2). The gneiss hills near to Isiolo have been eroded down to about 5,700 ft. and thus are somewhat lower than the end-Cretaceous peneplain, which lies at approximately 7,000 ft. to 7,500 ft. in the Matthews range (op. cit. pp. 2 and 4).

Six miles south-east of Mikanduri lies the *Mbokoro inlier* of quartzo-felspathic gneisses, rising over 2,000 ft. above the surrounding lava- and float-covered lowlands. This hill, together with the Basement System inliers to the immediate north, are in all probability relics of another discontinuous zone of hills, trending approximately in a north-south direction and including the small inlier on the Garba Tula-Isiolo road, and the hill Shaba a further nine miles to the north. This zone probably extends southwards to include the Mumoni hills and the Mtungani hills near to Kitui. The summit level of all these hills is approximately the same, being close to 5,000 ft., which is rather lower than the height recorded for Lolmotoni and Lengishu to the north-west of Isiolo. It is probable that the tops of the hills of the eastern zone are also relics of the end-Cretaceous peneplain.

The *Lowland areas* are either lava- or float-covered, with the lower Nyambeni basalts extending over a far greater area than the Mt. Kenya volcanics. In the northern part of the district the sub-Miocene erosion bevel is not visible owing to the fact that the comparatively thin terminal lavas of Mt. Kenya are unconformably overlain by the younger Nyambeni extrusive rocks, so that any evidence of the sub-volcanic topography is effectively concealed. On the southern margin of the area, immediately west of Kiliamamwakiameru, the sub-Miocene peneplain is recognizable at 4,000 ft., this being some 500 ft. lower than the level described west of the Matthews range (Shackleton, 1946, p. 2). With the exception of a small area on the northern boundary, no evidence of the end-Tertiary peneplain is visible as that surface is covered by the Nyambeni basalts which flowed over it, and which can be seen resting upon it elsewhere (Schoeman, 1951, p. 4; Dixey, 1948, Fig. 1, opp. p. 18; Shackleton, 1946, Fig. 2, opp. p. 2).

2. Drainage

The drainage pattern is essentially determined by three major factors: (1) the north-eastern slopes of Mt. Kenya, (2) the north-east to south-west watershed of the Nyambeni range, and (3) the structures in the Basement System.

A typically radial drainage pattern has developed on the slopes of Mt. Kenya. The rivers and streams have by no means reached maturity and therefore down-cutting of their courses strongly predominates over lateral erosion, resulting in steep-sided and comparatively deep valleys in the upper reaches. The streams and rivers from the eastern slopes of the mountain flow towards the Tana River, which is the recipient of all the drainage from eastern Mt. Kenya and the southern flanks of the Nyambeni range. As the Tana is approached the stream profiles gradually flatten. The drainage from the northern slopes of Mt. Kenya flows away northwards towards the Uaso Nyiro.

Streams and rivers flowing from the Nyambeni watershed have a general north-west to south-east trend, flowing essentially at right angles to the elongation of the range. As might be expected from the distribution of the rainfall more rivers, and rivers of greater volume, flow south-east to the Tana River. On the north-western flanks the streams are intermittent and seldom extend far across the lowlands. The valleys and gullies on this flank are often sheer and deep, for during wet seasons torrents gush down them and erosion is extreme.

The drainage of the Basement System areas is generally controlled by dip joints and by the strike of the rocks. The phenomenon of streams flowing at right-angles to the strike on Basement System rocks is again commonly found as in the Embu-Meru area (Schoeman, 1951, p. 5). North-west of Isiolo, streams developed along dip joints have eroded headwards and captured strike streams flowing northwards in the direction of the pitch of an anticline, forming pronounced "elbows of capture". The main river in this district, the Isiolo, flows northwards along the foot of the Basement System hills.

The drainage of Mbokoro is essentially radial, although there is a tendency for streams to follow the dip and strike directions.

III—GEOLOGICAL SUCCESSION, CORRELATION AND SUMMARY OF GEOLOGY

The rock succession, major geological events and correlation with adjacent areas are shown in the following table:—

Chronology	Rift Faulting (Kent, 1944)	Maralal-Nanyuki (Shackleton, 1946)	Meru-Isiolo	Embu-Meru (Schoeman, 1951)	Earth movements and erosional phases
RECENT		Black cotton soil and kunkar Lateritic ironstone	Black cotton soil and kunkar Silts and gravels Nyambeni parasitic volcanic activity	Soils, laterites and calcretes	
U.	R	Gravels, lateritic earth and clay	Upper Nyambeni lavas	River gravels and sands Gravel beds Parasitic cones of Mt. Kenya	
PLEISTOCENE .. M.		Parasitic cones Laikipian basalts	Lower Nyambeni basalts Lake beds	Lower Nyambeni basalts	(disturbance)
L.					
PLIOCENE			Mount Kenya Volcanic Series	Mount Kenya Vol- canic Series	End-Tertiary pene- planation
U.		Mt. Kenya Volcanic Series	2. Upper olivine basalts 1. Lower basalts		
MIOCENE .. M.	R	Phonolites Basalts Sediments			(disturbance)
L.					
EARLY TERTIARY ..					Sub-Miocene pene- plain (disturbance)
MESOZOIC					End-cretaceous pene- plain
ARCHÆAN		Basement System	Basement System	Basement System	

R=Major Rift faulting

The rocks of the area fall into two natural and distinct sub-divisions: (a) the Archæan or Basement System rocks and (b) the comparatively young Tertiary, Pleistocene and Recent extrusive rocks and subordinate sediments.

1. The Basement System

The Basement System forms the floor upon which all the remaining rocks of the area rest, and consists of schists, granulites and heterogeneous gneisses of varying composition, such as are widely distributed throughout East Africa.

Although the ancient Archæan rocks of Kenya have been metamorphosed to varying degrees by regional metamorphism and granitization, so that in many cases their original identity is difficult to decipher, it is generally accepted that they are paragneisses, that is, they were originally laid down as sedimentary deposits. In the area covered by this report the rocks of the Basement System are monotonous, consisting essentially of quartzo-felspathic gneisses containing varying proportions of biotite. It is considered that they were laid down as essentially arenaceous deposits with occasional layers of more argillaceous material, which would account for the present variation of biotite content. Since the individual bands of gneisses, granulites and schists are comparatively thin and cannot be distinguished on the present scale of mapping, the Basement System rocks have been mapped as an undifferentiated series.

After the formation of the sedimentary succession powerful crustal movements commenced, producing uptilting, great contortion and intense folding of the strata. Under the influence of these powerful disturbances, and with the addition of heat, and of alkaline granitizing fluids from the earth's interior, many of the sediments were metamorphosed into permeation gneisses and granitoid gneisses. Some of the rocks have been so heavily metasomatized and metamorphosed as not only to approach granite mineralogically, but also texturally. The rocks are frequently intensely veined by stringers of quartz and feldspar, while some layers and lenses are typically pegmatitic in texture.

There is no evidence of the geological evolution of the area between the period of metamorphism of the Basement System and sometime during the late Palæozoic or Mesozoic eras. At that time long-continued erosion set in, culminating in the formation of the end-Cretaceous peneplain, of which the Basement System inliers near Isiolo and Mikinduri are assumed to be relics. Subsequent crustal movements caused an arching up of the Central African region and more active erosion commenced again, reducing much of the high-level peneplain and leading to the maturation of a younger peneplain, the sub-Miocene, which has been identified at approximately 4,000 ft. south-east of Meru.

2. Tertiary to Recent Volcanic Activity, Erosion and Deposition

(1) THE MT. KENYA VOLCANIC SERIES

The Mt. Kenya volcanic rocks are confined to the south-western portion of the present area and only part of the sequence known elsewhere is found. Further north nearer Meru the partial succession reads:—

3. Basalts, tuffs and ashes of parasitic vents.
2. Upper olivine basalts.
1. Lower basalts, with kenyte and tuff.

The lowermost plains are basalt and olivine basalt and rest on the sub-Miocene bevel. Intercalated in this lower division near Mporiene, south-east of Meru, is a thin band of highly weathered and densely porphyritic kenyte, which indicates a minor alkaline phase. The entire division is thin, being not more than 500 ft. in thickness.

