



REPUBLIC OF KENYA

MINISTRY OF NATURAL RESOURCES
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE KINNA AREA

DEGREE SHEET 37, SW. QUARTER
(with coloured geological map)

by

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FOREWORD

The Kinna area, which lies to the north-east of Mount Kenya, is little known to the general public, lying as it does in a region traversed by few and poor roads. The establishment of the Meru Game Reserve, which extends into the south-western portion of the map, will help to open it up to visitors.

It is an area of great diversity of landscape and climate, varying from the forested Nyambeni Range, which approaches 6,000 feet in altitude, down to the semi-arid plains bordering the Tana river at only 1,200 feet.

Mr. Rix's report covers part of the eastern slopes of the Nyambeni Range, which is formed of many small volcanoes and their surrounding lava flows, and he also describes the Precambrian metamorphic rocks which appear below the Nyambeni volcanic field on its south-eastern side. Mr. Rix has included a useful chapter on correlation of the volcanic rocks in this and neighbouring areas.

None of the minerals discovered during the survey show promise of commercial exploitation and the main economic potential of the area lies in the water supplies originating in the Nyambenis, of which a very full account is given.

Nairobi,
18th April 1967.

B. H. BAKER,
Commissioner of Mines and Geology.

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ABSTRACT

The report describes an area of some 1,225 square miles in north-central Kenya on the eastern side of the Nyambeni Range, the boundaries of which are the Equator and latitude $0^{\circ} 30' \text{ N.}$ and longitudes $38^{\circ} 00' \text{ E.}$ and $38^{\circ} 30' \text{ E.}$ Approximately two-thirds of the region consists of lavas which were extruded on to a dissected end-Tertiary land surface of metamorphic rocks, this surface being exposed in the remaining one-third of the area.

The Basement System metamorphic rocks comprise gneisses, plagioclase amphibolites, crystalline limestone and quartzites, and the overlying Pleistocene-Recent lava flows form part of the Nyambeni Volcanic Series. The latter are chiefly olivine basalts, of which an upper and a lower series are recognized, with subsidiary phonolites and olivine melaneophelinites. Numerous vents and craters are present especially in the north-west.

Rocks intrusive into the Basement System are a perknite with associated ortho-amphibolite, probably Precambrian in age, and olivine dolerite dykes which are associated with the Nyambeni lavas and therefore Pleistocene in age. Other deposits are fossiliferous lacustrine limestones of Pleistocene age, superficial crustal deposits and volcanic and sandy soils. Sands form a superficial cover on Pleistocene sediments which occur in a fault graben in the eastern part of the area.

Detailed accounts are given of the petrography of the lavas and metasediments and of the structure and metamorphism of the latter rocks. The economic possibilities of the region are discussed and a detailed account is given of water supplies.

In a separate section an attempt is made to collate all the relevant information concerning the Nyambeni Volcanic Series and to treat this as a discrete volcanic episode.

GEOLOGY OF THE KINNA AREA

I—INTRODUCTION AND GENERAL INFORMATION

The geological reconnaissance described in this report comprises the south-west quarter of Degree Sheet 37. This sheet is bounded by the Equator and latitude $00^{\circ} 30' N.$ and longitudes $38^{\circ} 00' E.$ and $38^{\circ} 30' E.$ and is approximately 1,225 square-miles in areal extent. The area is part of the Eastern Province of Kenya, about two-thirds falling within Meru District and the remainder in Isiolo District.

Field work was carried out between February and August 1959.

Climate and Vegetation.—The climate is not unpleasant on the slopes of the Nyambeni Range in the west, being cooler and wetter than on the low-lying ground between Kinna and the Garba Tula and Melka Lorni regions. The only rainfall-recording station within the area is situated at Kinna and has very incomplete records; the annual average is perhaps 15-20 inches, but the eastern part probably has less than 15 inches of rain per year. In contrast Maua, situated to the west of the present area on the eastern slopes of the Nyambeni Range, has an average annual rainfall of 90 inches. The relatively arid country to the east of the range does, however, benefit from this precipitation in the form of the surface run-off.

The vegetation reflects the climatic zones. Although the indigenous tropical rain forest has been destroyed over large parts of the range, some small areas remain. The Ngaya Forest lies almost wholly within the confines of the present area, clothing the eastern slopes below the cultivated areas. A few patches of almost impenetrable undergrowth are encountered on the slopes, areas of secondary vegetation developed as a consequence of the destruction of the rain forests. On the flatter lava country the vegetation consists of fairly open grassland with scattered thorn trees. Ribbons of dense vegetation exist along the rivers which cross this area and consist of fig and palm trees, the latter often forming extensive *doum* palm "forests" where the water-table is shallow. The open vegetation on the lavas changes to medium and dense thorn bush on the sandy soils overlying the Basement System rocks. This type of bush, which is particularly thick in the south towards the Tana River, is characterized by species of *Acacia* and other thorn trees, and is very typical of large areas of eastern and northern Kenya.

The variation in climatic zones, abundance of water and variety of vegetation types has resulted in an abundance of game animals of almost every type. The abundance of game has led to the Meru District portion of the Kinna area being established as a game reserve.

Indigenous population and cultivation.—The Kinna region apart from the higher ground in the west is very sparsely populated. The tribe that inhabits the Nyambeni Range is related to the Meru tribe. They do not generally inhabit the lower slopes and the flat country to the east of the hills because of tsetse-fly infestation. In other respects, the country is well endowed and water and grazing are plentiful.

The drier areas which form part of Isiolo District (i.e. the Kinna, Garba Tula and Melka Lorni regions) are inhabited by the Boran tribe who are nomadic stock rearers, and often use the uninhabited parts of Meru District between the Ura and Bisanadi rivers to obtain grazing which is virtually unobtainable in their regions during dry seasons. The establishment of the game reserve in this part of the area has led to some disagreement over the grazing of domestic stock.

Other tribes in the region are the Watharaka and a few Wakamba settlers. The Watharaka, an apparent tribal mixture of Wakamba and Wameru occupy the land south of the Ura river, where they grow millet, supplementing their diet by poaching game animals and trading with the Wameru on the Nyambeni Range to obtain maize and bananas. A few Wakamba have settled on the eastern slopes of the range, chiefly in the Thaichu region.

The upper slopes of the Nyambeni Range are very fertile and densely populated. A variety of vegetables and fruits is grown but the ubiquitous crops are maize and bananas, the latter being particularly well suited to the prevailing climatic conditions. Cash crops such as coffee and more recently tea have been successful.

Communications.—There are no main roads within the area but there are a number of motorable tracks, and the only part that is really difficult of access is the lava region in the north-west. In the rainy season most of the tracks grow over and it is necessary to clear them in the dry season.

Generally the tracks on the Basement System rocks are sandy and fairly easy to motor, but those on the Nyambeni lavas have very rough surfaces resulting in a slow rate of travel, particularly on the ascent and descent of the Nyambeni Range.

Formerly the main road from Meru to Garba Tula ran via the Ura river in the south-west to Kinna, thence to Garba Tula and Wajir. Part of this track has fallen into disuse since the cutting of a new major through route between Garba Tula and Maua via the Ngaya Forest. The latter track has also been superseded to some extent by new roads built since the formation of the Meru District Game Reserve. The major access route now descends the slopes to the south of the Ngaya Forest from near Milu Tatu, a village five miles west of $38^{\circ} 00' E$. Another route that was formerly more important traverses the arid volcanic areas on the northern end of the range. This is still passable to four-wheel-drive vehicles but only with extreme difficulty due to the rough lava surfaces.

Maps.—A topographical map at 1:50,000 scale was prepared by the author from aerial photographs, using Kodatrace overlays. Ground control was obtained from trigonometrical beacons within the area together with additional points fixed by plane table resection to give a good network of control points. A useful pre-existing map was the Garba Tula sheet, E.A.F. 1705 1:500,000. The positions of the major trigonometrical stations were plotted from diagram VI. Garba Tula, E.A. Trigonometrical Survey Service. Form lines on the final map were sketched, controlled by a network of spot heights obtained with an Indian clinometer and an aneroid barometer, and must be regarded as only approximate.

II—PREVIOUS GEOLOGICAL AND EXPLORATORY WORK

A number of early explorers visited the Kinna region and the Nyambeni Range, most of them having journeyed up the Tana river.

In 1889, J. R. W. Piggott (1890)* travelled up the Tana river in this area, exploring its tributaries. The first tributary that he encountered had a large storm bed with only a small quantity of clear and slightly salt water in it; this was undoubtedly the lower course of the Bisanadi. Later he encountered another river flowing from the north and followed it for a distance of seven miles down to its confluence with the Tana, where he noted rocky banks 40 to 50 feet high. He named this river the Mackenzie after the first Administrator-in-Chief of the Imperial British East Africa Company. The point at which he first encountered the Mackenzie must have been very near to the Equator.

*References are quoted on p. 35.

The next journey up the Tana river, in 1891, was undertaken by C. W. Hobley (1894). He also crossed the large sand river which he named "Salt River" due to the brackish nature of the trickle of water in the centre of the large storm bed. Two days beyond this river he crossed the Mackenzie and described it as being much more constant in its flow than the former one. He noted a 50-foot waterfall above its confluence with the Tana, the river having carved a passage through hard, vertical hornblende schists. "Large gneiss veins run north-south and are traceable on the opposite bank by lines of cairn-like tors." Hobley also crossed the Ura and Thangatha rivers probably to the south of the present area. He supposed that the first three rivers (Bisanadi, Mackenzie and Ura?) rose in the prominent range of mountains to the north, that had been named the Kaiser Wilhelm Range by Peters. Capt. F. G. Dundas (Gedge, 1892) travelled up the Tana river to "Mt. Kenia" in 1891 and sighted a high range of mountains to the west (the Nyambeni Range). He crossed the Mackenzie river and apparently also the Ura and Thangatha rivers.

In 1893, Mr. Astor Chanler (1893) undertook an expedition to East Africa, journeying up the Tana river and crossing the Jombene (Nyambeni) Range. A map of the region was drawn by Lieut. von Höhnelt, surveyor attached to Mr. Chanler's expedition. This map indicates that the Mackenzie river is the large river now better known as the Rojewero. The expedition travelled up this river to the mountains, noting that it flows for 15 miles through alluvial soil mixed with lava blocks and that game abounded around the headwaters. The Jombene Range was seen to be fertile and thickly populated, with the result that the indigenous forest was being quickly destroyed.

In 1906, W. H. Broun (1906) completed a journey across the Nyambeni Range in a south to north direction. He crossed the Zangaza (Thangatha), Ula (Ura) and Kura (Kiolou?) rivers, reaching Laiju (Thaichu) where he noted a perfect volcanic cone forming a good landmark (Kilimakieru), and remarked on the great fertility of the region. He then traversed parallel to the Nyambeni Range crossing a total of 9 clear streams and noting two swamps. He describes crossing "volcanic ridges of vesicular lava; the flows decreasing with the height and size of the mountains". He camped at Mymboro (2,404 feet) close to a spring and an isolated hill (Kinna?) and noted the abundance of all species of game in this region. The expedition then crossed the arid and difficult lava region north-westwards towards Goitu Abaloni and reached Igembe crater after suffering considerably from thirst.

There are no records of later exploratory or geological work, and the area remained unmapped until the present survey was carried out.

III—PHYSIOGRAPHY

The area can be divided into four physiographical units (Figure 1):—

- (1) North Nyambeni area of volcanic cones.
- (2) Lava slopes and plains in the central and northern parts of the area.
- (3) Dissected areas of metamorphic rocks in the south and east.
- (4) Melka Lorni and Skot graben valleys in the east.

(1) NORTH NYAMBENI AREA OF VOLCANIC CONES

The northern end of the Nyambeni Range comes within the north-western portion of the Kinna area. This region consists of a pile of olivine basalt lava flows overlain by scoria cones. The latter exhibit various stages of erosion, some vents having well preserved craters and others having no recognizable crater. The state of preservation of some of the craters is due partly to their youthful age but also to the lack of surface drainage on the pumice and scoriaceous lava. In such circumstances volcanic landscape forms may retain their original form for a considerable time after their

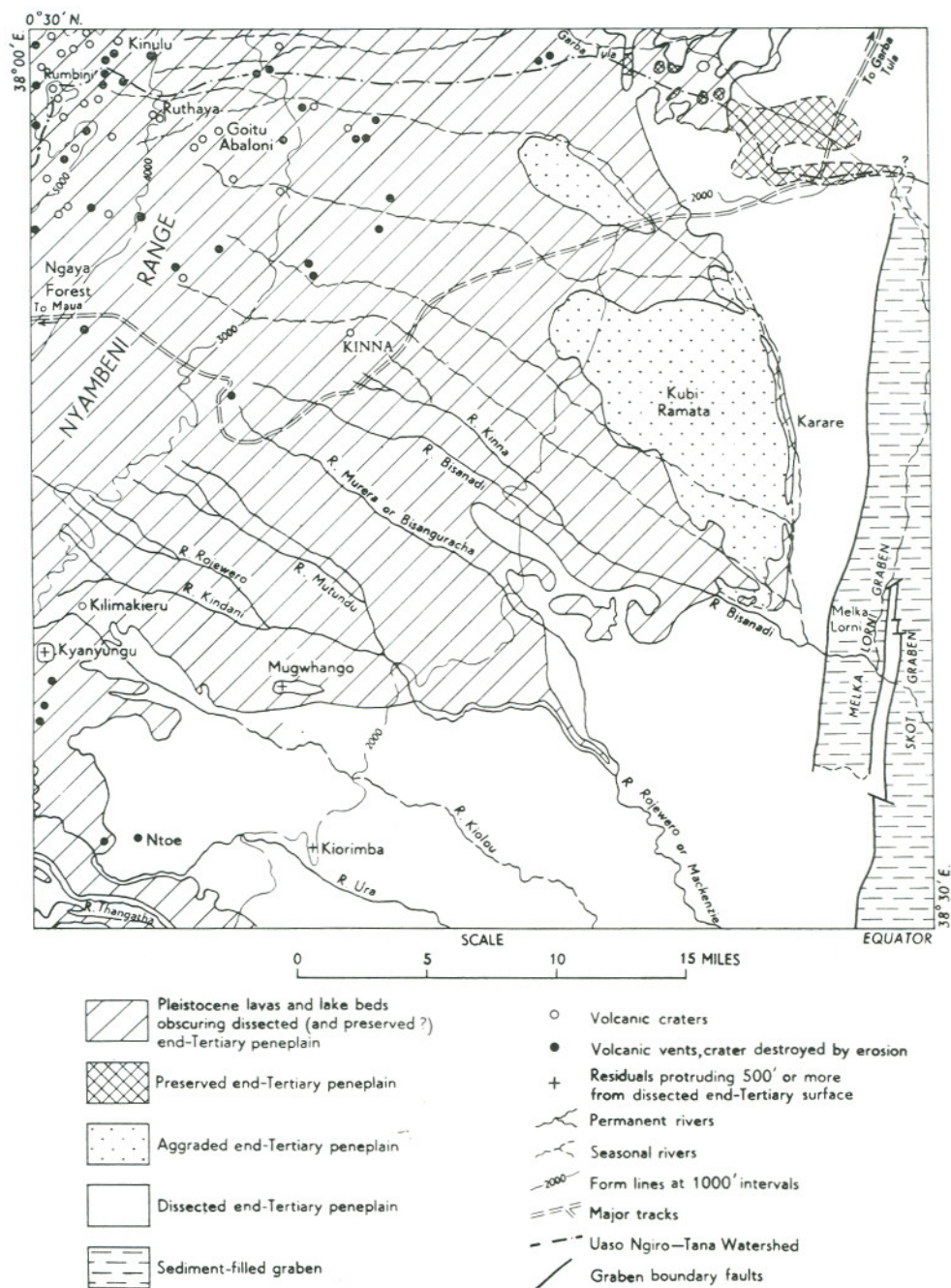


Fig. 1—Physiographical map of the Kinna area

formation and the occurrence of a perfectly formed crater does not necessarily indicate youth. A number of well preserved craters exist in the Kinna area, examples being Rumbini, Ruthaya, both of which contain small lakes during the rains—Kilimakieru, Goitu Abaloni and Kinulu. The area is very arid due to the immediate percolation of any precipitation and the consequent lack of surface run-off. Canyon type valleys, typical of drainage initiated on young lavas, are present in the Upper Nyambeni basalts in the Goitu-Ruthaya region.

(2) LAVA SLOPES AND PLAINS IN THE CENTRAL AND NORTHERN PARTS OF THE AREA

The valleys on the older lavas on the lower slopes of the Nyambeni Range and the lava plains to the east are wider and deeper than the young canyon type valleys in the Goitu region. Springs occur on the lower slopes where the lava cover thins over buried Basement System metamorphic rocks, and most of the streams on the lava plains are permanent. The larger streams, the Thangatha, Ura and Rojewero, drain the higher forested parts of the Nyambeni Range and are permanent when they enter the Kinna area in the west.

Most of the rivers drain south-eastwards from the north-easterly trending Nyambeni Range, and form part of the Tana catchment area. The Thangatha, Ura and Rojewero are the last permanent tributaries to flow into the Tana before the river commences its flow of 250 miles across the arid bushlands of eastern Kenya to the sea.

The main watershed between the Tana and Uaso Ngiro rivers is situated in the northern part of the map area. It follows the crest of the Nyambeni Range in the west but becomes merely a low ridge in the centre and east until it leaves the Kinna area seven miles south of the Garba Tula (Figure 1).

Lava flows have played a major part in the development of the drainage. These flows often followed large pre-existing river valleys, damming the tributary drainage and resulting in the development of lagoons and eventually rivers parallel to the edges of the flows. Numerous examples of this splitting of the drainage and development of parallel streams are to be seen in the present area. The best example is the lava flow in the south-western corner of the area flanked by two large parallel rivers, the Ura and Thangatha. This lava flow filled what must have been an extremely large valley in the pre-lava landscape of the dissected end-Tertiary peneplain, splitting the drainage so that the Ura and Thangatha rivers now reach the Tana at widely divergent points. The Bisanadi and Rojewero valleys both have their upper courses blocked by lava flows, and in both cases parallel streams developed along the lava flow and now unite round the nose of the flow.

(3) DISSECTED AREAS OF METAMORPHIC ROCKS IN THE SOUTH AND EAST

Features of the drainage pattern developed on the areas of metamorphic rocks are extreme dissection, incised stream courses and lack of control of drainage by rock types or structures. The first two features suggest that the drainage is still downcutting after a relatively recent rejuvenation, and the last feature suggests that the drainage was initiated on a surface other than the heterogeneous metamorphic rock surface seen at present and may therefore be superimposed. It is evident from the foregoing that the pre-lava land surface was well dissected and the earliest Nyambeni lava flows filled valleys in this surface, thus preserving it locally from further erosion. Dissection of those areas of the land surface not preserved by lava was at that time being accelerated for a number of reasons. First, the volcanic piles of Mt. Kenya and the Aberdares had begun eruption previous to the Nyambeni activity and had produced a Tana river of much greater vigour than that of mid-Pliocene times. Coupled with this was a regional tilt that heralded the end of the late-Tertiary peneplanation cycle. Thus the Tana river began to cut down vigorously whereas the tributaries east

of Mt. Kenya, not having this increased catchment and resulting increase in erosive power, cut down more slowly and are still not graded to the Tana valley. Herein lies the explanation of the incised, well-dissected land surface in the southern part of the Kinna area. The Kiolou river affords an excellent example of a mature, meandering river that has been incised due to rejuvenation, the Rojewero river enters the Tana by a steep, rocky channel with waterfalls, showing that it is not yet graded to the latter river. None of these tributaries have associated alluvial deposits.

Evidence for the nature of the cover on which the drainage was initiated is obtained from a study of the fourth physiographical unit, discussed below.

(4) MELKA LORNI AND SKOT GRABEN VALLEYS

The extent of the Melka Lorni and Skot graben valleys is sharply outlined on aerial photographs by the prominent boundaries of their infilling of sedimentary material. Irregular masses of metamorphic rocks protrude from the sediments within the graben. These are thought to have been irregularities on the floor of the graben buried beneath sediment and later re-excavated by erosion.

The presence and former distribution of the sediments is intimately associated with the history of the Tana drainage. Penecontemporaneously with the extrusion of the volcanic piles in central Kenya and consequent rejuvenation of the Tana river (i.e. late-Pliocene onwards), large areas of eastern Kenya are considered to have been extensive brackish lagoons or estuaries (*see also* p. 18). It is probable that an arm of one of these lagoons extended up the Tana valley in late Pliocene times, perhaps during a pluvial period, and filled the graben valley that straddled the Tana valley near $38^{\circ} 30' \text{ E}$. Evidence in the North Kitui area for this lagoonal extension is the presence of small patches of sediment and pebble sheets (Dodson, 1955).

Evidence in the Kinna area for former cover of sediment west of the graben is purely physiographical. The superimposed nature of the drainage on the metamorphic rock surface in the south-eastern part of the area has been mentioned earlier, and a study of the physiographical features of one particular river, the Bisanadi, provides detailed confirmation of this premise. The Bisanadi river shows a complete disregard for structure, flowing from metamorphic rocks into the Melka Lorni graben and through the horst block at Melka Yaka before crossing the sediments in the larger Skot graben. This would suggest that a former sedimentary cover blanketed both the graben and the land surface to the west. The Bisanadi drainage was initiated on this sedimentary surface and gradually eroded the sediments until the old land surface was re-exposed, the sediments being preserved only in the graben. The river was then flowing across metamorphic rocks on the western shoulder of the graben, most likely along convenient lines of weakness in the resistant rock ridges of Melka Lorni, and on sediments in the graben. On rejuvenation of the Tana River, perhaps by tilting (*see below*) the Bisanadi channel became incised into the metamorphic rocks near Melka Lorni but developed a meandering, sluggish course with alluvial deposits on the sediments in the graben. The contrast between these two stretches of the river is most striking and illustrates the marked change of gradient which occurs on the softer sediments east of the graben fault as a result of the river reaching base level more rapidly on sediments than on metamorphic rocks.

Similar features on a larger scale are displayed by the Tana river in the North Kitui area to the south. Large alluvial fans in the Tana valley near $38^{\circ} 30' \text{ E}$. are situated on sediments in the main Skot graben which crosses the Tana in this region, and sediments are also preserved in the smaller graben further upstream, the Tana having formed an oxbow cut-off meander, typical of maturity, at this locality (Dodson, 1955). The horst block between the two grabens is traversed by a youthful Tana that has formed a rocky, incised channel with waterfalls upstream from the Rojewero

confluence. Dodson interprets these features as being due to a gentle, easterly downward tilt about an axis at approximately $38^{\circ} 15' E.$ but this does not explain the alternation of youthful and mature stretches of the river which are striking features of the Tana between $38^{\circ} 15' E.$ and $39^{\circ} 00' E.$

After the sedimentary cover had been stripped off, further movements along the fault resulted in the raising of the western shoulder of the graben. The Bisanadi and its tributary streams were ponded back to form a small lake bounded on the east by the western shoulder of the graben. The lake was eventually drained when an outflow was formed near the lowest point of the ridge at Melka Lorni, the Bisanadi falling over a series of rocky steps into the graben.

Extrusion of the Nyambeni volcanic pile led to the development of other lakes in the northern and central parts of the area due to damming by lava flows (*see* page 22).

Erosion Surfaces.—A large portion of the Kinna area is covered with Pleistocene lava that flowed out onto a well dissected erosion bevel, the end-Tertiary erosion surface. Evidence for the dissected nature of the bevel is the rapid variation in height of the lava-metamorphic rocks terminal interface, the steepness of the gradient of the lava base and of the interflues on the metamorphic rock areas, and the presence of very large valleys dissecting the pre-lava landscape.

The portion of the end-Tertiary bevel that is not concealed by lavas consists of three areas which exhibit different features of degradation or aggradation. The best preserved remnant of the bevel is in the north-east corner of the area along the Uaso Ngiro-Tana watershed (Figure 1). The gradient (30 ft. per mile) along this watershed indicates that it may have been lowered to a level slightly below the former level of the peneplain.

The second area is one of aggradation in the Kubi Ramata region to the north of the Melka Lorni lava flow, which was formerly a degraded portion of the end-Tertiary peneplain but was aggraded again as a consequence of damming of the drainage by the lava flow. The end result is a large flat area having the appearance of a preserved erosion bevel whereas in fact this is only a pseudo-bevel produced by the later aggradation.

The rest of the exposed area lies below the end-Tertiary bevel. This includes the southern part of the area and the Skot graben valley in the east, both of which are now a considerable vertical distance below the former peneplain level. The events which caused this extensive erosion of the end-Tertiary peneplain have been described in sections (3) and (4) above.

A few residuals of more resistant metamorphic rocks in the area are probably degraded remnants of the earlier sub-Miocene surface (*cf.* Pulfrey, 1960).

IV—SUMMARY OF GEOLOGY

The geological formations within the area can be grouped as follows:—

5. Superficial deposits and Plio-Pleistocene sediments.
4. Pleistocene lake deposits.
3. Nyambeni Volcanic Series.
2. Intrusive rocks.
1. Basement System.

1. Basement System

These rocks are exposed only in the east and south in those regions where the end-Tertiary peneplain has been heavily dissected. A variety of metasediments, psammitic, semipelitic, pelitic and calcareous, forms the Basement System succession.

Psammitic types generally form upstanding ridges or isolated hills protruding from the dissected end-Tertiary peneplain. Semi-pelitic representatives are widespread but they are less resistant to erosion than the psammitic types and exposures are generally found only in stream beds. Pelitic members of the succession are rare and only one thin band was encountered. Calcareous metasediments are fairly common, mainly as bands and lenses of calc-silicate gneiss plus one band of crystalline limestone. Migmatites are prominently developed in a zone in the eastern part of the area.

2. Intrusive Rocks

A small *in situ* occurrence of perknite is thought to be related to the perknite suite that forms a north-easterly trending belt from the Embu-Meru area (Schoeman, 1951) to the Chanler's Falls area (Williams, 1966). The occurrence of fresh float blocks in the Bisanadi river valley suggests that there are intrusions of this hypersthene-bearing suite buried beneath the Nyambeni volcanic rocks. These intrusives are associated with belts of ortho-amphibolites grading into Basement System rocks and are probably Precambrian in age, having been emplaced during the metamorphism of the geosyncline which formed the Basement System metamorphic rocks (cf. Williams, *op. cit.*).

Two small dykes of olivine dolerite were mapped, a Pleistocene age being ascribed to them on the evidence of their likely association with the Nyambeni olivine basalts.

3. Nyambeni Volcanic Series

These volcanic rocks were extruded on a dissected end-Tertiary erosion bevel and are considered to be Pleistocene to Recent in age. They are chiefly olivine basalts of which there are two distinct effusive phases separated by a considerable interval. Two flows of olivine melanephelinite were mapped within the lower olivine basalts, and phonolite flows considered to be younger than the upper olivine basalts, occur in the west.

The numerous vents and craters associated with the Nyambeni episode consist of pumice and scoriaceous lavas, chiefly olivine basalts with occasional olivine melanephelinite, trachyte and doubtful basanite occurrences. The only pyroclastic rocks in the Kinna area occur in the north-west corner where they are overlain by the upper olivine basalts. They are part of a much larger field of pyroclastic rocks mapped in the Chanler's Falls region further north (Williams, 1966).

4. Pleistocene Lake Deposits

These beds, which are mainly of friable limestones, are in part older and in part younger than the Nyambeni lavas. Some of the lake deposits are due to aggradation of river valleys after the formation of lagoons by the damming effect of lava flows, an example of such lake beds being those along the Rojewero near Ndiandaya. Other lake deposits in the northern part of the area are of doubtful age but are thought to post-date the Nyambeni lavas. Fresh water gastropod fossils give no indication as to the age of the beds because of the wide time range (Miocene to Recent) of the forms present.

5. Superficial Deposits and Plio-Pleistocene Sediments

Typical peneplain deposits, including calcareous and ferruginous crustal deposits, are evident in small patches in the north-east where the end-Tertiary erosion bevel is as yet poorly dissected. Elsewhere the surface of the dissected bevel on Basement System rocks is covered with coarse, red sand.

Fine brown, grey and black volcanic soils, present in the central part of the area, are thought to have developed on the older volcanic rocks, but they may be in part due to volcanic dust settling in some of the Pleistocene lakes.

A thin surface crust of calcrete is usually developed on the lacustrine limestones, an exception being the lacustrine deposit near Melka Lorni.

Pink sands with rounded pebbles occur in the Skot and Melka Lorni graben valleys. River exposures indicate that these sands are thick and subsequent work farther east (Wright, in prep.) has shown the graben to be filled with Plio-Pleistocene pebbly sandstones, indicating that the pink sands near Melka Lorni overlie similar pebbly sandstones.

The geological history of the area is summarized below:—

<i>Earth movements</i>	<i>Period</i>	<i>Erosional phases and sequence of events</i>
	Recent	- Formation of soils - Continuance of formation of crustal deposits - Aggradation of rivers due to damming by lava; lacustrine deposits - Further effusive scoriaceous lava cones
Continuation of tilting movements in E. Kenya	Upper Pleistocene	- Phonolite flows and cumulo-domes - Upper olivine basalts - Pumice and scoriaceous lava cones
	Middle Pleistocene	Small explosive phase, tuffs, ashes and scoriaceous lavas
Major rift faulting? Formation of Skot graben and tilt movement in E. Kenya	Lower Pleistocene	- Lower Nyambeni basalts and melane-phelinites - Lacustrine deposits - Calcareous and ferruginous crustal deposits forming throughout Pleistocene period - Dissection of sediment cover and superimposition of drainage - Lagoonal sediments form in Tana valley and fill Skot graben
	Mid-Pliocene	- Tana River begins dissection of end-Tertiary bevel - Completion of erosion and peneplanation cycle forming end-Tertiary peneplain
	Lower Miocene	Completion of erosion and peneplanation cycle forming sub-Miocene peneplain
	Upper Cretaceous	Completion of erosion and peneplanation cycle—forming end-Cretaceous peneplain.
		Basement System land surface
		 Prolonged erosion
	Precambrian	- Intrusion of perknites - Folding and metamorphism - Accumulation of geosynclinal sediments of Mozambiquian Belt.