The upper olivine basalts overlie the lower basalts west of the meridian passing through Kienduri, and extend to the western boundary of the area. They appear to be much thicker than the lower basalts, but owing to the fact that they probably overlie kenytes and phonolites, which reach a thickness of 3,000 ft., further south, it would be unwise to estimate their thickness.

Many distinct features are formed on the lower north-eastern foothills of Mt. Kenya by the lavas and ashes of parasitic vents and craters. It is probable that some of the vents were contemporaneous with the eruption of the Upper basalts, but judging from the fresh and comparatively uneroded condition of many of the craters, for example Matei, Njonivola, Kinyenjeli and Nkonga, sporadic vulcanicity appears to have continued until quite recent times (cf. Schoeman, 1951, p. 7).

There is no evidence in the present area for the precise dating of the Mt. Kenya Volcanic Suite. Since, however, the lower basalts rest on the sub-Miocene bevel south-east of Meru they were presumably erupted in Miocene or later times. The second episode of major faulting of the Rift Valley is considered by Kent to have occurred in the Upper Miocene, and it seems probable that such vast outpourings of lava as come from the Mt. Kenya vent would be closely associated with this major crustal disturbance. Kent points out from stratigraphical evidence that "rift faulting has repeatedly terminated periods of extrusion" and cites examples from near Nairobi, and in Kavirondo, Turkana and Tanganyika (Kent, 1944, pp. 24-26). It is not definitely known whether the major eruption of Mt. Kenya ceased before the actual rifting or continued during the disturbance, but it is probable that spasmodic and occasional outbursts of vulcanicity on the slopes of Mt. Kenya continued after the rifting into Pliocene and even Pleistocene times.

Uplift and erosion subsequent to the main Mt. Kenya vulcanicity is evidenced by the end-Tertiary peneplain, which is present on the northern boundary of the area immediately east of the Basement System hills. Its level is about 3,200 ft., being several hundred feet below the sub-Miocene peneplain.

(2) THE NYAMBENI VOLCANIC SERIES

This series of eruptive rocks is sub-divided into three divisions:—

3. Basalts, phonolites, tuffs and ashes of parasitic vents.
2. Upper Nyambeni lavas.
1. Lower Nyambeni lavas.

The Lower Nyambeni basalts are porphyritic and often markedly vesicular, olivine-bearing types and, being very fluid and mobile at the time of eruption, spread out widely over the comparatively flat surface of the end-Tertiary peneplain, extending north, south and east of the boundaries of the present area. The lower terminal flows of basalt were thin, being no more than a hundred feet or so in thickness, but as the Nyambeni range is approached the number of individual flows increases and the total thickness of the division is approximately 1,000 feet. The boundary between the Mt. Kenya basalts and the lower Nyambeni basalts is difficult to map. Only two exposures were found showing a definite junction between the two sets of volcanic rocks, these being on the Meru-Kanjai road and in the Kazita River section. Consequently the mapped boundary is largely inferential, being based mainly on topography.

The various flows of the Upper Nyambeni volcanic rocks show an appreciable variation in composition and texture for, in addition to basalts and porphyritic olivine basalts, there are phonolites, porphyritic phonolites and tephrites present. These rocks build the Nyambeni range proper and extend in a south-west to north-east direction across the area. It was not possible to map individual flows or rock types, but it is interesting to note that there is a greater variation in topography and altitude between the less fluid intermediate volcanic rocks of this upper division than is found with the older and more fluid lower basalts, which spread evenly over a wide area. The boundary mapped between the upper and lower Nyambeni volcanic rocks is based on topographical considerations, for the lavas of the younger division rest on, and rise sharply from, the comparatively flat and smooth profile of the lower Nyambeni basalts. The extrusions of lava flowed over and covered Basement System monadnocks on the southern flank of the range, which have since been re-exposed by erosion and now protrude as inliers through a covering of soil and dust. In the south it appears that the lava

flows banked up against the northern side of Mbokoro and flowed around to the east and west of the inlier. Despite erosion of the main central vents a thickness of 2,500 ft. of upper Nyambeni volcanics remain, giving a total thickness of 3,500 ft. of lava for the Nyambeni episode.

With regard to the dating of the Nyambeni lavas the lower basalts are doubtless to be correlated with the Laikipian basalts of lower Pleistocene age, covering the end-Tertiary peneplain further west in the Nanyuki-Rumuruti district (Shackleton, 1946, p. 5). The later phase of volcanicity, resulting in the outpouring of the vast quantity of upper Nyambeni lavas, may have been closely related to a major crustal disturbance, such as the third and final major rifting of the Rift Valley of Middle to Upper Pleistocene age (Kent, 1944, p. 24).

Vulcanicity in the Nyambeni district continued longest towards the north-east as is evidenced by the rapid increase in the number of vents and recognizable craters in that direction. At the same time other parasitic vents and craters on the flanks of the range were active, and in all probability vents on the lower slopes of Mt. Kenya also extruded comparatively small volumes of lava and pyroclastic rocks. Many of the craters are composed of ash, or ash and lava, and a long period of erosion would have obliterated them or destroyed their form. The small amount of erosion suffered by many of them indicates their very young age. Most of the parasitic vents and craters tend to be grouped in a south-west to north-east zone (Fig. 2).



Fig. 2.—The distribution of recent volcanic craters and vents in the Meru-Isiolo area.

IV—PETROLOGY AND PETROGRAPHY

1. Basement System

The Basement System rock types found during the present survey are few when compared with those mapped in surrounding areas. They are all widely represented in other districts and the majority of them have been described in detail in previous reports. Unfortunately previous authors have sometimes given different names to the same or closely similar types of Basement System rocks and this has led to misunderstanding and rather chaotic nomenclature.

In an endeavour to simplify this state of affairs the rocks of the present area have been classified in the hand-specimen and slight differences in essential mineralogical composition, obvious only during microscopic examination have been ignored.

The following groups are distinguished:—

- (1) Schists—
 - (a) quartz-muscovite schists;
 - (b) anthophyllite-talc schists;
 - (c) biotite schists.
- (2) Pelitic and semi-pelitic gneisses—
 - (a) plagioclase-hornblende gneisses;
 - (b) biotite gneisses;
 - (c) banded biotite gneisses.
- (3) Psammitic gneisses—
 - (a) biotite leuco-gneiss;
 - (b) quartzo-felspathic granulites.
- (4) Granitoid gneisses.
- (5) Pegmatites.

(1) SCHISTS

Schists are poorly represented in this area and where present they are thin and insignificant, being no more than a few feet in thickness lying between more massive bands of quartzo-felspathic gneisses. The schists show little or no evidence of having suffered granitization, there being little or no introduction of microcline or other alkaline minerals. They are easily weathered and this is probably the reason for the scarcity of outcrops, although it is possible that, since the structure of schists is so favourable for permeation by metasomatizing solutions, the original schists have now been converted into rocks of completely different mineral assemblages and appearance.

(a) Quartz-muscovite Schists

The best exposures of quartz-muscovite schists are found at the foot of Nandera, south-west of Kiagu, and again near the summit of the same hill. The schists are of medium to coarse grain with a well developed schistose structure. Biotite is seldom to be found in them.

Specimen 36/477, from the foot of Nandera, is a silvery-grey limonite-stained, schistose rock with small flakes of muscovite set in a granular base. A thin section of this specimen shows interpenetrating plates of feebly pleochroic muscovite in a base of anhedral grains of quartz and untwinned feldspar, some of the latter being somewhat decomposed. A few olive-green, rounded grains of tourmaline are present together with magnetite, as accessories. Specimen 36/468, from near the summit of Nandera, is similar, but in addition contains a little microcline and perthite. Another muscovite schist exposed near the summit of Nandera is represented by specimen

36/472. It is highly weathered and in thin section shows that small books of muscovite are cemented by limonite, the original quartz and felspar having been completely removed or replaced. The cleavage planes of the muscovite, along which limonite has penetrated, are often bent and distorted.