V—DETAILS OF GEOLOGY

1. Basement System

The Basement System rocks are classified as follows:—

- (1) Psammitic metasediments
 - (a) Quartz-felspar gneisses
Quartz-felspar-hornblende gneisses
 - (b) Quartzites
- (2) Semi-pelitic metasediments
 - (a) Biotite gneisses
 - (b) Biotite-garnet gneisses
- (3) Pelitic metasediments
 - (a) Garnet-sillimanite gneisses
- (4) Calcareous metasediments
 - (a) Crystalline limestones
 - (b) Calc-silicate gneisses
- (5) Metavolcanic rocks
 - (a) Plagioclase amphibolites
- (6) Migmatites
- (7) Undifferentiated Basement System rocks

(1) PSAMMITIC METASEDIMENTS

Quartz-felspar and quartz-felspar-hornblende gneisses have a wide distribution within the Kinna area, and thin bands of quartzite were also mapped. These rocks always form low ridges and inselbergs due to their relative resistance to erosion.

It is supposed that these types represent metamorphosed psammitic members of the sedimentary succession although alkali metasomatism with resultant recrystallization has obliterated all traces of their original sedimentary structures. However, the rocks form both continuous bands and impersistent lenses interstratified with the metamorphic representatives of other rock types, indicating a probable sedimentary origin. The gneisses of psammitic origin are probably derivatives of arkose beds and lenses, whereas the lenticular quartzites are the result of metamorphism of impersistent pure sandstone horizons within the geosynclinal sediments.

(a) *Quartz-felspar and quartz-felspar-hornblende gneisses*

These two types are not differentiated on the map because variations in composition are somewhat irregular, and hornblende occurs with a patchy distribution rather than in particular horizons.

The rocks are usually leucocratic, coarse grained, and weather to a yellow or buff colour, darker if the content of hornblende is considerable. Microscopically the predominant constituents are quartz and felspar, the latter often forming large crystals, with accessory minerals such as magnetite, sphene and apatite.

The quartz and potash felspar form a granular mosaic with the subordinate plagioclase felspar present in interstitial laths. The potash felspar in these rocks, which has probably replaced a lot of original quartz and albite, is nearly always microcline, which shows very distinct cross-hatched twinning in contrast to the second form, microcline-perthite, where the twinning is much less distinct. The plagioclase

is always within the albite-oligoclase range and is subordinate in amount to the potash feldspar. Accessory minerals are magnetite, sometimes showing hydrous alteration, sphene and occasionally apatite.

A specimen typical of the quartz-feldspar gneisses is 37/256* from two miles south-east of Nambala Buyo. In thin section the fabric of this rock consists of quartz, microcline, microcline-perthite and subsidiary plagioclase in the albite-oligoclase range. Numerous small fragments of sphene are also discernible in the slide. Specimen 37/265 from one mile north of Karare trigonometrical beacon shows a quartz-feldspar-hornblende gneiss containing large crystals of quartz and microcline with smaller anhedral crystals of albite. Microcline-perthite is also present and accessories are apatite and sphene. Iron staining has produced bright reddish brown coloration along crystal interfaces. In addition, green hornblende in rather ragged crystals is an important constituent of this rock. Specimen 37/315 from Kubi Ramata is a quartz-feldspar gneiss that contains a small percentage of corundum, the latter being visible both in hand specimen and thin section.

Types with small amounts of biotite, often clearly secondary after hornblende, are common and are considered to be transitional to the quartz-feldspar-biotite gneisses, the latter rocks being classified with the semi-pelitic metasediments. A thin section of 37/345 from the Kiolou river shows large quartz grains, sericitised feldspar (oligoclase), and untwinned feldspar which is possibly orthoclase. Crystals of colourless mica with which are associated ragged flakes of chlorite may in fact be bleached biotite. Small crystals of microcline are also present.

The prominent bands of quartz-feldspar gneiss in the south-western part of the area are continuations of the bands of granitoid gneiss in northern Tharaka which Dodson (1955, p. 14) considers to have crystallized from mobilized rocks. These rocks in the Kinna area are considered to be the representatives of siliceous members of the original sedimentary sequence metamorphosed *in situ*, not remobilized.

(b) Quartzite

Quartzite occurs only sporadically, and most of the outcrops are lenticular suggesting that they were originally impersistent siliceous horizons. The quartzites in the south-west are coarse-grained and white, but the band mapped near Melka Lorni is a dark rock which in hand specimen is seen to consist of clear, dark brown quartz.

In thin section these rocks are seen to consist of an interlocking mosaic of sutured quartz crystals. A thin section of specimen 37/396 from one mile east of Ntoe shows in addition to the quartz, a few small flakes of microcline and specimen 37/263 from one mile south-east of Karare trigonometrical beacon shows a scattering of opaque iron ore granules and fragments of chlorite.

(2) SEMI-PELITIC METASEDIMENTS

These rocks are metamorphosed representatives of former semi-pelitic members of the succession, such types being widespread, particularly in the south-western and central parts.

Generally the foliation produced by the biotite content makes these rocks fairly susceptible to weathering, and they do not form any pronounced feature. Their occurrence is restricted to the lower ground, and their extent is often only traceable by disconnected exposures in stream beds. These rocks have been divided into two groups on the criterion of the presence of garnet in appreciable quantity in some bands.

*Numbers 37/256 etc. refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

(a) *Biotite gneisses*

In hand specimen, these rocks are usually yellow to buff coloured and have a marked foliation due to the orientation of the biotite flakes. Thin section 37/262 from two miles north-west of Karare has a fabric consisting of microcline, microcline-perthite, quartz and plagioclase feldspar with scattered crystals of biotite. Specimen 37/356 is a foliated biotite gneiss from the Kiolou river one mile south-east of Moli in which numerous biotite flakes, strongly pleochroic from light yellow to dark brown, have a marked linear arrangement. Quartz and plagioclase feldspar, both twinned and untwinned, are the other major constituents, together with a few small garnets.

(b) *Biotite-garnet gneisses*

Three bands of biotite-garnet gneiss were mapped. All these occur in association with migmatites, two being at Melka Lorni and one in the Kiolou river.

In hand specimen the rocks are generally light coloured with darker biotite-rich portions. Garnet is a prominent constituent, sometimes forming euhedral crystals up to 10 mm. diameter. They are pinkish brown in colour and are probably of the almandine variety.

Thin section 37/351, from the Kiolou river two and a half miles south-east of the Ura track crossing, is a biotite-garnet gneiss containing much biotite and a few large euhedral pink garnets. The leucocratic constituents are quartz, sericitised feldspar, probably orthoclase, and oligoclase-andesine. Some flakes of sericite and bleached biotite are also present. Sphene and iron ore, the latter often showing alteration to brown hydrous compounds, are accessories. Sample 37/307, from four miles south of Melka Lorni, is similar. Quartz and oligoclase-andesine are the leucocratic minerals and there are also numerous crystals of biotite.

(3) PELITIC METASEDIMENTS

One band of rock to which a pelitic origin can be ascribed was mapped. This is considered to have been an argillaceous horizon in a predominantly semi-pelitic and psammitic succession.

(a) *Garnet-sillimanite gneiss*

This rock is light coloured in hand specimen with dark streaky concentrations of biotite. Euhedral pink garnets and numerous acicular crystals of sillimanite are evident. Thin section 37/333, from the Ithambanchego river at Kichnu, shows euhedral pale pink almandine garnets and needles of sillimanite. Quartz, oligoclase-andesine and biotite are the other minerals present.

(4) CALCAREOUS METASEDIMENTS

Only one band of crystalline limestone representing a previous calcareous sedimentary horizon was mapped but more numerous occurrences of calc-silicate gneisses were encountered. These were impure calcareous beds, probably marls and calcareous sandstones, within the original succession.

(a) *Crystalline limestone*

A thin band of crystalline limestone was discovered in the Kiolou river. In hand specimen, this rock is coarsely crystalline, varies from white to pink in colour and exhibits numerous rhombohedral calcite cleavages. A thin section, 37/339 from the Kiolou-Kathangachi junction, shows the rock to consist of large, interlocking crystals of calcite with a few scattered granules of forsterite. No other calc-silicate minerals are present.

(b) *Calc-silicate gneisses*

A number of small, probably lenticular bodies were mapped and are thought to represent intercalations of calcareous material. Some of the lenses occur near to the crystalline limestone band and in places flank it, but no contact is exposed. Other lenses occur within the migmatite succession and smaller lenticles which have not been differentiated on the map are also present. All these bands and lenses conform to the Basement System strike. In hand specimen the rocks exhibit green, black, brown and violet tints depending upon the identity of the calcium-rich minerals contained in the rocks.

Thin section 37/280, from a large calc-silicate lens within the migmatites at Melka Lorni, Plate Ia, shows large ophitic plates of labradorite-bytownite and numerous crystals of salmon-pink garnet. The garnet forms a large proportion of the slide due to the tendency of this mineral to be concentrated in bands and clots, but this concentration is not typical of the rock as a whole. Other minerals are colourless to pale green diopside, optically negative epidote and strongly pleochroic dark green hornblende.

In 37/281 from the same locality green diopside is present in crystals giving a biaxial positive figure with a large axial angle. Garnets and yellowish green epidote are other constituents.

Specimen 37/294, from a sand river north of Boji, has diopside and garnet as prominent constituents. Some of the almandine garnets enclose dark green, slightly pleochroic material, thought to be chlorite developed as an alteration product. Calcic plagioclase and hornblende strongly pleochroic from yellow to dark green are also present.

The rock from Melka Lorni (37/312) consists of a fine-grained mosaic of clinozoisite granules. In thin section this mineral is colourless, has weak birefringence and exhibits anomalous first order polarization colours with greenish yellow prominent. Garnet and calcic plagioclase are also present.

In sample 37/308 from a segregation in the migmatites one and a half miles west of Gutich, there is epidote showing pleochroism from pale yellow to dark green and giving a biaxial negative figure with an optic angle of approximately 80° . Large salmon-pink garnets and plates of a low birefringent material, probably scapolite, are constituents. Another calc-silicate segregation in gneisses is specimen 37/322 from the Rojewero river at the Equator. This rock consists of green diopside enclosing patches of strongly pleochroic green hornblende and ragged flakes of pleochroic epidote. Aggregates of labradorite-bytownite are also present as is idocrase in aggregates of pale orange-brown, slightly dichroic euhedral crystals giving a uniaxial negative interference figure. Specimen 37/338 from the Kiolou-Kathangachi junction also shows large diopside plates together with hornblende, showing typical amphibole cleavage and irregular patches of calcite.

The rock from the Kiolou river at the Tana track crossing (37/348) is noteworthy for its content of large crystals of scapolite showing two well developed cleavages at right angles, Plate Ib. Diopside, calcic plagioclase and hornblende are associated minerals.

(5) METAVOLCANIC ROCKS

Rocks rich in amphiboles are considered to represent original intercalations of volcanic material inter-stratified with the sediments. These rocks are concordant with the semi-pelitic and migmatitic rocks in which they occur.

(a) *Plagioclase amphibolites*

A number of impersistent bands and lenses of plagioclase amphibolite were mapped. In hand specimen they are usually dark green to black, and are often mottled due to their content of plagioclase. Small bands and lenses, impossible to differentiate on the map, are numerous within the migmatites.

A typical mineral assemblage is illustrated by thin section 37/289 from Melka Lorni. Pale green diopside, much altered to strongly pleochroic blue-green hornblende, forms a large proportion of the rock, the leucocratic minerals being quartz and andesine.

In sample 37/310 from Melka Lorni hornblende and andesine make up the bulk of the rock. In addition this rock contains the manganian zoisite thulite, which is pale pink and pleochroic and displays both normal and berlin blue anomalous interference colours.

(6) HORNBLLENDE MIGMATITES

A large proportion of the metamorphic rocks found within the Kinna area consist of banded migmatitic rocks which are developed in the Basement System in many parts of Kenya. They occur as banded gneisses consisting of alternations of felsic and mafic bands. Occasionally these bands are highly contorted, injection and plastic deformation having taken place. The banding observed over a considerable number of outcrops of migmatite is regular with occasional distortions and irregularities due to injection and plastic flow. In the Melka Lorni region, which appears to form the core of the migmatite zone exposed in the eastern part of the Kinna area, the contortion and disruption of the mafic bands is extreme and much granitic material has been introduced. Ptygmatic folding is common and boudinage structures occur, lenses of amphibolite being enclosed within the plastically deformed rocks. (Plates IIa, b, IIIa.)

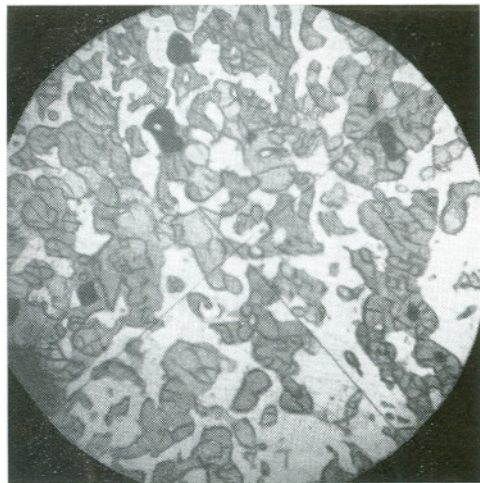
Processes producing such structures have been discussed at length in earlier reports of the Kenya Geological Survey. The process which may be principally responsible is that of magmatic soaking with metasomatism (molecular interchange between host rocks and permeating fluids) taking place. On the other hand, some authors postulate mechanical processes, i.e. *lit-par-lit* injection of acidic material, produced by differential fusion of material at depth. It is considered by the writer that in the Kinna area both processes occurred, the latter mostly in the intensely deformed migmatite zone of Melka Lorni whereas metasomatism played the predominant part elsewhere.

Specimens from the mafic bands have a considerable content of hornblende, biotite being subordinate and leucocratic minerals sometimes forming only a very small proportion of the rock. The felsic bands consist of coarse-grained quartzo-felspathic material that is considered to have been introduced into a host rock represented by the hornblendic bands. Occasionally calc-silicate lenses are found within the migmatite sequence, which is everywhere rich in calcium due to the semi-calcareous nature of the original sediments.

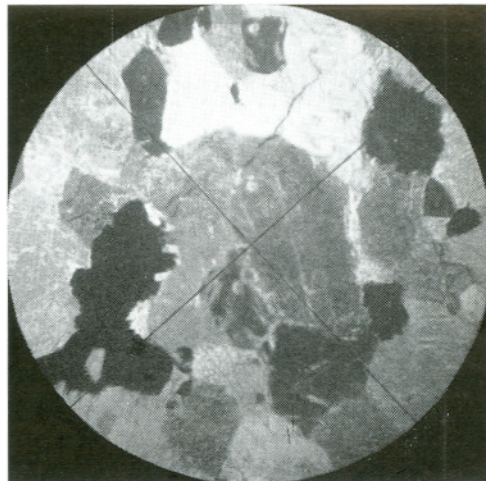
(7) UNDIFFERENTIATED BASEMENT SYSTEM ROCKS

A number of exposures of metamorphic rocks near the eastern boundary of the area were not visited and have therefore been indicated on the map as undifferentiated crystalline rocks. These areas of rock exposure, delimited from aerial photographs, were considered originally to be outside the limits of the map area, due to inaccuracies in the first base map used. The narrow tract of country involved is situated within the Skot graben and consists chiefly of sands overlying sediments, with a few upstanding masses of metamorphic rocks which mark irregularities on the floor of the graben. The small block near the south-eastern corner of the area is faulted on the western side and the small inlier near Sabas has a faulted southern boundary. The block within the graben near Garcia probably consists of rock types similar to the biotite gneisses that form the Melka Yaka horst block. Subsequent work in the area to the east (Wright, report in preparation) has shown that the inliers of metamorphic rocks near the north end of the graben consist of biotite-hornblende gneisses.

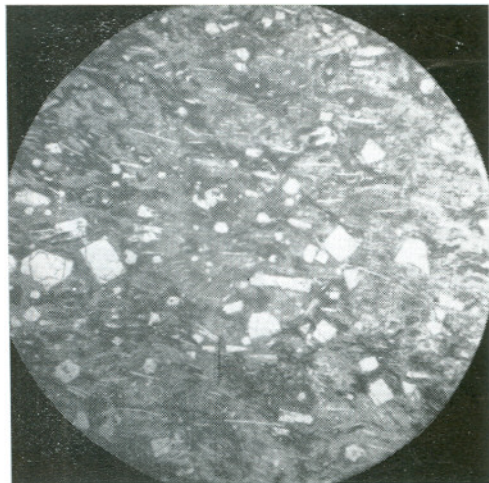
PLATE I



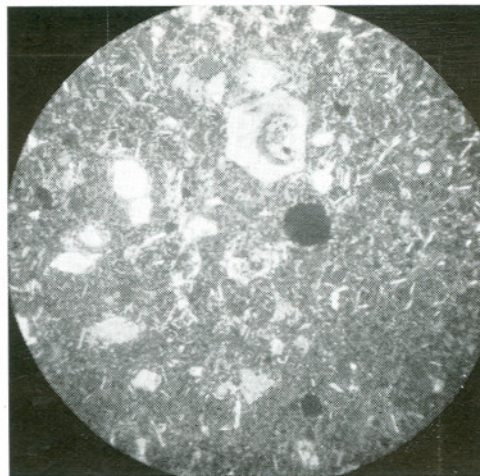
(a) Calc-silicate gneiss 37/280, Melka Lorni. Ordinary light, $\times 20$. Crystals of garnet (dark grey) and epidote (pale grey) enclosed within a crystal of labradorite



(b) Calc-silicate gneiss 37/348, Kiolou river. Crossed nicols, $\times 20$. Large crystal of scapolite (centre) and smaller crystals of scapolite and diopside



(c) Olivine basalt 37/334, Ithambanchego river. Crossed nicols, $\times 20$. Large zoned titanaugite crystal and microphenocrysts of olivine in a groundmass of labradorite laths and titanaugite and magnetite grains.

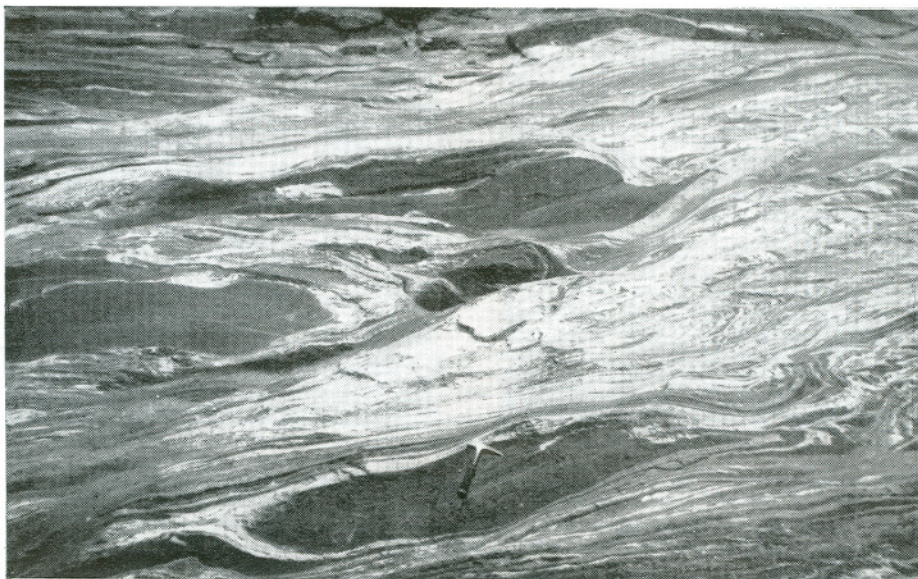


(d) Phonolite 37/402, Thaichu. Ordinary light, $\times 20$. Microphenocryst of nepheline in a groundmass of sanidine laths and aegirine-augite crystals with interstitial nepheline

PLATE II

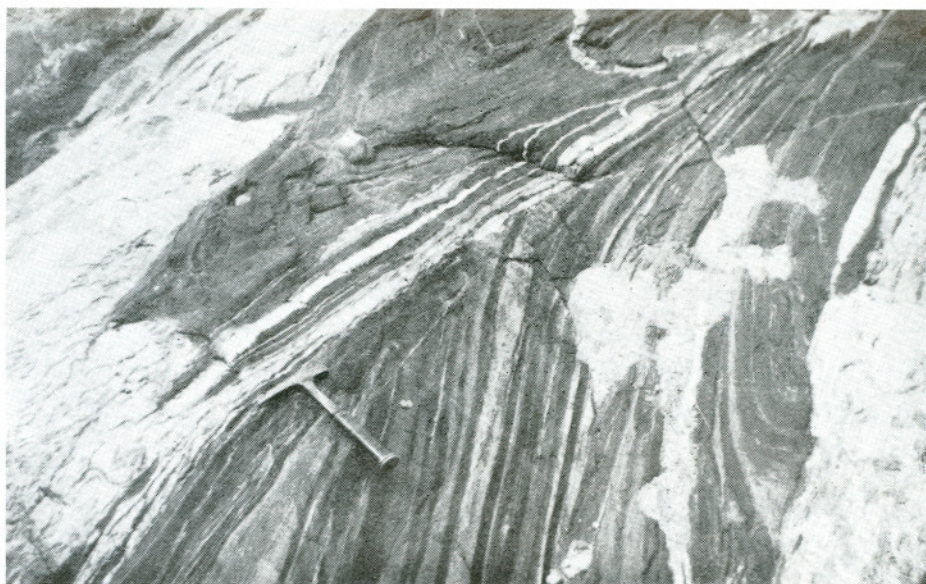


(a) Boudinage structures in migmatite, Melka Lorni



(b) Amphibolite lenses in contorted migmatite, Melka Lorni

PLATE III

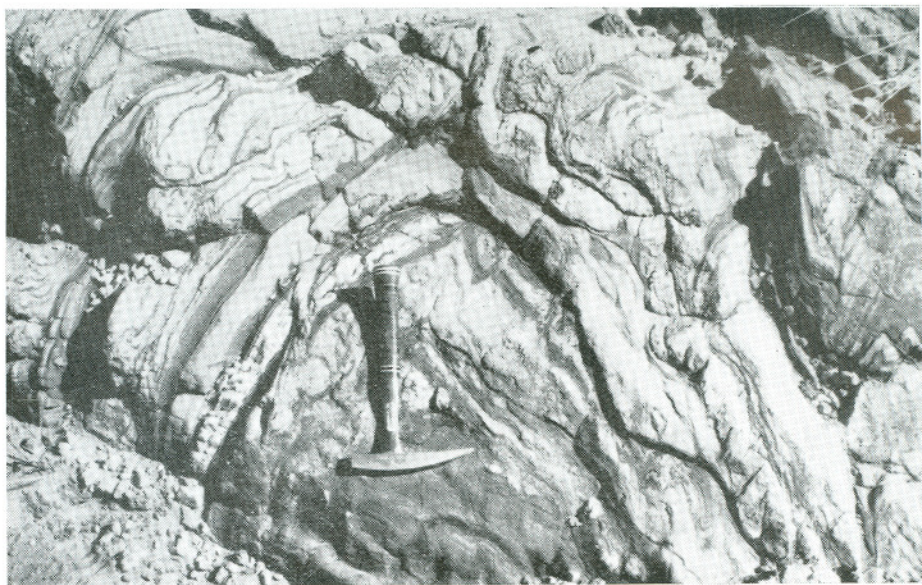


(a) Cross-cutting quartzo-felspathic veins in migmatite, Melka Lorni



(b) Pegmatite veins in banded gneisses, Melka Lorni

PLATE IV



(a) Minor anticlinal fold in banded gneisses, Melka Lorni



(b) Goitu Abaloni crater breached by lava flow

2. Metamorphism and Granitization

The general consensus of opinion concerning the Basement System metamorphism is that an original succession of geosynclinal sediments was regionally metamorphosed into a series of gneisses and schists with the production of broad migmatite belts, and more rarely the production of true granitoid gneisses by processes of granitization during intense crustal movements.

Processes of granitization have been discussed in previous reports and attempts have been made to relate the features displayed by the Kenya Basement System metasediments to a particular granitization process. Schoeman (1951) considers that the banding of the succession in the Embu-Meru and Kitui regions is a reflection of previously existing structures in banded pelitic gneisses, and concludes that the concept of metasomatism is more reconcilable with this feature than is the injection of granitic material. Dodson (1955), however, considers that banding in the migmatites in the North Kitui area is probably due to *lit-par-lit* injection, whereas the more homogeneous types have undergone an evenly distributed alkali metasomatism actuated by magmatic soaking. Sanders (1954) considers that the Basement System gneisses of the Kitui granitization belt have been produced by alkali metasomatic processes; Saggerson (1957) contributes to this view for the major part of the Kitui gneisses but describes injection of material locally along the axis of the Kitui migmatite belt where migmatites and granitoid gneisses occur.

In the present area it is evident that the major process in the production of the more regularly banded gneisses has been alkali metasomatism. However, the irregularly banded migmatites at Melka Lorni, which are considered to be the northern continuation of the Kitui granitization zone, show the development of plastic flow and boudinage structures, and, locally, almost complete loss of banding, indicating *lit-par-lit* injection and differential fusion of host rocks in depth. The latter processes are probably complementary here and take precedence over the purely metasomatic effects which occur further away from this postulated axis of granitization. It has been suggested (Dodson, 1955, p. 22) that this belt is near to the centre of the geosyncline in which the original sediments were deposited. The writer would tentatively agree with this view. Contributory evidence from the present area is the steeply dipping or vertical foliation observed over a large part of the area, particularly in the Melka Lorni belt, and the intensely migmatized rocks of the axial zone.

In the Chanler's Falls area to the north (Williams, 1966) the Basement System structures follow the regional trend observed in the Kinna area, but the overall structure is more complex. The rocks are obscured by younger volcanic rocks between Garba Tula and the Uaso Ngiro river, but looking at the broad regional picture the metamorphic features can be traced northwards in the same way that they can be continued southwards from the Kinna area. However, Williams records two major periods of metamorphism on the evidence of later pernite intrusions having a regional trend slightly inclined to that of the Basement System rocks nearby. The effects of the second metamorphic phase on the already metamorphosed rocks of the Basement System are not easily appreciated in the Chanler's Falls area and in the Kinna area no evidence of two periods of metamorphism was discovered. One pernite intrusion within the Kinna area has surrounding ortho-amphibolites which conform to the regional strike of the metamorphic rocks in this region, suggesting that the emplacement and metamorphism of the pernite intrusions took place during the major Basement System metamorphism.

The mineral assemblages in the area indicate that the rocks belong to the amphibolite facies of Turner and Verhoogen (1951), i.e. regional metamorphism under moderate temperatures and high pressures. The occurrence of sillimanite within the area would suggest that part at least of the rocks studied fall within the sillimanite-almandine sub-facies of the amphibolite facies.

Mineral assemblages in the amphibolites and calc-silicate rocks of the Kinna area are:—

(a) *Amphibolites*

Hornblende-epidote	}	Plus oligoclase, biotite, quartz.
Hornblende-almandine-epidote		
Hornblende-diopside-epidote		
Almandine-diopside-hornblende		

(b) *Calc-silicate rocks*

Epidote-diopside-hornblende	}	Plus scapolite, oligoclase, quartz.
Epidote-zoisite-diopside-calcite		
Garnet-diopside-calcite		

These are typical of the almandine-diopside-hornblende sub-facies, suggesting high grade deep-seated regional metamorphism. Thus two sub-facies of the amphibolite facies would appear to be represented. In the opinion of the writer this is probably a reflection of compositional differences in the original sediments rather than variations in intensity of metamorphism.

Two interesting trends can be traced northwards along the regional strike of the Basement System in eastern Kenya. One is towards gradual disappearance of limestone bands northwards along the regional strike. In the South Kitui area (Saggerson, 1957) limestones are prominent members of the metasedimentary succession, whereas they are less important in the Kitui area further north (Sanders, 1954). In the Mwingi (Crowther, 1957) and North Kitui (Dodson, 1955) areas the distribution has become sporadic. Within the Kinna area only one limestone band was discovered during the present survey, and in the Chanler's Falls area to the north (Williams, 1966) no limestones were recorded. Calc-silicate gneisses and granulites do persist and a considerable thickness of hornblendic rocks occurs within the succession. These trends are presumed by the writer to be reflections of original facies changes within the geosynclinal sedimentary sequence, much of the calcareous rocks in the original sequence in the Kitui region giving way northwards to generally semi-pelitic and psammitic sediments.

Another trend noted is towards disappearance of sillimanite northwards along the regional strike. This mineral has been recorded from a number of areas along the same regional strike as the present area (Dodson, Crowther, Sanders, Saggerson, op. cit.). In the present area only one occurrence of sillimanite has been recorded, and in the Chanler's Falls area to the north the mineral was not found. In the Chanler's Falls area extensive areas of pelitic sediments devoid of sillimanite occur, and Williams concludes that the grade of metamorphism there is relatively moderate. It is possible that there is a slight general decrease in metamorphic intensity northwards along the regional strike from a maximum intensity in the Kitui region.

3. Intrusives

Minor occurrences of rocks intrusive into the Basement System were encountered in the Kinna area. A small intrusion of perknite, probably Precambrian in age, and a number of intrusive pegmatites of post-Basement System age were found. Two dykes of olivine dolerite, which are genetically associated with the Nyambeni lavas and therefore probably Pleistocene in age, were also mapped.