(b) *Anthophyllite-talc Schists*

These rocks are confined to one exposure, of small area, due west of Isiolo. The hand-specimen, 36/270, is light brownish-grey in colour and a finely asbestiform mineral is megascopically visible. In thin section the rock is seen to be highly altered, the asbestiform mineral, anthophyllite, being converted to an irregular mixture of talc and chlorite, while much fine granular quartz is found in the base. Small quartz veinlets and stringers ramify throughout the rock, many of them appearing to have been formed by injection rather than by replacement processes.

(c) *Biotite-schists*

Biotite schists again are poorly represented, occurring as small scattered lenses and sheets in the more massive gneisses. Specimen 36/301, from three miles west of Isiolo, shows in thin section a predominance of brownish-yellow, highly pleochroic biotite with about 20 per cent of quartz and acid plagioclase near to oligoclase in composition. Accessory apatite is present with a little secondary white mica.

(2) PELITIC AND SEMI-PELITIC GNEISSES

(a) *Plagioclase-hornblende Gneisses*

This class of gneiss is composed almost entirely of plagioclase and hornblende. Of these rocks (Schoeman, 1951, p. 10) says "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." He goes on to compare their composition with dioritic rocks and points out the possibility that some are meta-intrusives. All the specimens collected in the present area were obtained from bands of composite gneiss and, as no definite evidence indicating an intrusive nature was observed, it is considered that these plagioclase-hornblende gneisses represent original lime- and soda-rich argillaceous intercalations in the predominantly arenaceous sedimentary succession.

In the hand specimen they have a homogeneous texture and are in general medium-grained and gneissose with a crude foliation. Generally the coloured minerals are distributed evenly throughout, but occasionally, as in specimen 36/299, from two and a half miles west of Isiolo, some of the mafic minerals are segregated into clots.

A sufficiently detailed petrological description of this type of gneiss is given by Schoeman who found very similar rocks in the Embu district (1951, p. 10). Typical specimens from the present area are 36/219 from Kallamando, 36/512 from the slopes of Magamia, and 36/240 from west of Isiolo. The last specimen contains a higher percentage of potash felspar than the previous examples, in which the orthoclase or microcline content is low or nil. A slightly different type is represented by specimen 36/299 for, although biotite is present in the other examples, in this rock brownish-green biotite is more abundant than the rather dirty brown amphibole.

Specimen 36/262, from five miles north-east of Isiolo, is plagioclase-hornblende-garnet gneiss but since only one small exposure was seen it is included for convenience in this class. Green pleochroic hornblende is again the dominant mafic mineral, but is accompanied by appreciable garnet and light brown highly pleochroic biotite. Perthitic felspar and plagioclase are also present accompanying quartz, but the felsic mineral content is low, being about 15 per cent. Sphene is a common accessory, together with a little apatite and secondary white mica,

(b) Biotite Gneisses

Biotite gneisses are well developed, especially in the larger Basement inliers near to Isiolo and in the Mbokoro inlier. Every gradation may be seen in the field from biotitic quartzo-felspathic leucogneisses to these mesotype biotite gneisses. In the hand-specimen the rocks of this class are of medium to fine grain and, with the exception of occasional thin quartz veinlets (for example in specimen 36/303), of homogeneous composition. Rocks of similar appearance and composition have been described in previous reports (Shackleton, 1946, p. 10; Schoeman, 1951, p. 21 and Bear, 1952, p. 12).

The proportions of the essential component minerals, i.e. quartz, microcline, plagioclase and biotite, vary, sometimes appreciably, reflecting the varying composition of the original sediments and the varying degree of metasomatism by permeating alkaline fluids. Typical examples of these rocks are specimen 36/303, from four miles west of Isiolo; specimens 36/466 and 36/470 from the eastern slopes of Nandera; and specimen 36/576 from north-east of Magamia, the last being an example of the coarser-grained varieties. The following estimated volumetric compositions indicate the variable composition of the semi-pelitic biotite gneisses:—

		36/303	36/466
		%	%
Quartz		25	36
Microcline		20	10
Plagioclase		30	35
Myrmekite		4	3
Biotite		20	15
Accessaries		1	1

Rocks generally similar to the above but with a smaller biotite content were also found. They were originally sediments of a semi-pelitic nature and consequently do not carry so high a biotite content as those derived from more pelitic sediments. There is a correspondingly higher percentage of felsic minerals in them. A few accessaries are sometimes noticeable, the commonest being iron ore and apatite, with occasional sphene and secondary white mica.

Occasionally the biotite gneisses exhibit the effects of metamorphic diffusion in a manner already illustrated by Searle (1954, Fig. 2A) in connexion with rocks from the Masai-Sultan Hamud area. A similar phenomenon is seen in specimen 36/478, obtained from a small stream section three-quarters of a mile north of Nandera. In this specimen, however, instead of garnets as in the Masai rocks, small crystals of magnetite are surrounded by an aureole of quartzo-felspathic material, the remainder of the rock being rich in a brownish-green biotite.

(c) Banded Biotite Gneisses

For the purposes of this report the term "banded" is confined to rocks showing banding in the hand-specimen, the individual bands varying from fine to coarse, that is from about one-eighth of an inch across to two inches. They contain less biotite than the gneisses described previously, and are thought to have been derived from semi-pelitic sediments. Specimen 36/291, from west of Isiolo, is a fine-grained and finely banded biotite gneiss, in which the foliation planes are speckled with very small flakes of mica. Similar rocks have been described (Holmes, 1919, p. 54) from Mozambique having essentially the same mineral constituents, these being quartz, oligoclase, microcline, biotite, a little orthoclase (with secondary sericite) and a little primary muscovite. The banding is caused by the concentration of biotite flakes along definite horizons in the rock. Specimen 36/251, from the northern side of the Isiolo Gap, has coarser bands of approximately one inch thickness with the

same essential mineral composition as specimen 36/291. Further examples are 36/463, from the eastern slope of Nandera; 36/534, from east of Mikanduri; and 36/318 from south-west of Isiolo. Semi-pelitic gneisses of similar appearance and composition have been described by Shackleton from the country between Nanyuki and Maralal (1946, p. 10).

(3) PSAMMITIC GNEISSES

These rocks are the most common and widely distributed of all the types present in the Basement System of the area, and are of medium to fine grain with a very low colour index, the dominant ferromagnesian mineral being biotite. They are considered to have been derived from arenaceous deposits such as sandstones and arkoses. The outcrops are frequently well jointed with the joints corresponding to the dip and strike directions, the former direction being the most common.

Bear (1952, p. 17) points out that in the area south-east of Embu psammitic gneisses and granulites form the higher land. In the area covered by this report the Basement inliers consist, in the main, of psammitic gneisses and thus rocks of a pelitic and calcareous nature, as are found in areas to the south, are probably present beneath the covering of the Mt. Kenya and Nyambeni volcanics. Weathering of the psammitic rocks has given rise to the formation of massive crags, these being best developed north-west of Isiolo, on Kiega and on Mbokoro.

(a) *Biotite Leuco-gneisses*

In the hand-specimen the leuco-gneisses are of medium-grain and equigranular with a light-grey to light-brown colour. In some specimens the biotite flakes are aligned along bedding or foliation planes giving an indistinct gneissosity, while others have a more streaky and irregular texture. With decrease in biotite content these rocks grade to the quartzo-felspathic para-granulites, while with increase in biotite content there is a gradation to the semi-pelitic and pelitic biotite-gneisses.

Specimen 36/320, from the inlier south-west of Isiolo, is a whitish rock with a low colour index. In a thin section biotite makes up approximately six or seven per cent of the rock, the remainder consisting of microcline, an acid plagioclase near to oligoclase, and quartz with a little accessory iron ore. Specimen 36/298, from west of Isiolo, is a similar rock with the exception of having a smaller microcline content and a correspondingly higher percentage of acid plagioclase. In specimen 36/188 from the inlier near the Isiolo-Garba Tula road acid plagioclase greatly predominates over microcline, which is almost absent, while iron ore is more abundant than in previous examples.

Rocks having a similar appearance and composition have been called biotitic quartzo-felspathic gneiss by Bear (1952, p. 17) and the petrological description of these rocks together with the description of Shackleton's (1946, p. 11) *psammitic biotite gneiss* correspond very closely with the biotite leuco-gneisses of this report, so named since the rocks are both gneissose and leucocratic.

(b) *Quartz-felspar Para-granulites*

These rocks consist almost entirely of quartz and felspar, and indistinct partings suggest that they have been derived from sandstones and possibly arkoses. The colour of the granulites varies from whitish pink to light brown. Typically they are equigranular and fine-grained with a sugary texture, although coarser-grained varieties do occur. They are highly felspathic rocks with mafic minerals, either biotite or black iron ore, completely subordinate; the alkali-felspar content varies somewhat from specimen to specimen according to the degree of metasomatism to which the rocks have been subjected.

Typical examples are 36/450 and 36/445, from Mbokero; 36/275, from west of Isiolo, and 36/524, from Kithanga. Quartz-felspar para-granulites of similar type have been described from the Nanyuki-Maralal district (Shackleton, 1946, p. 11) and from south-east of Embu (Bear, 1952, p. 18).

(4) GRANITOID GNEISSES

The granitoid gneisses, found mainly to the east of Mikanduri in the Basement System inliers now being uncovered by erosion, are granitic in both texture and composition and can be compared closely with non-intrusive granites described from Makueni (Dodson, 1953, p. 12) and from the Embu district (Bear, 1952, p. 20). Owing to the limited development and exposure of such rocks they have not been distinguished on the map.

Shackleton (1946, p. 15) described granitoid gneisses from near Timau as being metamorphosed intrusive rocks, but in the present area no intrusive contacts were observed, although it must be admitted that good exposures are scarce. Since no intrusive contacts were seen and the predominating Basement System rocks in the area are of sedimentary origin the granitoid gneisses are also considered to be sediments, but sediments in which granitization has proceeded almost to completion. In areas to the south, Bear and Schoeman have found it possible to trace gradations from schists to gneisses, granitoid gneisses and to intrusive granites, but in the present area scarcity of outcrops prevented such a gradation from being observed.

Evidence of foliation has almost disappeared in these rocks; for example, in specimen 36/564 from two and a half miles north-east of Magamia, the foliation planes are extremely faint and almost indistinguishable. The rock is greyish and granitic in appearance, being coarse-grained and equigranular. In thin section the felsic minerals are seen to be quartz, microcline, acid plagioclase and myrmekite, the mafic components being a brownish-green biotite with a little dirty-green hornblende. Accessory minerals present are sphene and iron ore. Specimen 36/565, from a nearby locality, contains more green hornblende than biotite. Specimen 36/585, from one and a half miles east of Magamia, has a lower percentage of microcline with a correspondingly higher proportion of acid plagioclase. The ferromagnesian minerals in this specimen are biotite and hornblende in approximately equal proportions. Specimen 36/305, from the eastern slope of Lolmotoni, is not quite so granite-like in texture as the previous specimens, although it may be grouped with this class.

(5) PEGMATITES AND APLITES

Pegmatitic veins are abundant in the Basement System rocks. They sometimes have a discordant relationship to the bedding, sometimes a concordant relationship, and elsewhere are present as anastomosing vein systems. They vary greatly in size, the smaller veins being as thin as a quarter of an inch, while the larger veins range up to several feet in thickness.

Most of the smaller bodies appear to have been formed by replacement or by segregation. The segregational type is illustrated by specimen 36/261, from the southern side of the Isiolo Gap, which consists of an aggregate of microcline-micropertthite, acid plagioclase, quartz and a little white mica. The replacive type is represented by the rock from which specimen 36/293 was obtained west of Isiolo. It consists of microcline-micropertthite, acid plagioclase and quartz, and is seen replacing biotite gneiss. Searle (1954, Fig. 2d) illustrates a similar vein from an exposure in the Selengai River in the Masai-Sultan Hamud area. A little white mica accompanies the felsic constituents in some cases, as in specimen 36/513 from the south-eastern slopes of Magamia.

A large number of the pegmatites have a cross-cutting relationship to the bedding, indicating that they must have succeeded granitization, or at least marked the final phase of that process. Specimen 36/177 from such a vein in the Basement System inlier of Buloi is a coarse pegmatite, consisting of allotriomorphic grains of microcline-micropertthite, orthoclase, quartz and biotite. The vein was clearly injected into biotite leuco-gneiss and biotite gneiss. Specimen 36/260 from four miles north-west of Isiolo is a much coarser-grained variety.

The ratio of quartz to felspar in the different veins varies appreciably. A gradation is seen from pegmatitic veins consisting almost entirely of felspar through veins with these minerals in approximately equal proportions to veins consisting almost entirely of quartz. In the rocks examined, white mica and biotite are the commonest coloured minerals, while iron ore is occasionally developed. The absence of typical pegmatite minerals, such as tourmaline, indicates that the pegmatite-forming fluids were devoid of hyperfusibles.

Aplites are not so common as pegmatites. Most of the thin, irregular anastomosing veins, which often accompany pegmatites, are usually of an aplitic nature. They show, as do the pegmatites, variable ratios of felsic constituents.

2. Post-Archæan

(1) THE MOUNT KENYA VOLCANIC SERIES

The Mt. Kenya volcanic rocks are more widely developed in the Embu-Meru area south of the present area, where a full succession has been recognized (Schoeman, 1951, p. 8). The rocks in the Meru district are almost identical, both in the hand-specimen and in thin section, with those described by Schoeman (1951, pp. 46-49). The thin kenyte intercalation (specimens 36/730, 36/732 and 36/623, from five miles south-east of Meru) in the lower basalt division is much weathered, but is similar to the kenytes described by Schoeman (op. cit., p. 46) from their major development.

(2) THE NYAMBENI VOLCANIC SERIES

(a) *The Lower Nyambeni Basalts*

Although the lower Nyambeni basalts have a wide distribution, their composition and textures are remarkably consistent over the whole area. A comprehensive petrographical description of them has been given by Schoeman (1951, p. 49).

(b) *The Upper Nyambeni Volcanic Rocks*

(i) *Basalts*.—The basalts are similar in composition and texture over the whole area. In the hand-specimen they are usually porphyritic with phenocrysts, varying in size, of black augite, greenish olivine and occasional white plagioclase in a blackish grey aphanitic base. Phenocrysts commonly make up to 20 per cent of the rocks, although in a few specimens up to 40 per cent consists of phenocrysts. The texture of the groundmass is intergranular with a semi-fluxional orientation of plagioclase microlites frequently developed. The phenocrysts of ferromagnesian minerals are usually euhedral, although they are often resorbed to varying degrees by the groundmass. The phenocrysts most commonly consist of olivine, which often exhibits secondary changes, as is evidenced by borders of iddingsite and the conversion of this latter mineral to ferruginous hydrates. Entirely fresh olivine is seldom seen. Mega- and micro-phenocrysts of pale augite usually accompany the olivine, although in a few specimens it is the predominant ferro-magnesian mineral. The augite is

usually pale green-brown in colour and frequently exhibits zoning, while some crystals show secondary changes to chlorite. Microphenocrysts of plagioclase are also found in some specimens. The groundmass, the intergranular texture of which is characteristic, consists of felted microlites of plagioclase with granular pyroxene, magnetite and occasionally olivine. Finely granular iron ore invariably makes up a considerable portion of the groundmass. Most of the lava-flows are characterized by intense vesiculation, the vesicles usually being completely irregular in shape and varying appreciably in size. Vesicle infillings, although by no means common, consist usually of carbonates, with occasionally infillings of zeolites and limonite. Specimen 36/409, collected from one mile west of Lare, is a finely vesicular, microporphyrritic olivine basalt. In thin section phenocrysts of olivine and pale brown augite are seen in a fine-grained groundmass consisting of granular pyroxene, magnetite and small lath-shaped plagioclases. The plagioclase laths in the groundmass of specimen 36/352, from three-quarters of a mile south of Kanune, are a little larger than in the previous specimen, and the microphenocrysts are of pale green augite and olivine, altering marginally to iddingsite. A slide of specimen 36/426, a highly but finely vesicular porphyritic olivine-basalt from a road section one mile east of Lumeria, shows phenocrysts of augite and olivine of two generations, with augite the predominant ferromagnesian mineral. The augite is pale green in colour and frequently exhibits zoning. The olivine, as is common in these rocks, has an alteration border of reddish iron hydrate.