(1) PEGMATITES

These rocks occur as discordant intrusions exhibiting sharp contacts with the surrounding rocks. They appear to have been intruded along lines of weakness in the Melka Lorni region, where faults and associated pegmatite intrusions can be

traced in stream sections. The pegmatite veins are very irregular and often have anastomosing veins intruding the country rock for some distance, as a result of *lit-par-lit* injection (Plate IIIb). The margins of the veins are finer in grain than the central portions but the difference is not well marked.

In appearance the pegmatites are coarse-grained, white to pink, quartzo-felspathic rocks. A feature is the presence within them of ovoid and irregular mineral segregations notably epidote, biotite and magnetite, the latter being the most common.

These rocks are late-stage pegmatites intrusive into the metasediments. Field relations indicate that the pegmatites owe their origin to magmatic injection rather than anatexis or ionic diffusion in the solid state.

(2) PERKNITES

Perkrite is exposed in the Kiolou river in association with ortho-amphibolites which appear to be conformable with the Basement System metasediments in this region. It appears that the emplacement of this perkrite occurred during the metamorphism of the original sediments, the metamorphism of the perkrite being contemporaneous.

The rocks exposed in the Kiolou river are dark, glistening rocks with numerous amphiboles. In thin section 37/352, from the Kiolou river, two miles south-east of the Ura track crossing, it is seen that almost 40 per cent of the rock consists of hornblende showing strong pleochroism from light yellowish brown to dark brown. This hornblende is considered to be partly original but mostly secondary as a result of amphibolitization of ortho- and clinopyroxene in the perkrite. The orthopyroxene is hypersthene which is present in large plates showing very distinctive pleochroism from pink to colourless or more rarely very pale green. The clinopyroxene is colourless to pale green augite.

From the mineral composition it would appear that this rock is a partially amphibolitised hornblende websterite (cf. Pulfrey, 1946). This rock is therefore a type transitional between a true unmodified perkrite and its completely amphibolitised representative, an ortho-amphibolite. This rock is considered to be associated with the suite of perknitic rocks in the Embu-Meru area (Pulfrey, op. cit. Schoeman, 1951) and its extension in the Chanler's Falls and Archer's Post areas (Williams, 1966 and Jennings, 1967). In the former area it is seen that the main belt trends north-north-easterly but some lateral scatter of exposures of intrusive perkrite occurs away from the axis of the belt. This axis almost coincides with the axis of the Nyambeni Range and it is to be expected that perknites and gabbros of this suite are buried beneath the lavas that form the range. Evidence of this was obtained from the Kinna area. The basalt lava flow which extends from Kinna to Melka Lorni undoubtedly flowed in a large pre-existing river valley draining south-eastwards to the Tana river. In the lower part of this valley, which was not inundated by lava, where it crosses the exposed metamorphic rocks at Melka Lorni fragments of unaltered perkrite were discovered which are presumed to have come from hypersthene-bearing intrusions now buried beneath the high eastern slopes of the Nyambeni Range. In thin section 37/272 of this rock interlocking green augite crystals are seen to make up most of the rock, with plates of orthopyroxene showing ophitic relationship to it. The orthopyroxene is hypersthene, either colourless or pleochroic from pink to colourless, with a high birefringence. Some pale green hornblende accompanies the augite, and andesine-labradorite is present in large, well twinned crystals. Dactylic and amoeboid growths of dark green pleonaste spinel showing complex intergrowth relationships with augite and hornblende are a prominent feature of the thin section. The rock is considered to be a spineliferous hornblende websterite.

Another float specimen, 37/330, was obtained from a tributary of the Bisanadi near to the edge of the lava flow which now fills the major valley. In thin section the rock is seen to contain pleochroic hypersthene, blebs and dactylic growths of

dark green pleonaste spinel, light green augite and slightly more plagioclase feldspar than 37/272. This rock is also derived from concealed hypersthene rocks and is identified as a slightly less basic type, a spineliferous melanocratic hyperite.

(3) ORTHO-AMPHIBOLITES

The only undoubted metamorphosed intrusive rock within the area is the band of amphibolite which contains the perknite already described. In the Kiolou river section the amphibolite is conformable within the Basement System succession. Examination of specimen 37/352 from this locality shows that it is a partially amphibolitised websterite, a type transitional to true ortho-amphibolites. It was considered justifiable to indicate this as a core of perknite but restricted to the river section exposure. Away from the river section the exposure of amphibolitic rocks can be traced only by surface fragments. It appears that these flanking rocks are ortho-amphibolites grading into other Basement System rock types from the central perknitic core. The much larger intrusions in the Chanler's Falls area (Williams, 1966) show similar features, large bodies of hypersthene-bearing rocks exhibiting relatively unmodified cores surrounded by zones of amphibolitised perknites and ortho-amphibolites conformable with Basement System metasediments.

(4) OLIVINE DOLERITES

Two dyke intrusions of rocks of basaltic composition were mapped in the eastern part of the area. These dykes are probably feeder dykes of the lower olivine basalts of the Nyambeni Volcanic Series, having been intruded along fissures, joints or other planes of weakness. They are therefore Lower Pleistocene in age and in composition are the hypabyssal equivalents of the olivine basalts.

Thin sections 37/259 from half-a-mile east of Peggy trigonometrical station and 37/282 from Melka Lorni show that these rocks are coarser in grain than the olivine basalts and consist of large titanite crystals and labradorite laths, the two minerals exhibiting an ophitic texture. Large euhedral olivines, locally replaced by iddingsite, are present and magnetite is an abundant secondary mineral. 2V determinations on the olivine phenocrysts indicate only slight enrichment in iron.

Specimen 37/311 from Melka Lorni again contains plagioclase laths and titanite crystals in ophitic relationship, with abundant magnetite. Feldspar phenocrysts are of the composition andesine-labradorite, whereas the groundmass feldspars are oligoclase-andesine. Vesicles are present infilled with calcite fringed with a green fibrous mineral possibly chlorite.

4. Plio-Pleistocene Sediments

Photogeological evidence for the presence of sediments in the Skot graben valley and its branch, the Melka Lorni graben, is the marked contrast of tone vegetation and drainage pattern between the sand-covered metamorphic rocks and the sand-covered sediments. In the Kinna area, sediments are exposed only near Skot on the eastern margin of the area. However, the nature of the sands east of the Melka Lorni fault gives strong indication of an underlying sedimentary formation delimited by the graben faults.

The sands in the graben are pink to white with many rounded quartz pebbles on the surface, particularly in the Ogargesa region near the northern end where extensive pebble sheets occur. Bluffs in the Lagabowa and Bisanadi rivers expose a considerable thickness of sands but most of these are probably alluvial in origin. Near Skot clayey and sandy sediments are exposed in the Bisanadi and have recently been found to be very extensive in the Kora Wells area to the east (Wright, in prep.). The coarse, pebbly nature of the sands east of the Melka Lorni fault and the presence of sediments near Skot suggest that the sedimentary material preserved in the graben consists of pebbly calcareous sandstones overlain by a thick layer of superficial material.

The age of the sediments in the graben is Plio-Pleistocene, the major evidence for this assertion being physiographical. Extensive outcrops of sediments of the same age occur further east (Wright, op. cit.) and in fact a major portion of north and east Kenya is covered by these deposits (cf. Dixey, 1955). In eastern Kenya most of the available stratigraphical information has been obtained from oil exploration boreholes, where the presence of foraminifera confirms estuarine or lagoonal conditions in eastern Kenya. The floors of the lagoons and swamps are considered to have been subsiding due to recurrent tilting movements from Upper Pliocene onwards, resulting in the accumulation of a considerable thickness of shallow water sediments.

5. Nyambeni Volcanic Series

This term was used by Schoeman to refer to the olivine basalts from Nyambeni vents resting on the end-Tertiary bevel in the Embu-Meru area (Schoeman, 1951). During the mapping of the Nyambeni range the term was extended to include all the volcanic rocks associated with the range (Mason, 1955). Work in the Kinna area completes the mapping of the Nyambeni volcanic rocks and the term Nyambeni Volcanic Series is used to include all the volcanic rocks resulting from the Nyambeni vulcanicity.

In the present area, a number of rock types are recognized and described below.

(1) OLIVINE BASALT GROUP

The greater part of the extrusive rocks of the Nyambeni Range consists of olivine basalts. Within the Kinna area it is possible to differentiate two distinct episodes of basalt extrusion. The lower olivine basalts were the initial flood basalts erupted from north-north-easterly aligned fissures along what is now the axis of the Nyambeni Range. The pre-existing Basement System topography was inundated by relatively fluid and mobile olivine basalt lava. Tongues flowed down pre-existing river valleys and penetrated a considerable distance south-eastwards along them. This produced the parallel drainage and inversion of topography which are typical features of this type of lava country. The process envisaged is a quiet welling up and extrusion of lava in relatively mobile sheets. The upper olivine basalts exhibit a much more youthful topography, typified by distinct flow scarps and the development of narrow, steep-sided drainage channels.

In hand specimen the olivine basalts are dark blue to black aphanitic rocks and few differences are discernible in the field. Occasionally olivine crystals are observed in some types and in others a finely vesicular texture can be seen, the vesicles being usually infilled with carbonate although zirconites are sometimes present. In thin section the rocks exhibit considerable variation. Normal olivine basalts predominate but they grade through transitional types to basanites and mugearites.

(a) Olivine Basalts (*Fig. 3 at End*)

Olivine is almost always present as microphenocrysts, and in very few of the sections examined were olivine crystals noted in the groundmass as a second generation. Most of the olivines are partially resorbed and have uniform rims of brown iddingsite, and rarely the olivines are completely pseudomorphed by brown iddingsite. Numerous 2V determinations on optic axis sections of the olivines show that in all cases the optic axial angle is large, in the region of 80° to 90°. A few sections showed slight curvature of the isogyre and indicated positive optical character. These determinations indicate the magnesian character of the olivine and the lack of enrichment in iron.

The clinopyroxene in these rocks is always titanaugite, usually violet in colour and strongly zoned, the outer zones typically exhibiting the deepest colours. This mineral occurs in two generations, as large zoned phenocrysts and as small laths and granules in the groundmass. Both generations seem equally rich in titanium.

The plagioclase in the olivine basalts lies within the labradorite range. The plagioclase typically forms one generation of crystals, in the groundmass, and in only a few sections were plagioclase phenocrysts noted. The proportion of plagioclase in these rocks varies considerably and some might be classified as melabasalts.

Magnetite is an important accessory mineral and the groundmass of most of the olivine basalts is highly charged with magnetite granules and octahedra. Zeolites and calcite infill occasional cavities and vesicles in the lavas.

The mineralogy of the upper olivine basalts is exactly similar, and the latter rocks also show basanite variants. Specimens typical of the olivine basalts of both the upper and lower series are:—

37/284 from Melka Lorni, 37/334 (Plate I (c)) and 341 from Kichnu, 37/353 from Rojewero-Murera confluence. 37/358 from Bwatherongi river, 37/387 from Thangatha river, 37/360 from Rojewero river and 37/389 from two miles west of Kinna.

(b) *Basanites*

In thin section some olivine basalts are seen to be deficient in plagioclase to such an extent that the mineral is reduced to scattered needles and laths in the groundmass, which also contains interstitial nepheline. These rocks are therefore typical basanites. Basanites occur with apparent random distribution in both the lower and upper series of olivine basalts, and very detailed mapping would be required to differentiate them on the map.

The mineralogy of the basanites is similar to that of the olivine basalts, the difference being that the plagioclase is quite subordinate to the clinopyroxene which forms most of the rock. The latter mineral displays attractive zoned phenocrysts and a late generation of granules in the groundmass. Olivine is present as phenocrysts somewhat smaller than those of clinopyroxene. Magnetite is ubiquitous as an accessory mineral, and nepheline occurs as minute interstitial crystals in the groundmass. Examples of basanites are 37/245 from two miles north-west of Kinna Peak and 37/394 and 395 from Magado crater track near Malala.

(c) *Mugearites*

A number of basaltic specimens were collected in which olivine and oligoclase-andesine are important; the presence of more sodic plagioclase in these basalts classifies them as having mugearitic affinities. No differentiation is possible on the map as these varieties are widely distributed and like the basanites seem to occur throughout the lower olivine basalt sequence rather than within a given group of flows.

In thin section (cf. 37/373 from the Kinna-Maua track east of Ngaya Forest) the rocks are typically of fine grain and less melanocratic than the normal olivine basalt. Olivine is usually not quite so abundant, while the more sodic plagioclase and clinopyroxene are the important constituents. Like the olivine basalts the texture is intergranular, the plagioclase forming a mosaic with the clinopyroxene and micro-phenocrysts of olivine.

(2) OLIVINE MELANEPHELINITES

Two flows of ultra-basic lavas were mapped in the Kinna area. In hand specimen these rocks are black aphanitic types which are virtually impossible to distinguish from olivine basalt. In thin section, however, these rocks are seen to contain no plagioclase feldspar. The predominant mineral is clinopyroxene but olivine is an essential constituent. Interstitial nepheline is present in the groundmass.

The two olivine melanephelinites show quite different textures. The flow near Garba Tula is coarse-grained and shows well developed crystals of titanite in two generations, and at first sight appears to be an augite. The Kinna flow, however, (specimen 37/250) is of very fine grain and exhibits only a groundmass generation of clinopyroxene crystals.

The clinopyroxene is a zoned, purple, titaniferous augite. In specimen 37/253, from the flow near Garba Tula, the large titanites are most distinctive in the thin section, and a further generation of small twinned titanite granules forms most of the groundmass.

Olivine forms phenocrysts generally smaller than the titanite. In 37/252 from the Garba Tula flow olivines form fairly large phenocrysts but 37/250 from Kinna shows olivine only as microphenocrysts with a remarkable preferred orientation. Most of the olivines in the latter section show yellow or grey first order polarization colours enabling good optic axis interference figures to be obtained. The axial angle proves to be almost 90° , and their composition is therefore magnesian.

Nepheline in the melanephelinites can only be discerned by using high microscope magnification. It occurs in granules interstitial to the clinopyroxene in the groundmass.

(3) TUFFS, ASHES AND PUMICE BEDS

The small exposure of tuffs, ashes and pumice in the extreme north-west of the area is a southward continuation of a large outcrop of pyroclastics mapped in the Magado region (Williams, 1966). In the latter area these rocks are well exposed in stream sections and gullies, but in the present area exposures are few and small, and much of their outcrop is mantled by debris from the nearby later cones and vents. Near Malala the tuffs appear to pass beneath the upper olivine basalts, and thus to be older than those basalts. In contrast, the scoriaceous lavas and pumice from the vents themselves are demonstrably younger than the upper basalts.

(4) PHONOLITES

In the western part of the Kinna area tongues of phonolite extend eastwards from the higher parts of the Nyambeni Range. The flows have flat tops with very marked scarp edges usually deeply dissected into gullies, and are thus very distinctive on aerial photographs.