(ii) *Phonolites*.—Specimens of phonolite were collected from widely separated localities. There is, however, a concentration of such intermediate lavas on the southern flank of the range, in the vicinity of Maua, to the east of the range and on the north-east slopes near Lumeria, where there is a parasitic vent. A light yellowish-brown weathered surface is a diagnostic feature of exposures of these alkaline rocks in the field. In the hand-specimen the phonolites are greenish-grey to blackish-grey in colour, though some of the specimens are brownish in colour and are rather fissile and brittle. Some of the specimens are macroporphyritic, when small, greasy-looking, "square" sections of nepheline and prismatic sections of felspar can be seen set in a fine-grained aphanitic base. Phenocrysts sometimes make up about 50 per cent of the rocks, although usually they constitute about 20 per cent or less. Vesiculation of the flows is not seen.

Nepheline is often found in well-formed phenocrysts showing typical "square" and hexagonal cross-sections. Specimens 36/377 from east of Kanune, and specimen 36/563 from the southern flank of the range show two generations of nepheline. The first generation is present as macrophenocrysts, while the second consists of small microphenocrysts, both being set in a cryptocrystalline groundmass. The predominant coloured mineral is green ægirine-augite, which is present in the form of microlites. A little dendritic cossyrite is present. The extremely fine-grained groundmass consists of felspar microlites which, from refractive index determinations, is considered to be orthoclase. In specimens 36/555, from the Katchula River; 36/556, from the Wandu stream; and 36/561, from the Thangather River, the ægirine-augite is in the form of trichites rather than microlites. Dendritic cossyrite accompanies the sodic pyroxene, while nepheline again forms megaphenocrysts and micro-phenocrysts, these being embedded in a cryptocrystalline groundmass of potash-felspar, interstitial nepheline and a little analcite. Thin sections of specimens 36/427 and 36/428, from the south-western slope of the parasitic vent of Logua, and 36/441 from Mjowge, show ægirine-augite present as microlites, trichites and irregular shreds. The microlites tend to be concentrated in small aggregates. In specimen 36/441 the microlites of ægirine-augite show a definite alignment although the preferred orientation is not reflected by the irregular trichites and shreds. The sodic amphibole cossyrite again accompanies the pyroxene. Specimens 36/552 and 36/559, from the southern flanks of the Nyambeni range, exhibit the ægirine-augite in still another habit. In these rocks it is granular, being

fine-grained in the former example but much more coarse in the latter. Specimens 36/559 and 36/561, which was mentioned above, illustrate the textural differences that are sometimes found in rocks collected from the same flow. Specimen 36/425 from 3 miles south-west of Kanjai contains approximately 40 per cent of nepheline in the form of microphenocrysts, showing perfect "square" and hexagonal sections. The coloured mineral is ægirine-augite, which, with a little iron ore is embedded in a much coarser groundmass consisting of orthoclase microlites and interstitial nepheline and analcite. Specimen 36/347, from 2 miles west of Maua, is a similar rock.

The above phonolites may be referred to the *Kenya type* (Campbell Smith, 1931, p. 230). Phonolites approaching the *Losuguta type* (op. cit. p. 236) are represented by specimens 36/421 and 36/422, from two miles south of Kangeta, though biotite was not observed in them. They are a drab greenish-black in colour, and contain phenocrysts of both nepheline and felspar set in a crypto-crystalline groundmass. Specimen 36/548, from east of Mikanduri does contain a few flakes of biotite showing resorption phenomena with the groundmass. A large crystal of iron ore has developed from an ægirine-augite crystal, around which there is an aureole devoid of pyroxene. Interstitial nepheline and analcite are present in the fine-grained groundmass. Specimen 36/554, collected from a neighbouring locality, contains no biotite but has irregular segregation of its orthoclase laths.

(iii) *Tephrites*.—The tephrites are closely associated with phonolites in the field and therefore are more common on the southern and eastern flanks of the Nyambeni range. In the hand-specimen it is most difficult to distinguish between the tephrites and basalts, and in fact in most cases it is only possible to classify the rocks by the examination of thin sections.

The tephrites are greyish-black in colour, and basaltic in appearance. Most of them are finely porphyritic with small insets of basaltic hornblende or felspar in a dark aphanitic base, with the phenocrysts constituting up to 40 to 50 per cent of the rocks. The ferromagnesian minerals in these rocks are alkali-rich pyroxenes and amphiboles, present both as phenocrysts and irregular patches in the groundmass. Titaniferous augite is common, as is ægirine-augite. Lamprobolite is a frequent constituent, usually with a dark, almost isotropic border, and green hornblende occurs in quite large phenocrysts. The felspar of these rocks is usually plagioclase although occasionally phenocrysts of anorthoclase are present. The plagioclase insets contain a larger proportion of the albite molecule than the small microlites of the groundmass, which are probably of labradorite or a more calcic plagioclase.

Specimen 36/336, obtained from a small roadside exposure three miles south of Maua, is an example of a nepheline tephrite. Large megaphenocrysts of brown pleochroic lamprobolite with dark, almost isotropic borders, and lilac-coloured pleochroic titaniferous augite are set in a fine-grained groundmass. A few flakes of corroded biotite are also seen although they have been almost completely resorbed. Concentrations of iron ore and augite are believed to be the result of complete resorption of biotite phenocrysts. A few microphenocrysts of plagioclase are present but this mineral is mainly confined to the groundmass. The groundmass consists of an interlocking felt of plagioclase microlites, granular augite, nepheline and iron-ore. The nepheline is more apparent when stained and well-shaped square and octagonal sections are seen. Apatite is present as an accessory mineral. Specimen 36/539, collected just to the south of Mikanduri Catholic Mission, is a very similar rock; ægirine-augite is more abundant and lamprobolite is not developed. There is a large number of crystals of biotite now represented by concentrations of magnetite grains which were released during the complete resorption of biotite flakes by the groundmass. An appreciable amount of the ægirine-augite crystals exhibit corrosion features. Specimen

36/423, from a road-section immediately south of Lumeria, is also a nepheline-tephrite. The dominant ferromagnesian mineral of this rock is titanite, much of which exhibits the exsolution of iron ore. The plagioclase is of two generations; the first present as microphenocrysts and the second confined to the fine-grained groundmass. Small "square" nephelines are present as microphenocrysts and also as constituents of the groundmass. Specimen 36/325, from north of Kit Mau, contains megaphenocrysts of plagioclase, one of the insets being strongly zoned. The dominant coloured mineral is patchy ægirine-augite, while magnetite aggregates are all that remain of previous megaphenocrysts of either biotite or an amphibole. Specimen 36/328 also from north of Kit Mau, contains megaphenocrysts of pleochroic, green hornblende. Ægirine-augite is the dominant pyroxene, although a few small insets of titaniferous augite rimmed by ægirine-augite are also present. Specimen 36/329, collected from the track north of Kit Mau, has plagioclase present in three generations. The first generation forms macrophenocrysts rich in the albite molecule. One such inset exhibits very fine polysynthetic twinning. Second generation plagioclase is present as microphenocrysts, while the third is a constituent of the groundmass. The second and third generation plagioclases are much more calcic than the macrophenocrysts. Iron ore, both as ghost relics after certain ferromagnesian minerals and also in granular form in the groundmass, is a common constituent of all these rocks.

Minor Intrusives.

From indistinct lines noted on the aerial photographs two thin dyke-like bodies were found to the west of the parasitic vents of Mulu, a few miles south of the Garba Tula-Isiolo road. The two dykes, about 12 in. in thickness and separated by less than a quarter of a mile, trend approximately north-south. They are basanites and cut ashes derived from the parasitic vents of Mulu and are therefore of quite a recent age.