In hand specimen the phonolite is of dark greyish green colour, flecked with white, and is fine grained non-porphyritic and fissile. A typical thin section, 37/402 from Thaichu (Plate 1 (d)) shows numerous microphenocrysts of nepheline, usually square in cross-section and often zoned, set in a fine-grained groundmass of fluxionally orientated laths of feldspar and grains of green aegirine-augite with interstitial grains of nepheline. Dendritic crystals of brown, slightly pleochroic cossyrite together with occasional crystals of light brown pleochroic kataphorite are also present in the groundmass. The zoning of the nepheline phenocrysts was well brought out by the staining technique used to differentiate the interstitial nepheline. The feldspar is a member of the sanidine-anorthoclase cryptoperthite series, and from its clarity and lack of polysynthetic twinning is referred to the sanidine division.

(5) PUMICE AND SCORIACEOUS LAVAS OF CRATERS AND VENTS

The numerous volcanic cones within the area consist of pumice and reddish scoriaceous lava, often ropy, with a few lava bombs on the sides of the cones. Numerous well developed clinopyroxene crystals can be picked up on the sides of the vents.

The notable feature of these vents is the apparent absence of pyroclastics. At first sight eroded fans near some of the older vents appear to be of tuffs and ashes but on closer examination the fragments are seen to be scoriaceous lava and pumice fragments eroded from the vents.

Petrologically the rocks vary somewhat between individual vents but it was found that the lavas from any one vent are reasonably uniform in composition. All except three of the vents are of olivine basalt or basanite. One vent is a rather unusual occurrence of lamprobolite trachyte and two others are of olivine melanephelinite.

In thin section the scoriaceous lavas are more glassy than specimens from lava flows. Most of them exhibit a basaltic composition in that they contain titanite phenocrysts, more rarely olivine, and needles of plagioclase in a cloudy groundmass usually containing abundant clinopyroxene and magnetite granules. Cavities and seams are common, and are often filled with calcite or fibrous zeolites. Most of them tend towards a melabasaltic composition, plagioclase never being a very prominent constituent. No undoubted primary, interstitial feldspathoid was identified in these rocks but nepheline was suspected in some of the vent rocks. Examples of scoriaceous basaltic rocks are 37/362 from Kilimakieru, 37/393 from Kinulu, 37/404 from Rumbini and 37/409 from Kamaaru.

The rocks from the two vents of scoriaceous olivine melanephelinite lava, Kinna (specimen 37/344) and Ntoe (37/397) are distinctive in thin section. Numerous microphenocrysts of partially resorbed olivine with brown iddingsite borders are seen, but plagioclase is absent. The groundmass enclosing the olivine microphenocrysts contains granules of magnetite, clinopyroxene and interstitial nepheline. The volcanic vents of Kinna and Ntoe are more than twenty miles apart, and clearly do not share the same magma chamber.

The single occurrence of trachyte forms Nyonyoni vent, which consists of a greyish lava flecked with white and having a red oxidation crust. The lava is compact rather than scoriaceous or ropy and is considered to have been fairly viscous when extruded.

Thin sections of this rock 37/382 and 383, show the rock to have numerous pleochroic brown lamprobolite crystals exhibiting good crystal shapes but with varying degrees of magmatic corrosion, the latter condition indicating that the mineral was not in stable equilibrium in its magmatic environment. Most of the crystals show aureoles of magnetite with an unaltered core of lamprobolite, but some are completely replaced. The other important constituents of the rock are aegirine-augite and feldspar, which form a fine-grained groundmass with a strong fluxional orientation typical of trachytes. The aegirine-augite is present as laths and granules whereas the feldspar forms small needles. The latter are assumed, because of their clarity, to be sanidine.

The lava from Githoi is problematical. In hand specimen the lava is a compact red rock, highly contaminated and with numerous cracks and vesicles infilled with white material. It contains xenoliths of basaltic lava of a type which occurs as flows nearby. In thin section 37/365 it is somewhat glassy and amorphous with zeolite filled cavities in a dark reddish black matrix. This rock may have been extruded as a viscous plug or neck of highly contaminated trachyte lava, possibly autobrecciated.

6. Pleistocene Lake Beds

Exposures of fossiliferous calcareous rocks occur in this area, typically associated with the lava flows. These are lacustrine sediments laid down in large, shallow lagoons, many of which have arisen by the damming of drainage channels along the edges of lava flows.

The relationships of these rocks to the lava flows is not always clear. In the Kinna region the Melka Lorni lava flow dammed the southerly flowing streams situated to the north of the flow. The river was then aggraded and deposits of bedded friable limestones were formed along the sides of the flow. Similarly, the Rojewero river lava flow resulted in some obstruction of the drainage and bedded limestone deposits were formed in marginal lagoons. These rocks have risen as a direct result of the obstruction of the drainage by lava and are therefore younger than the lava.

However, other occurrences such as the lacustrine deposits between Garba Tula and Kinna form flat expanses terminating at the foot of scarps of olivine basalt lava flows. No borehole evidence is available so it cannot be proved whether or not these deposits extend under the lava flows, but it is considered highly likely that they do so from evidence of the abrupt termination against the lava. As an example, the olivine melanephelinite flow in the north of the area near Garba Tula has lake beds situated on either flank, and their extent is not elongated and marginal as would probably be the case if this were due to obstruction of the drainage. It therefore appears that these beds extend under the lava, the melanephelinite having flowed across pre-existing lake beds. Other evidence is obtained by analogy with adjacent areas. In the Chanler's Falls area (Williams, 1966) these beds have been penetrated by boreholes which show that limestones and clays rest on the Basement System. This is apparently the case throughout that region, and it is concluded that all the beds are of Lower Pleistocene age. In the Archer's Post area, however, (Jennings, 1967), damming of the Uaso Ngiro by lava has taken place and some lagoons post-dated the lava, while river sections show that elsewhere these beds are overlain by lavas, with interdigitation in places.

The Kinna-Garba Tula occurrences are flat lying, the surface indication being a superficial layer of calcrete a few feet thick on the upper surface of the limestone beds. Only where small stream sections occur, e.g. at Kithima-ya-Mugomo, is one able to observe that the surface sheets of calcrete are a superficial expression of underlying lake beds. It is not known whether the lake beds rest directly on metamorphic rocks or on basalt covering the latter rocks. They are undoubtedly in part overlain by basalts.

The lake deposits at Melka Lorni are also pre-lava, but owe their origin to a late movement of the Melka Lorni graben fault which caused uplift of the shoulder and ponding back of the Bisanadi to form a lake. These deposits have no calcrete crust but are exposed as surface mounds with still faint traces of bedding and exhibit little recementation due presumably to relatively rapid erosion by the Bisanadi. The deposits which are post-lava in age are very similar in appearance to the pre-lava lagoonal types. A calcrete crust is often developed and there are numerous fragments of lava in the beds near the margins of the flows. This is particularly well seen in the Rojewero at Ndiandaya. In hand specimen the lake deposit from Melka Lorni is typically a white, homogeneous, friable limestone. Specimens from the Kinna-Garba Tula lagoonal deposits are indistinguishable from normal calcareous crustal deposits, but rare stream sections indicate the presence of limestone beneath this secondary crust. In the absence of stream sections it is sometimes possible to find fossils in the recemented surface material, indicating that this material is not the normal calcrete developed on metamorphic rocks.

In thin section (e.g. 37/291 from Melka Lorni) friable limestone is seen to be a homogeneous mass of fine-grained calcite with areas of coarser crystalline calcite which represent shell fragments. Of the recemented types 37/286 from two miles west of Boji is recemented with veins and fissures of more coarsely crystalline calcite, and 37/328 from Melka Gorbessa shows large ovoid structures in the calcite. Sample 37/329, also from Melka Gorbessa, appears to be a cryptocrystalline mass of calcite and silica, and the reaction with acid is rather slow. Specimen 37/401, from Ndiandaya, is less well recemented and areas of differential staining are present in the calcite. In most of the latter specimens fragments of extraneous material are evident, mainly angular fragments of quartz, hornblende, plagioclase and microcline.

Fossils—Three fossil localities are marked within the present area, the most prolific being the occurrence near the Rojewero. The species are all fresh water gastropods ranging from Pleistocene to Recent, and thus useless for dating purposes. Two species were found in the Kinna area as against three in the Archer's Post area. These were

identified by making comparisons with descriptions by J. Parkinson of material which he collected in the Garba Tula and Archer's Post regions (Parkinson, 1920), the fossils having been identified by Mr. R. Bullen Newton. The two fossil species present in the Kinna area are *Planorbis* sp. and *Melania tuberculata*. The species recorded by Parkinson from Archer's Post, but which was not found in the Kinna area, is *Limicolaria rectistringata*. This fossil is common in the former area (Jennings, 1967) and is considered likely to be present in the Kinna beds. Specimens containing fossils are 37/336 (*Melania*) and 37/398 (*Planorbis*).

7. Quaternary Superficial Deposits

The first two types discussed below are typical peneplain deposits. They are developed only in the north-eastern portion of the area where the end-Tertiary peneplain is preserved along the watershed between the Tana and Uaso Ngiro rivers.

(a) Ferruginous Crustal Deposits

These deposits, which occur in the main watershed region in the north-eastern corner of the area, are bright red in colour and contain quartz and gneiss pebbles in a hard lateritic matrix. This highly ferruginous residual formation is the result of leaching and capillary action experienced during tropical weathering conditions.

(b) Calcareous Crustal Deposits

Small patches of carbonate-rich residual deposits were also mapped in the north-east corner of the area. Though similar in appearance to the calcrete crusts developed on the lake beds, these deposits have formed on bevelled metamorphic rocks. They have an origin similar to that of the ferruginous types, but enrichment of calcium carbonate has taken place in this case.

(c) Red Sandy Soils

These developed as an ubiquitous cover on the metamorphic rocks, and consist largely of angular fragments of quartz in a finer floury matrix derived from the breakdown of the underlying crystalline rocks.

(d) Pink Sands With Pebbles

Coarse pink and white sands overlie Plio-Pleistocene pebbly sandstones in the Skot and Melka Lorni graben valleys. They contain numerous pebbles, usually rounded, of quartz, felspar and gneiss fragments. The pebbles typically form a thin scattering over the surface of the sediments in the graben but in places, as near Ogargesa at the north end of the graben, they are concentrated to form pebble sheets.

(e) Brown, Grey and Black Volcanic Soils

Dusty brown, grey and black volcanic soils form extensive flat areas adjacent to the edges of olivine basalt flows. It is not certain whether these soils overlie some of the oldest olivine basalt flows or whether they are the result of erosion of nearby lavas and deposition of fine volcanic material in lagoons.

The black soils often surround areas of lake beds, some of which consist largely of fine, volcanic fragments, but there are large areas of volcanic soils under which it is fairly certain there are no lake beds. Thus it is likely that the volcanic soils are developed on some of the earliest basalt flows, but no more definite evidence can be advanced. These grey and black soils absorb moisture readily, the result being the production of black cotton soils typical of areas of bad drainage.

VI—STRUCTURE

Structural information in the metamorphic rocks is not very abundant because almost two-thirds of the area is obscured by lava, and in the remaining one-third bed rock is often poorly exposed, particularly in the north-east and south. However, the structure of the exposed Basement System appears to be relatively simple (Figure 2).

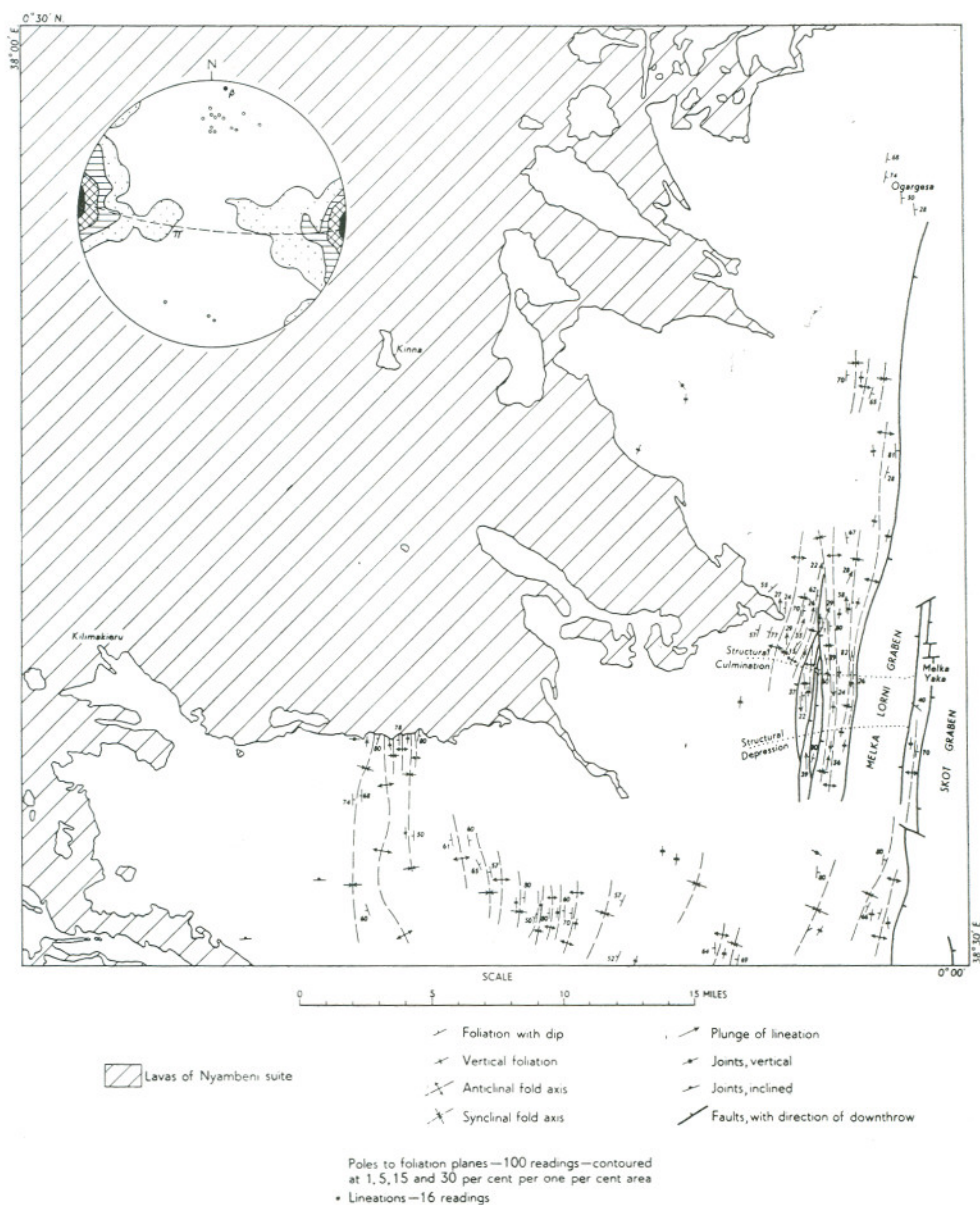


Fig. 2—Structural map of the Kinna area

1. FOLDS

Lineation and foliation measurements were plotted on a stereographic projection (inset Figure 2). The rocks were found to be structurally homogeneous with respect to an axis trending 006° and plunging at 5° northwards. A feature of the folding is the very high proportion of vertical and steeply dipping beds. Few occurrences of gently dipping beds were observed and no beds were seen in a horizontal attitude, indicating that the folds near Melka Lorni are tightly packed and near isoclinal. A reversal of the plunge direction of the lineations points to a structural culmination in the Melka Lorni region. These folds which are shown in the section on the geological map clearly indicate the effects of the severe compressional forces which were operative in this region. Farther away from this zone of relatively intense folding the folds are a little more open, but the incidence of vertical beds is still high. Minor folds were observed at a number of localities (Plate IV (a)).