Specimen 36/656, from the eastern-most dyke, of basaltic appearance, is slightly vesicular, fine-grained and porphyritic. In thin section the phenocrysts are seen to be olivines, often with a discoloured margin of iddingsite. A few microphenocrysts of plagioclase are also present. The ferromagnesian mineral in the groundmass is a palish mauve titanium-rich variety of augite. The other constituents of the base are laths of plagioclase and interstitial feldspathoids, nepheline and analcite. Iron ore is not abundant, although it occurs both in largish crystals and as a granular constituent of the groundmass. A number of the vesicles are seen to be infilled with calcite and zeolites.

Feldspathoidal Staining Technique

A number of thin sections of the alkaline lavas of the Nyambeni suite were stained, using Shand's technique (1939, p. 508). The application of syrupy phosphoric acid for three to four minutes, followed by washing and staining with 0.25 per cent methylene-blue as recommended by Shand, was found to be satisfactory. After staining specimens 36/347 and 36/425, both phonolites, were found to contain nephelines showing a well marked zonal structure. Zoned nephelines exactly the same as are seen in the above rocks are illustrated in Shand's paper (op. cit. p. 511). As a result of staining various types of nepheline, Shand came to the conclusion that albite is the cause of zoning in nepheline crystals. He went on to say, "more correctly expressed, the zoning of nepheline crystals is due to the rhythmic deposition of layers of nepheline-substance alternately richer and poorer in silica" (op. cit. p. 512). The stained nepheline crystals in the phonolites from the Nyambeni range compare with the albite-rich nepheline stained by Shand (op. cit. p. 512) and those in the Bohemian phonolites in that the outer zones are often uncoloured.

(3) SUPERFICIAL DEPOSITS

(a) *Pleistocene*

Pleistocene deposits are of very limited distribution in the area. In a section of the western Marania River, east of Lolmotoni, a thin gravel upon loam can be seen lying above the Mt. Kenya basalts. The loam, produced by the decomposition of the basalt, is clayey and brownish-red in colour. The gravel is thin, being no more than twelve inches in thickness, and consists of pebbles, mostly sub-rounded, of variable size up to four inches in diameter. The pebbles are chiefly of Mt. Kenya basalt with subordinate Basement System gneisses. The matrix is grey in colour, sandy and rather friable.

The largest area covered by superficial deposits is situated north-west, west and south-west of Isiolo. Sections up to thirty feet in thickness can be observed along the river courses here. The following succession was noted in the course of the Isiolo River near to the *boma*:—

- (4) False-bedded, consolidated, poorly graded arenaceous deposit (12 ft.).
- (3) Rhythmical deposit of friable shales (4 ft.).
- (2) Red-brown argillaceous soil (2 ft.).
- (1) Vesicular, porphyritic olivine basalt

Much of this material west of Isiolo was probably deposited as a result of torrential conditions during the Gamblian Pluvial period of Upper Pleistocene times, although it is likely that further material was brought down from the Basement Hills and deposited in Recent times.

(b) *Recent*

Recent deposits in the area consist of soils and kunkar limestones. The types of soil developed depends on three factors: (a) the distribution of the rainfall, (b) the underlying formation, and (c) the drainage conditions. Over most of the Nyambeni range and the foothills of Mt. Kenya a thick fertile soil and sub-soil have developed due to the high rainfall and easily decomposable nature of the volcanic rocks. The soils are mainly red-brown to dark brown loams and grade downwards into more argillaceous sub-soils, which when lateritic are commonly termed *murrum*. In drier parts of the district these soils are not developed.

An impure superficial limestone generally known as *kunkar*, is commonly developed in the drier parts of the area to the north. East of Isiolo airfield a deposit of such material is so widely developed that the area is locally called the *Limestone Plain*. The formation of kunkar is considered to be due to the bringing up to the surface by capillary action of solutions rich in calcium carbonate. This impure limestone is often dispersed through the rotted rock, but north of Isiolo it is also found in more or less distinct layers a foot or two below the surface of black cotton soil areas.

Forming an aureole around the Basement System exposures are typical pale reddish, sandy, granular soils. They are immature and consist essentially of much quartz, and little altered feldspar and ferromagnesian minerals. Their presence west of Isiolo completely obscures the junction between the Basement System paragneisses and the lower Nyambeni volcanic rocks. Specimens of molluscs (*Unio* and *Melanoides tuberculata*) have been obtained from shallow trenches in similar sediments near to Isiolo. Unfortunately the range of these fossils is far too wide to be of value in the dating of the deposits. Black cotton soil, the development of which is the result of poor drainage, has but a small distribution in the area, except to the west of Isiolo where an appreciable deposit is found on the interfluvium between the western Marania and Isiolo Rivers. Elsewhere it has only formed in a few widely dispersed localities where the natural drainage is poor, as in the vicinity of Mulu and Mbokoro.

V—METAMORPHISM AND GRANITIZATION

Recent work in Kenya has shown that the Basement System rocks represent an original mainly sedimentary succession. They have been converted into schists and heterogeneous gneisses by regional metamorphism and granitization. The mineral assemblages observed in the gneisses and granulites may be compared with the biotite zone of Harker, which is a zone of comparative low-grade metamorphism. A number of the granulites collected from the present area compare closely to the description of the Struan Flags as given by Harker (1950, p. 247). However, since the variety and extent of metamorphic rock types in the area is limited, it would be unwise to endeavour to make a statement on the degree of metamorphism of the Basement System rocks generally. In view of the grade of metamorphism attained in nearby areas it is unlikely that the Basement System rocks of the present area do, in fact, represent Harker's biotite zone. Eskola's conception of grade of metamorphism (Turner and Verhoogen, 1951, p. 420) cannot be applied to these rocks, for material has been added during metamorphism and his principle depends upon the metamorphism of a closed system, in which material is neither added nor subtracted from the original rock. Contemporaneous addition of material throws the original system out of equilibrium and a true conception of grade is not obtainable. Various processes of granitization have been discussed by Schoeman (1951, p. 11) and of them the process which appears to have operated dominantly in the Basement System rocks of this area is that of metasomatic permeation by highly fluid, active alkali-rich solutions. This alkali metasomatism resulted essentially in the feldspathization of the original rocks. Y.Cheng (1943, p. 112) uses the term *permeation gneiss* for rocks produced by this process of molecular exchange between host-rock and permeating fluids. Illustrations of permeation psammitic gneisses and permeation pelitic gneisses are found in the Sultan Hamud area (Searle, 1954, Fig. 3). Rocks comparable with Read's (1931, pp. 88, 109, etc.) injection gneisses are not present in this area, and likewise migmatites as defined by Turner and Verhoogen (1951, p. 294) are absent. Other opinions and observations of the granitization of Basement System rocks have been expressed by Shackleton (1946, p. 21), Bear (1952, p. 20) and Baker (1954).

VI—STRUCTURE

Major Structures

The major structures of the area are shown in Fig. 3.

In the vicinity of Isiolo, in the northern part of the area, a northerly pitching anticlinal axis continues an axis postulated by Shackleton (1946, Fig. 7) to the north-north-west where, however, the trend of the fold is north-north-west. The dips recorded from west of Isiolo and from Kallamandorap and Kallamando indicate that the fold is a monocline (Fig. 4). The flexure in all probability continues southwards, under the overlying volcanic rocks, to Kitui and to the east of the Yatta Plateau. (Baker and Saggerson, 1951, pp. 1 and 2; Dodson, 1953, p. 16; Schoeman, 1948, Fig. 1 and p. 40; Bear, 1952, p. 35).

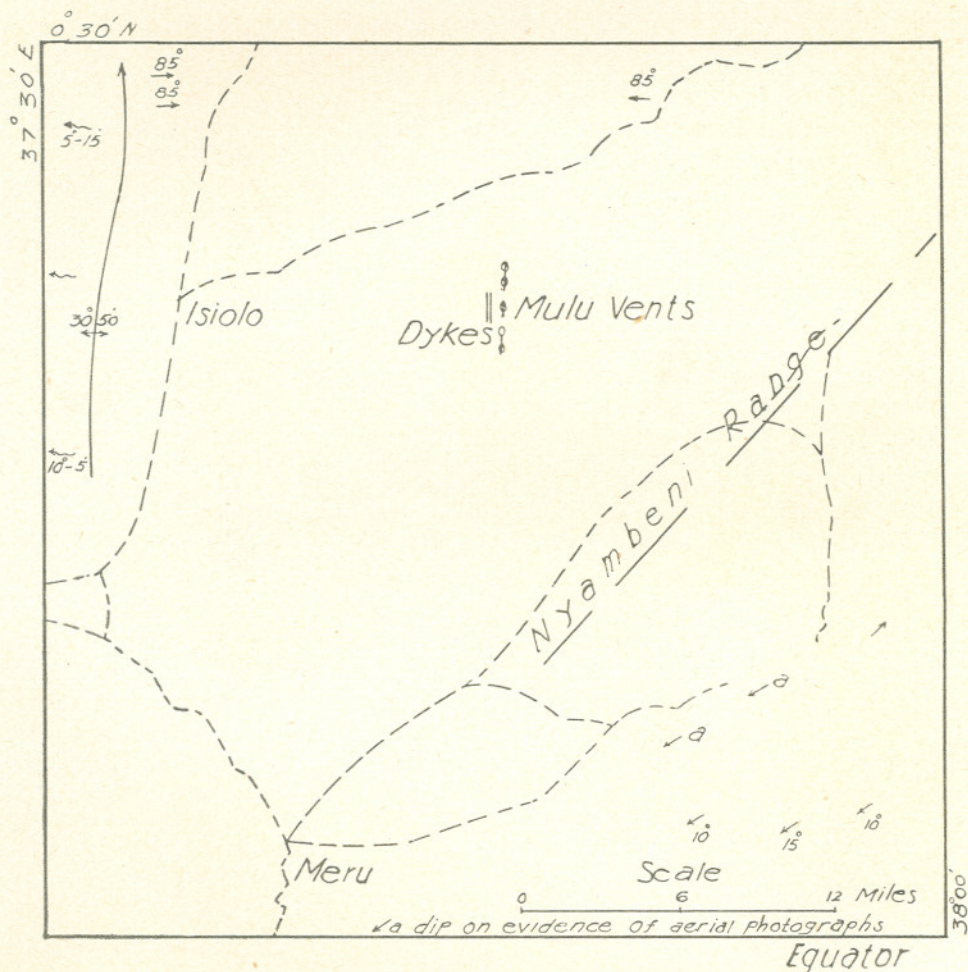


Fig. 3.—Structural map of the Meru-Isiolo area.

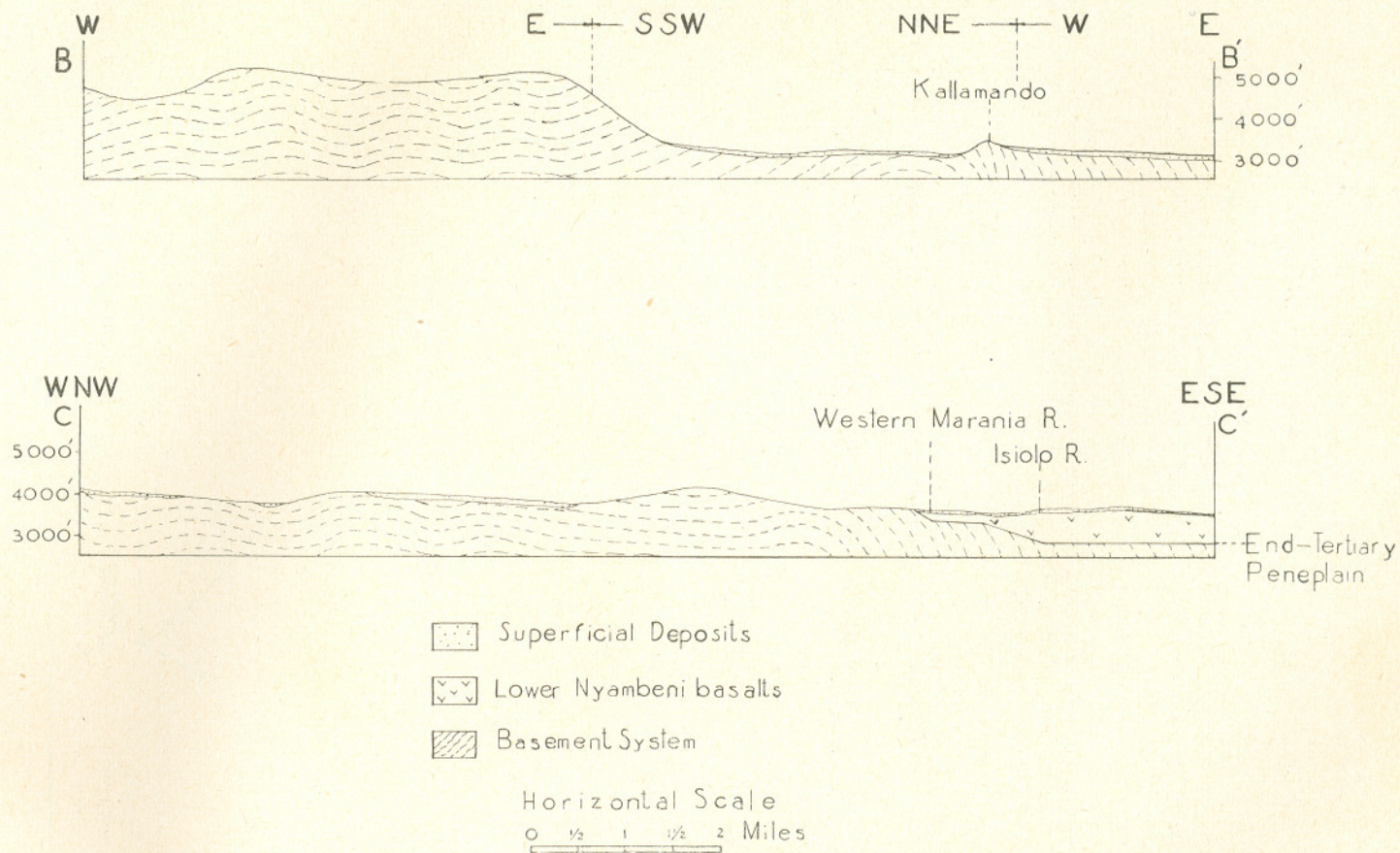


Fig. 4.—Geological cross-section to illustrate the structural axis in the Basement System rocks near Isiolo. The lines of section B-B' and C-C' are shown on the map.

The near-vertical dip recorded from north of Isiolo is also found in the Basement System hill some 20 miles along the Garba Tula road. It is probable that in this area the dip is due to isoclinal folding as it is to the west between Nanyuki and Maralal, where Shackleton (1946, pp. 26 and 27) obtained evidence which strongly suggests that type of folding.

The direction of dip seen, or inferred from aerial photographs, in the Basement System inliers on the southern flank of the Nyambeni range is approximately to the south-west and west-south-west, with the exception of a small exposure near to Kanune. Here a dip to the north-east was recorded, but it is probably due to a minor disruption, evidence of which is effectively concealed by the overlying volcanic rocks. The general dip of 15° to 30° to the south-west recorded in these inliers suggest that they represent the north-eastern flank of a north-west to south-east synclinal flexure postulated by Schoeman in the quarter-degree area to the south (Schoeman, 1951, p. 52; Baker and Saggerson, 1951, Map I).

The alignment of the Nyambeni volcanic range is not related to the dip and strike of the Basement rocks in the area but does fit in with the general tectonic pattern postulated by Baker and Saggerson (1951). The directions of this pattern are north-west to south-east and north-east to south-west, the Nyambeni range having the latter trend. To account for the formation of the range a structural weakness is postulated, radiating to the north-east from beneath Mt. Kenya. This trend is an approximate continuation of the axis of deposition of Jurassic and later sediments extending north-eastwards from Wajir, and it is considered that crustal weakness would probably develop along this axis (Baker and Saggerson, 1951, Map IV). Mention must be made of the Chyulu hills south of Kibwezi which extend in a north-north-west to south-south-east direction, that is almost at right-angles to the Nyambeni range. Both the Nyambeni and Chyulu hills show a great development of parasitic cones which have suffered little erosion, and it is quite probable that the outpourings of lava in the two areas occurred simultaneously.