The structural geometry of the region results in a distribution of outcrop which makes structural interpretation relatively easy. Vertical beds, which are of necessity parallel to a fold axis, produce a series of near straight outcrops parallel to the major fold axes. The psammitic bands near Melka Lorni are the most resistant members of the succession and indicate a near closure before the outcrops are obscured south of the Bisanadi river. This closure is a very acute one due to the low gradient of the fold axis and the vertical attitude of the beds.

A relationship exists in the Kinna area between the intense folding in the Melka Lorni region and the granitization axis and migmatite belt to which reference has already been made. This supplies further evidence for the tentative assertion that the belt of intensely folded migmatitic rocks, traceable from some distance southwards, is situated in what was originally a central position in the geosyncline in which these sediments accumulated.

The structural homogeneity is apparent in the adjacent North Kitui area (Dodson, 1955) and Archer's Post area (Jennings, 1967). However, two periods of folding have been recognized in the Chanler's Falls area (Williams, 1966) associated with two periods of metamorphism. No evidence was obtained in the Kinna area to suggest the presence of two periods of folding.

2. FAULTS

Faults in the Kinna area are of two distinct ages. The older faults are those at Melka Lorni which have been intruded by pegmatites; they are probably post-Basement System metamorphism in age. The westernmost of these older faults at Melka Lorni appears to be a normal fault with quite a large downthrow, whereas the others are reversed faults with relatively little movement. The evidence for the existence of these faults is the juxtaposition of different rock types, resulting in step features in the river bed, the river often following the line of weakness, and the presence of intrusive pegmatites along the faults.

The younger set of faults are those which have formed the western faults of the Skot graben valley and the Melka Yaka horst. The evidence for the presence of the western fault of the Melka Lorni graben is the remarkable straight line boundary, seen on aerial photographs, between an upstanding surface of metamorphic rocks on the west and a flat area of white sand to the east. This fault extends northwards in a gently curving course and eventually dies out near Ogargesa. It downthrows to the east and is thought to have a maximum throw of 300 to 400 feet north of Melka Lorni.

The westernmost fault of the Melka Yaka horst block is relatively short and forms the eastern boundary of the Melka Lorni graben. The eastern fault of the horst block now takes the place of the Melka Lorni fault as the western boundary fault of the major graben. This fault is stepped at intervals due, it is thought, to short cross faults.

On the air photographs the fault boundaries of the horst block show up as straight lines with abrupt steps in them. The throw of the fault near the Equator in the Kinna area is probably of the order of 600 feet. A small Basement System outcrop occurs in the extreme south-eastern corner of the area in the main graben, and appears to be a triangular wedge faulted on the east only and now tilted and protruding through the sediments.

The only other suggestion of faulting within the Kinna area is a possible sub-lava fault near Kinna giving rise to the line of springs running south-westwards from Kinna to Kilimakieru.

VII—ECONOMIC GEOLOGY AND WATER SUPPLIES

1. Minerals

A few minerals were discovered during the mapping but they are all present in very small quantities, and are unlikely to prove of value.

Garnet—Garnets are locally abundant in the garnetiferous gneiss bands. They are, however, of rather poor quality and do not reach a size greater than 10 mm. in diameter. No garnets of gemstone quality were seen.

Magnetite—Segregations of magnetite occur at Melka Lorni and also on the southern boundary of the area near Kalusikaumu. The former are irregular segregations in pegmatites, small and of no economic importance. The latter are magnetite-bearing quartzo-felspathic gneisses which are considered to be a continuation of the magnetite-bearing granitoid gneiss zone of Tharaka (Dodson, 1955).

Building Sands—Numerous sand rivers in the area contain coarse quartz sands which would be suitable as building sands. It has not been necessary to exploit these but abundant supplies are available if required.

Black Sands—Occasional concentrations of black sands occur in some of the sand rivers, particularly the Kiolou and Kathangachi. These consist chiefly of magnetite and ilmenite but are not considered extensive enough to be significant.

Persistent rumours of alluvial gold within the area are, in the opinion of the writer, completely unfounded. *Radiometric monitoring* was carried out during traversing on the metamorphic rocks. No traces of radioactivity were noted and the prospects of discovering radioactive minerals in the area are considered remote. A traverse by car-borne scintillometer was undertaken from Garba Tula to Maua via Kinna. Results were negative except for a slightly higher response near Kinna.

2. Water Supplies

The only mineral of economic importance associated with the lavas is water, though the lavas themselves might prove useful for aggregates for building projects. The run off from the Nyambeni Range is very important as a source of surface water for the lowland areas, and to recharge the ground water table. The water supplies of the Northern and Central Province portions of the area are discussed separately below.

(1) NORTHERN PROVINCE PORTION

(a) Existing Supplies

Existing supplies in the Northern Province portion of the Kinna area, viz. north-east of Kinna, are very meagre in contrast to the Central Province portion, where no water problem exists. Between Kinna, Garba Tula and Melka Lorni there are no supplies of permanent water. A few shallow pans are present in the north-east corner of the area, examples being Nambala Orura and Nambala Daka. Water is also

obtainable from small sand rivers, in particular the sand river on the western side of the Melka Lorni ridges, where water is dammed up by sub-surface rock barriers. The north-central part of the area is an arid, uninhabited lava-strewn region in which water supplies are non-existent, with the exception of infrequent shallow lakes where water accumulates in volcanic craters during the rainy season. Ruthaya and Rumbini craters are known at times to contain water and from time to time Kilimakieru may contain small quantities.

(b) Surface Excavations

The meagre water supplies have been supplemented by surface works undertaken by Howard Humphries and Sons under the Northern Frontier Province and Samburu District Water Development Scheme 1950-58 (Howard Humphries, 1958).

Two dams were originally built at Matasara but were not particularly successful because they were built on fine, silty soil formed on lake beds. One of these was enlarged during the 1950-1958 development scheme.

A new tank was built alongside the Kinna track at Hara Abaloni. This tank is of the type having a retaining wall alongside a sand lugga and a spillway leading from the lugga into a shallow excavation behind the wall. Thus flood waters are diverted from the lugga into the tank, forming a surface sheet of water which provides for the utilization of some of the previously wasted flood water.

Details of these surface excavations are:—

<i>Name</i>	<i>Capacity (million gallons)</i>	<i>Date completed</i>	<i>Excavation (cubic feet)</i>	<i>Remarks</i>
Matasara I pan	1 $\frac{3}{4}$	May 1953	12,000	Improved
Matasara II pan	$\frac{1}{2}$	May 1953	3,300	Improved
Hara Abaloni tank	2	July 1953	10,000	New

(c) Ground Water

No boreholes have been drilled in the present area but a few miles north of the present area boreholes along the Isiolo-Wajir road at the Garba Tula turn-off and Kubi Turkhana give good supplies of water. In the Kubi Turkhana borehole water was struck at a depth of 134 feet, 117 feet of the overburden being lava. In the bore hole near Garba Tula water was struck at a depth of 34 feet in sediments overlying the Basement System (Williams, 1966). This ground water represents sub-surface drainage from the higher rainfall areas of the Nyambeni Range in the western part of the Kinna area.

(2) CENTRAL PROVINCE PORTION

(a) Hydrology

South-west of Kinna there are numerous permanent surface streams flowing south-eastwards from the higher forested parts of the Nyambeni Range to the Tana river. The northern end of the range is lower, and consists of scattered pumice and scoriaceous lava cones and vents, with the result that no permanent streams flow from this section of the range since any precipitation percolates rapidly through these rocks and recharges the ground water table in the underlying basalts, thus feeding the springs near the Uaso Ng'iro and the boreholes along the Isiolo-Wajir road.

The surface discharge of this section of the Tana catchment was the subject of an investigation by Mr. R. C. Jones, Ministry of Works hydrologist, which was undertaken during the geological survey of the Kinna area (Jones, 1959). Jones' report lists the flow of the four major rivers draining the western flanks of the Nyambeni Range, the Bisanadi, Rojewero, Ura and Thangatha.

The Bisanadi, which has a measured flow of a little more than 3 cusecs at Gorbasa, dwindles to 0.25 cusecs at Melka Yaka, and is normally dry before reaching the Tana, which follows a roughly west to east course about five miles south of the southern border of the Kinna area.

The Rojewero and its tributaries have a total flow of just over 50 cusecs on the slopes of the range, which tapers to 43 cusecs at the confluence of the last tributary, the Murera, and it is estimated that an average of 30 cusecs reaches the Tana.

The fourth major river, the Thangatha, was measured as 40 cusecs at a gauge on the southern boundary of the map area, the flow at its confluence with the Tana being estimated as about two-thirds of this amount.

From the measured discharges of these four rivers a total discharge of approximately 155 cusecs is calculated. Evaporation and transpiration losses are probably in the region of 50 cusecs (this includes the disappearance of the Bisanadi) so that a net total of 100 cusecs reaches the Tana river from the Nyambeni catchment. This will rise considerably with heavy rainfall but is thought to be about the average discharge.

(b) *Water Analyses*

Water samples from the Ura and the Thangatha were submitted to the Government Chemist by the Ministry of Works hydrology department. The salient features of the analyses are an extremely low content of total solids, a very low salinity, low carbonate content and negligible fluorine content. In both samples the total solids are only 80 p.p.m. and the fluorine content 0.7 and 0.2 p.p.m. for the Ura and Thangatha rivers respectively.

(c) *Ground Water*

The Rojewero, Ura and Thangatha rivers rise in the higher forested parts of the Nyambeni Range, whereas the Bisanadi and the tributaries of the Rojewero rise from a line of springs and swamps situated on the eastern slopes between Kinna and Kilimakieru. The more important of these springs and swamps are:—

(i) *Kithima ya Mugomo*—This depression near Kinna lies in fossiliferous lake beds, and is probably an exposure of the ground water table. No inflow or outflow is visible in the depression.

(ii) *Murera Springs*—These springs well up through fissures in basalt. Small fragments of quartz are brought to the surface by the water which suggests a shallow subsurface interface between the lavas and the underlying Basement System metamorphic rocks.

(iii) *Bisanadi Swamp*—Lava flows flank this hollow, which has no visible feeder springs, and is probably sited on a large fissure from which it is fed. The outflow is the source of the Bisanadi river.

(iv) *Bunguma*—This occurrence is a pool of water in a deep hollow in lake beds. It appears to be a lava collapse structure exposing the water table in a similar manner to Kithima ya Mugomo.

VIII—A SYNTHESIS OF THE NYAMBENI VULCANICITY

The degree sheets covering the Nyambeni Range and associated areas of lava have now been geologically mapped, and the following is an attempted synthesis of the geology of this eruptive episode treated as a complete unit. It is probable that further small outcrops of lava of Nyambeni age occur north of the Uaso Ngiri. Recent work in the Kauro-Merille area (Rix—awaiting publication) has shown that there are a number of Recent lava cones between the Uaso Ngiri and Marsabit, near to 38° longitude, which are possibly manifestations of the latest phases of the Nyambeni vulcanicity.

The lavas included within this discussion cover the areas shown on the map of the Nyambeni Volcanic Series (Figure 3, at end). Most of the lavas of Nyambeni age in this part of Kenya are indicated on this map with the exception of a few vents on the west and south sides of Mt. Kenya and the Thiba basalts on the southern flanks of that mountain which are contemporaneous with the Nyambeni episode.

1. Nyambeni Volcanic Series—Definition

Nyambeni Volcanic Series was a term initiated by Schoeman (1951, p. 8) to refer to the olivine basalts occurring in the Embu-Meru area which were extruded from Nyambeni vents. Mason (1955, p. 8), during the mapping of the Meru-Isiolo area, extended the use of the term to include all the volcanic rocks associated with the Nyambeni Range. This is essentially the usage which will be retained here although Mason's division into a lower and upper series has been considerably extended. The series has been subdivided on petrological grounds, apart from the lower and upper groups of olivine basalt which are clearly of quite different ages. The Nyambeni Volcanic Series is thought to be Pleistocene to Recent in age.

2. Lava Groups

(1) LOWER OLIVINE BASALTS (WITH VARIANTS)

The lava group having by far the largest volume is the lower olivine basalt group. These rocks were extruded from fissures during the early phases of vulcanicity in this region, and being very mobile they spread rapidly over the irregular land surface of metamorphic rocks, resulting in the present wide distribution of basalt.

A collation of information from the various areas in which these rocks occur shows that the predominant rock type is olivine basalt. The rocks have been described petrologically by Schoeman (1951), Jennings (1967), Williams (1966), and Rix (this report). Throughout the series magnesian olivine is ubiquitous and resorption borders of iddingsite are extremely common. A purple titanite which is another major component is usually present in two generations. Magnetite is ubiquitous in the groundmass and zeolites and calcite occur as vesicle infillings. Variations from this rock type are relatively minor. There is a tendency for plagioclase to be somewhat subordinate, resulting in rocks with a melabasaltic composition. The plagioclase in the basalts is rarely present as phenocrysts, usually occurring as groundmass laths, and in the melabasaltic types such as have been recorded from the Kinna and Chanler's Falls areas, the feldspar is reduced to the status of scattered needles in the groundmass. Groups of flows within this sequence have feldspar phenocrysts and the lavas in the Archer's Post area were divided into older and newer types of olivine basalt mainly on this feature (Jennings, 1967). Other variations include types with a more sodic plagioclase, in the andesine-oligoclase range, giving rise to lavas with mugearitic affinities. This type has been recorded from Kinna and near Leragai in the Nanyuki area (Shackleton, 1946). Basanites have been recorded from the Archer's Post and Kinna areas.

The olivine basalts, with their local variations, are very widespread, and include basalts which were extruded from vents on the slopes of Mt. Kenya in addition to the extensive flood basalts extruded from the main Nyambeni centres. Two important series of basalts come within the former category, the so-called Upper Laikipian basalts (Shackleton, 1946) on the northern slopes of Mt. Kenya and the Thiba basalts (Fairburn, 1966 and Baker, 1967), on the southern slopes. The correspondence of age between Shackleton's Upper Laikipian lavas and the recent basalts on the northern slopes of Mt. Kenya is refuted by Baker. Evidence in the Mt. Kenya area, not available within the area mapped by Shackleton, shows clearly that the bulk of the Mt. Kenya volcanic suite rests on Laikipian basalts. The basalts on the north side of Mt. Kenya are among some of the most recent flows on the mountain and therefore cannot in

any sense be Laikipian in age, and are almost certainly correlatable with the Nyambeni lavas. Near the Uaso Ngiro river these basalts join up with and are indistinguishable from basalts of the Nyambeni Range (*see* map).