The parasitic volcanic vents known as Mulu, near the Isiolo-Garba Tula road, and the two basanite dykes to the west follow a different trend. Here an approximate north-south direction is followed, which corresponds to the presumed strike of the underlying Basement System rocks. The volcanic vents of Mulu show a definite north-south alignment and appear to have welled up along fissures parallel to the underlying Basement System strike. In the Northern Province the Huri hills and Marsabit hills consist of volcanic rocks also aligned along the strike of the Basement System rocks, which is here north-east to south-west (Baker and Saggerson, 1951, Map IV).

No evidence of *faulting* was found anywhere in the area. The recorded dips, west of Isiolo, appear to be due to faulting, but there is no displacement visible and they are thus considered to be due not to faulting, but rather to the sharp anticlinal flexure mentioned previously.

Minor Structures

Minor corrugations and bucklings are found in the Basement System rocks in the north-western portion of the area, which suggest that a north-south crustal compression must have operated. It cannot be said whether the minor structures were formed contemporaneously with the major structures, or whether they came into being at a later date. The form of some of the minor folds suggests that the rocks were approaching a semi-plastic state at the time the folds were impressed on them.

Jointing and Cleavage

Generally speaking jointing and "cleavage" is well developed in the Basement System rocks. It was not possible to effect detailed measurements, but certain types show wide and consistent development. A flaggy and slabby structure is commonly

formed by closely-spaced cleavage planes (? jointing) parallel to the foliation. Dip jointing, normal to the strike and foliation, is very prominent and often influences the direction of streams. Strike jointing, variably inclined to the foliation, though it is often approximately at right-angles to it, is frequently seen.

According to Schoeman, (1951, p. 52) the jointing and cleavage is to be regarded as a late tectonic feature resulting from conditions of declining temperature and regional pressure.

VII—ECONOMIC GEOLOGY

(1) GENERAL

Up to the present day prospectors have paid little attention to the present area and no claims have been pegged. The reconnaissance survey has not revealed any mineral deposits of importance nor are the geological conditions such that intensive prospecting is recommended. The area over which Basement System rocks are exposed is small and consequently the chances of economic minerals being present are correspondingly slight.

None of the minerals found in adjacent areas have been found in any quantity. Mica, such as is present in small flakes in the schists, is of no value. Kyanite, sillimanite, asbestos, graphite, magnesite and limestone, along with other minerals of wide distribution in the Colony were not found. The few pegmatitic veins recorded consist essentially of quartz and felspar and little else.

Many streams were panned and the heavy concentrates examined for valuable minerals, unfortunately with negative results. The commonest minerals in these concentrates were iron ore, mica flakes, a little garnet, rutile and augite. Magnetite was by far the most abundant mineral in all the concentrates examined.

(2) BUILDING STONE

Building stone is worked in a number of small quarries to supply local needs. The consolidated tuffs which have been examined, are rather too soft and easily weathered for good building stone. Basaltic tuff is quarried on the north-western flank of Maua, along the Miatheni river and on the northern side of the Nyambeni range, in the Liliaber river valley. All the workings are small and only supply local requirements.

(3) WATER SUPPLY

Surface water

The run-off from the Nyambeni and Mt. Kenya volcanic areas is much greater than that from the Basement System rocks, owing to the greater degree of weathering and porosity of the metamorphic rocks. The forested areas of Mt. Kenya and the Nyambeni range have, however, a thick cover of soil and humus and consequently rain-water, instead of running away quickly, is stored and slowly seeps away into perennial streams and rivers, most of which flow to the south-east towards the Tana river. North of the Nyambeni range the rainfall is small and consequently the streams are seasonal, very few running during the dry season.

Ground-water

A borehole, C. 1620, has been recently drilled half a mile to the east of the Basement System inlier on the Isiolo-Garba Tula road. This borehole penetrates lava for the first 105 ft. and then continues to a total depth of 400 ft. through various types of gneiss. Water was first struck at 236 ft. and again at 260 ft. and 380 feet. The yield per hour is given as approximately 1,200 gallons and the rest-level as 220 feet.

A number of boreholes have been drilled near Isiolo, several of them by the army during the war. None extend into the Basement System rocks, the water obtained being either from basaltic lava or from old lake beds resting upon the end-Tertiary peneplain below the lavas. Borehole C. 90, approximately 2 miles west of Isiolo, supplies the *boma* with water. The yield is 1,050 gallons per hour and the rest-level 95 feet. Borehole C. 87 near to the airfield, penetrates the lake beds. The yield is approximately 1,000 gallons per hour and the rest-level is quoted as 44 feet. Two further boreholes, C. 97 and C. 98, of 120 ft. and 204 ft. total depth respectively, have high yields. The former yields about 3,000 gallons per hour and the latter about 3,500 gallons per hour; the rest-level in both cases is given as 48 feet. The above figures show that the Lower Nyambeni lavas carry appreciable quantities of water and it is probable that further boreholes along the Garba Tula road would strike water, although it must be noted that the rest-level falls from approximately 50 ft. near the Isiolo airfield to 220 ft. near the Basement System inlier along the Garba Tula road, that is, a fall of 170 ft. in 18 miles.

VIII—REFERENCES

- Baker, B. H., 1954.—"Geology of the Southern Machakos District." Report No. 27, Geol. Surv. Kenya.
- Baker, B. H. and Saggerson, E. P., 1951.—"Notes on the Tectonics of Kenya Colony Basement System." Paper read at the fourth E.A. Interterritorial Geological Conference (not published).
- Bear, L. M., 1952.—"A Geological Reconnaissance of the area south-east of Embu." Report No. 23, Geol. Surv. Kenya.
- Campbell Smith, W., 1931.—"A Classification of some Rhyolites, Trachytes and Phonolites from part of Kenya Colony, with a note on some Associated Basaltic Rocks." *Quart. Journ. Geol. Soc.*, London. Vol. LXXXVII, pp. 212-258.
- Cheng, Y., 1943.—"The Migmatite area around Bettyhill, Sutherland." *Quart. Journ. Geol. Soc.*, London. Vol. XCIX, pp. 107-154.
- Dixey, F., 1948.—"Geology of Northern Kenya." Report No. 15, Geol. Surv. Kenya.
- Dodson, R. G., 1953.—"Geology of the south-east Machakos area." Report No. 25, Geol. Surv. Kenya.
- Gracie, D. S., 1930.—"A Preliminary Survey of some of the Soils in Kenya." Bulletin No. 1 of 1930. Department of Agriculture.
- Harker, A., 1950.—"Metamorphism." Third Ed.
- Holmes, A., 1919.—"The Pre-Cambrian and Associated Rocks of the district of Mozambique." *Quart. Journ. Geol. Soc.*, London. Vol. LXXIV, pp. 31-98.
- Kent, P. E., 1944.—"The Age and Tectonic Relationships of East African Volcanic Rocks." *Geol. Mag.* Vol. LXXXI, pp. 15-27.
- Milne, G., 1936.—"A Provisional Soil Map of East Africa." East African Agricultural Research Station, Amani.
- Parkinson, J., 1920.—"Report on the Geology and Geography of the northern part of the East African Protectorate." Col. Rep., Misc. No. 91, London.
- Read, H. H., 1931.—"The Geology of Central Sutherland." Mem. Geol. Surv. Scotland.

- Schoeman, J. J., 1948.—"A Geological Reconnaissance of the area west of Kitui Township." Report No. 14, Geol. Surv. Kenya.
- 1951.—"A Geological Reconnaissance of the Country between Embu and Meru." Report No. 17, Geol. Surv. Kenya.
- Searle, D. L., 1954.—"Geology of the Sultan Hamud area." Report No. 29, Geol. Surv. Kenya.
- Shackleton, R. M., 1946.—"Geology of the country between Nanyuki and Maralal." Report No. 11, Geol. Surv. Kenya.
- Shand, S. J., 1939.—"On the staining of feldspathoids, and on zonal structure in nepheline." *Amer. Min.* Vol. 24, pp. 508-513.
- Turner, F. J. and Verhoogen, J., 1951.—"Igneous and Metamorphic Petrology."