The Thiba basalts on the southern side of Mt. Kenya are similar in age to the basalts discussed above and are therefore considered to be contemporaneous with the Nyambeni Volcanic Series. This group name is, however, not applied to the Thiba basalts as they occur some distance from the Nyambeni region.

Thus, the picture is of a thick pile of effusive olivine basalts having a widespread distribution mainly centred in the Nyambeni region to the north-east of Mt. Kenya but also including basalts on the slopes of the mountain. It is considered likely, by analogy with other areas of the alkaline volcanic province of the eastern Rift, that the variation within the lavas is not systematic nor repetitive, but random. The writer considers that spatial differentiation in different parts of the subsurface magma chamber caused the variations within the pile of flows.

(2) OLIVINE MELANEPHELINITE

Two lava flows of this rock type were mapped in the Kinna area, and Williams describes occurrences in the Uaso Ngiro river section of ultrabasic lavas which are now considered to be olivine melanephelinites. This rock has also been recorded in cones and vents in this and adjacent areas. The rock consists of olivine phenocrysts, titanite in two generations, iron ore and nepheline, the latter interstitial to other groundmass minerals and generally identifiable only by staining techniques.

There does not seem to be a straightforward gradation from olivine basalt-basanite-melanephelinite as one might anticipate. The melanephelinite lavas are discrete flows within the olivine basalt series, and the writer attributes this to local concentration of alkaline material within the magma chamber due to differentiation.

(3) TUFFS, ASHES AND SCORIACEOUS LAVAS

A large area of tuffs, ashes and scoriaceous lavas was mapped in the northern part of the range (Williams, 1966); to the west it appears to be overlain by the lower olivine basalts and to the south by the upper olivine basalts. Thus these rocks were developed contemporaneously with the effusive olivine basalt phase, probably towards the end of that phase. The explosive episode seems to have been fairly localized in the northern end of the lava field.

(4) UPPER OLIVINE BASALTS

This division of the Nyambeni Volcanic Series forms the main "platform" of the range in the Lare region and extends down the eastern slopes near Goitu Abaloni. Mason (1955) did not differentiate these lavas from other flows of his Upper Nyambeni lavas, and their boundary west of longitude $38^{\circ} 00' E.$ has been drawn by the present writer from aerial photographs.

The upper olivine basalt flows are readily differentiated on their distinctly younger appearance; typical features are the distinct flow scarps, particularly well seen on aerial photographs, and the development of narrow canyons along drainage lines. Prolonged erosion on the lower olivine basalts has opened out the earlier canyons and transformed them into broad open valleys.

Petrologically, the lavas are similar to the lower olivine basalt group. The chief rock type is olivine basalt but melabasalt and basanites were mapped in the north-western corner of the Kinna area.

(5) PHONOLITES AND TEPHRITES

Phonolites with subsidiary tephrite flows form the higher southern parts of the Nyambeni Range. These lavas seem to have been relatively viscous and have formed a large pile making up the main mass of the range. The flows have steep scarp edges

and are characteristically gullied; the large rivers in the higher parts of the range, e.g. Ura and Thangatha, have incised deep gorges into these young lavas. Two occurrences of flat-topped, steep-sided circular or elongated lava hills were mapped on the eastern slopes. These are not connected to the main phonolite flows and are thought to have been extruded on the flanks of the range as cumulo-domes, the best example being Njoguni.

These phonolites are of the fissile, micro-porphyrific type. Those occurring on the flanks have microphenocrysts of nepheline set in a fluxionally orientated groundmass of sanidine (?) and aegirine-augite laths and granules. More markedly porphyritic types are recorded (Mason, 1955) from the upper parts of the range.

Tephrites, containing both plagioclase feldspar and nepheline, occur in the phonolite flows in various localities.

(6) TRACHYANDESITES

One occurrence of this rock type was mapped in the northern part of the range. This flow is seen to have come from a particular vent, Choro, and is quite a different rock type from any other lava of the Nyambeni episode. The explanation of its origin is probably analogous to the melanephelinite occurrences in that it is a fortuitous extrusion of trachyandesite lava from a portion of the magma chamber in which differentiation has resulted in magma of this composition.

The extent of the flow can be clearly seen on aerial photographs due to a distinctly different vegetation cover to that on the surrounding basalts. The trachyandesite is younger than the lower olivine basalts and the tuffs and ashes in the northern part of the range. It may therefore be contemporaneous with the upper olivine basalts or the phonolites, but it could be even younger and may in fact be one of the youngest lava flows of the Nyambeni episode.

Petrologically the lava is trachytic and microporphyrific. It contains clino- and probably orthopyroxene with oligoclase and probably anorthoclase as leucocratic constituents. Accessories are iron ore and interstitial analcite. (Williams, 1966.)

(7) PUMICE AND SCORIACEOUS LAVAS NEAR VOLCANIC CRATERS AND VENTS

Pumice, scoriaceous lavas, tuffs, ashes and agglomerates form the numerous craters and vents of the Nyambeni vulcanicity. The craters and vents on the eastern side of the range consist entirely of pumice and scoriaceous lava and a similar situation is evident in the north-west towards Archer's Post. There is also a wide area of tuffs, ashes and scoriaceous lavas in the northern end of the hills, towards Magado, which has been mentioned earlier.

The explosive phase seems to have been relatively localized in this region with Magado a phreatic explosion crater similar to those on the slopes of Mt. Kenya indicated on the accompanying map. In contrast to this the vents on the rest of the range were not explosive. They were formed most likely by "fire fountaining" (Cotton, 1952, p. 136) and the production of scoria mounds.

The rock types forming most of the vents are of basaltic or melabasaltic composition but there are occurrences of more unusual types. On the eastern slopes two vents Ntoe and Kinna, are composed of melanephelinite and are in a considerably eroded state. Further occurrences of alkaline basic and ultrabasic types are at Matoni hill, in the west near Timau, which is composed of nepheline basanite, and a nepheline basalt vent to the north-west of this (Shackleton, 1946). Occurrences in the north-west near the Uaso Ngiri river have been described as analcite basanites and olivine analcites (Jennings, 1967). These rocks are exactly similar to types discussed above except that the interstitial feldspathoid is primary analcite, not nepheline.

Two isolated instances of vent lavas of completely different types were discovered. A lamprobolite trachyte forms Nyonyoni vent on the eastern slopes of the Nyambeni Range. The petrology of this rock has already been discussed (p. 22). The other unique occurrence is the trachyandesite lava which forms Choro vent.

3. Landscape Forms

(1) MOBILE LAVA SHEETS—FISSURE ERUPTIONS

The greater part of the lavas that build up the Nyambeni Range, olivine basalts and variants, were extruded as mobile sheets from a series of fissures. The early basalts were very fluid and infilled the metamorphic topography to form a dome in the region of the fissures. The upper Nyambeni lavas were also extruded as sheets but they were either less fluid or the force of extrusion was not great enough for any flows to extend great distances from the axis of extrusion.

(2) PHONOLITE FLOWS AND CUMULO-DOMES

The phonolites seem to have been more viscous lavas than the basaltic representatives, as is evidenced by the steep scarp edges to the flows and the large pile of these lavas forming the high parts of the range. The two cumulo-domes on the eastern flanks are considered to have been formed as upwellings of viscous lava which did not flow very far from the region of the fissures.

Petrological information noted earlier possibly sheds light on the apparent viscosity of these lavas. Porphyritic, blocky phonolites generally form extensive plateaux in Kenya. However, phonolites which form in other ways, such as cumulo-domes or tholoids, are seen to be fissile and fine grained with a microporphyritic texture only rarely discernible in hand specimens. It is suggested that there is an association between modes of extrusion and petrological features of the two types of phonolites in which these two contrasting sets of features are observed.

(3) PUMICE AND SCORIACEOUS LAVA CONES

The numerous volcanic vents and craters on the Nyambeni Range are considered to be only rarely explosive in formation. The cones were formed most likely as scoria mounds as a result of "fire fountaining" (Cotton, 1952, p. 136). These small cones some of which (Goitu Abaloni and Rueka) have been breached by lava, form excrescences on the main pile of lava flows. The few large explosion craters indicated on the map show little relief but are rather holes in the ground. These observations agree with those in basaltic lava provinces in other parts of the world, where violent explosive activity is the exception rather than the rule. A further piece of evidence is the paucity of observed instances of lava flows emanating from these vents. A few do occur, notably the trachyandesite flow from Choro and the basalt flow from Goitu Abaloni (Plate IVb).

These scoria mounds probably represent the latest phase of volcanic activity in the Nyambeni Range. The age of the pyroclastics in the northern end of the range is, however, somewhat greater, and the craters whence they came must have been initiated at a relatively early stage. The state of preservation of some of the lava craters is remarkably good in many cases. Good examples are Ruthaya, Rumbini, Kilimakieru and a number on the western slopes. These cones range in height from 50 feet to about 600 feet.

(4) PARALLEL DRAINAGE AND INVERSION OF RELIEF

The early Nyambeni lavas flowed out on a well-dissected mid-Pliocene erosion bevel with isolated larger hills protruding above the general level. This topography was gradually buried but the most important feature of the infilling of the metamorphic land surface by lava was the following by the flows of large river valleys draining the

old land surface. Lava flows following river valleys often extend considerable distances from the extrusive centres, and result in the obstruction of the tributary drainage to the main river valley and the development of lagoons along the margins of the lava flows. These lagoons lead to the formation of parallel rivers flanking the lava flow.

Eventually, erosion of the surrounding metamorphic surface by tributary streams reduces it to a level below that of the lava surface, thus producing an inversion of relief. In areas of older lavas this proceeds until the lava capping and underlying rocks remain as an upstanding plateau, such as the Yatta Plateau in southern Kenya.

The feature of parallel drainage development is well exhibited on the eastern side of the Nyambeni Range. Good examples are the Bisanadi lava flow, the narrow tongue of lava flanked by the Rojewero and Murera rivers and the flow flanked by the Ura and Thangatha rivers that extends towards the Tana river. The long tongue of lava in the extreme south is probably another example, one of the flanking rivers being the Mutonga. The Nyambeni Range is too young for any very marked inversion of relief to have been produced; that seen is a maximum of 50 feet from the valley to the lava top.

4. Volcanic History of Nyambeni Range

The Nyambeni vulcanicity is thought to have been initiated in the Lower Pleistocene period. The fissures from which lava extrusion occurred were probably north-easterly trending faults which can now be traced by dykes projecting from the northern end of the range near the Uaso Ngiro river. These faults extend from beneath Mt. Kenya, and the Nyambeni and Mt. Kenya volcanic suites are probably intimately connected. The Mt. Kenya Suite resulted from activity which pre-dated that giving rise to the Nyambeni Volcanic Series. It seems that the focus of activity was sited on the southern end of these faults in the Upper Pliocene but during the Lower Pleistocene the focus moved north-eastwards. Following this shifting of the active centres, further activity in the Mt. Kenya area was only spasmodic, giving rise to numerous adventive cones, the Thiba basalt flows in the south and the flows on the northern side which reached to the Uaso Ngiro.

The Nyambeni phase began with the extrusion of fluid olivine basalt from north-easterly aligned fissures. Initially these fissures were probably marked by a line of scoria mounds which were inundated as large volumes of lava welled up through the fissures. These flood basalts spread over a pre-Pleistocene landscape of metamorphic rocks that had been bevelled by erosion in end-Tertiary times and then dissected again by the Tana and Uaso Ngiro rivers. This dissection probably lowered the Tana basin by a maximum of 600 feet below the surface of the bevel. Thus only in the watershed region between the two large rivers are the lavas resting on the preserved end-Tertiary surface.

The extent of the Lower Pleistocene extrusion of olivine basalts and minor variations is very wide and a considerable volume of lava was extruded, which is tentatively considered to be about 1,500 feet thick at its maximum development. The thickness was estimated by projecting the surface of the end-Tertiary bevel beneath the known profile of the lava.

Contemporaneous with and consequent upon the extrusion of this volume of lava was the development of lagoons and the subsequent production of parallel drainage, described earlier.

The tectonic and volcanic events in this region are thought to be associated with Lower Pleistocene movement of Rift Valley faults. In the Middle Pleistocene, little extrusion is thought to have taken place, although the explosive activity at the north end of the range continued.

In the Upper Pleistocene further movements of the great Rift Valley faults took place, which is thought to have initiated the second major extrusive phase of the Nyambeni episode. The earlier manifestation of this phase is probably the localized explosive activity in the north, which now reached its peak of activity. Subsequently further effusion of olivine basalts occurred. Their distribution is more localized than the earlier olivine basalts probably due to less powerful pressures in the now elevated lava column, and the younger basalts have a relatively large thickness in the axial region of the fissures but extend only a short distance down the slopes. One flow, probably the most recent of this group, is seen to emanate from Goitu Abaloni crater.

The phonolites which form the southern part of the range are also thought to have been formed in the Upper Pleistocene. The earlier phonolite flows are possibly contemporaneous with the later olivine basalt flows, but the bulk of them seem to post-date the basalts. The cumulo-domes of this lava on the flanks of the range were probably relatively viscous "blisters" which rose from elongated fissures.

The thickness of the upper olivine basalts is probably between 1,500 ft. and 2,000 ft. but this is very approximate. The phonolites and tephrites probably attain a similar thickness but again this is largely conjectural.

Although vents began to form in the Lower Pleistocene and were spasmodic in the Middle Pleistocene, they attained their maximum development in the Upper Pleistocene, and the majority of the vents post-date the majority of the lavas. Examples of early vents are Kinna, Moliti and Ntoe on the eastern slopes, the vents on the northern slopes of Mt. Kenya which have given rise to basalt flows, and some near the Uaso Ngiri river in the north-west. These form only a small proportion of the total number of vents and craters most of which are much younger in age, some being undoubtedly Recent. The vulcanicity probably continued longest in the north end of the range where there are many more intact craters, for example Choro, Rumbini and Goitu.

Precipitation on the range was formerly far higher than at present and the ground water table is considered to be falling in the Nyambeni lavas. Springs are seen but streams that formerly flowed from them have retreated; deep canyons occur on young lavas which are now arid wastes for nearly the whole year. Vegetation established itself relatively quickly on the Nyambeni Range due to the high precipitation, chiefly on the eastern slopes. Even on the youngest lavas there are tall grasses but typically parkland type of country exists on the eastern slopes. On the highest slopes high precipitation and tropical weathering resulted in a deep soil cover on which extensive indigenous forests developed. These have been gradually destroyed for cultivation and are now fragmentary, the two largest forests still remaining being the Ngaya and Nyambeni forests.

On the western side of the range, which is in the rain shadow area, the development of vegetation is limited to stunted thorn bush, in marked contrast to the luxuriant forests of the eastern side, and soil creep and gully erosion is all too obvious.

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