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GEOLOGY OF THE CHANLER'S FALLS AREA

DEGREE SHEET 37, NW. QUARTER

(with coloured geological map)

by

L. A. J. WILLIAMS, B.Sc., F.G.S.

Geologist

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FOREWORD

The Chanler's Falls area lies in a semi-arid region of north-eastern Kenya traversed by the Uaso Ngiro river, a permanent watercourse which was of great interest to the early explorers, one of whom, Lieut. Chanler, discovered the waterfall which now bears his name.

Though the area shows no promise of large mineral deposits, possibilities of a small production of mica and beryl exist. Perhaps the most valuable mineral in the area is water, and the report gives a full account of the water potential as proved by river-flow records and borehole data. But the main interest to a geologist lies in the diversified rock types mapped, ranging from Precambrian metasediments to late sediments and lavas. Mr. Williams has devoted a considerable amount of work to unravelling a complicated sequence of basic and ultrabasic plutonic rocks and their metamorphosed equivalents, and compares and contrasts them with somewhat similar rocks at various other localities in Kenya.

The author also gives a detailed account of the complicated structure of the area, and recognizes two phases of metamorphism which apparently coincide with two distinct periods of folding.

B. H. BAKER,
Commissioner (Mines and Geology).

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ABSTRACT

The report describes the geology of an area of some 1,200 square miles lying across the boundary of the Eastern and Rift Valley Regions of Kenya and enclosed by longitudes $38^{\circ} 00'$ and $38^{\circ} 30' E.$, and latitudes $0^{\circ} 30'$ and $1^{\circ} 00' N.$ Relics of the sub-Miocene erosion level stand above an end-Tertiary surface that has been widely dissected by the Uaso Ngiro drainage system.

Much of the area is underlain by metasediments, migmatites, granitoid gneisses and mylonites of the Basement System. A suite of hypersthene-bearing basic and ultrabasic plutonic rocks, together with associated ortho-amphibolites, hornblende ortho-gneisses, pegmatites, quartz veins and leucocratic ortho-granulites, are considered to be Precambrian in age though younger than the Basement System. Dykes fall into two groups; Precambrian metadolerites and Tertiary or early Pleistocene olivine basalts. Coarse cemented river deposits (Merti Beds) found in the scarps of the Merti plateau are assigned to the late Tertiary, and a similar age is proposed for olivine basalts that cap these sediments. Unfossiliferous limestones and clays, deposited on the end-Tertiary peneplain, are referred to the lower Pleistocene. Pleistocene volcanic rocks cover about a third of the area; they are mainly olivine basalts, associated with numerous vents composed of tuffs, agglomerates and scoriaceous lavas. Quaternary deposits comprise a variety of soils, reworked deposits derived from the Merti Beds, and calcareous deposits formed from spring waters.

Two phases of regional metamorphism are invoked and are tentatively correlated with two distinct periods of folding during which earlier northerly and north-westerly trending structures were refolded about north-easterly axes.

Mica and beryl were being worked on the western boundary of the area at the time of the survey, but the prospect was later abandoned. Traces of many other economic minerals were found, but no workable deposits have so far been discovered. The water resources of the area are briefly reviewed.

GEOLOGY OF THE CHANLER'S FALLS AREA

I—INTRODUCTION

This report describes the geology of an area of some 1,200 square miles lying astride the Uaso Ngiro river and bounded by meridians 38° 00' and 38° 30' E. and parallels 0° 30' and 1° 00' N. It embraces the north-western quarter of degree sheet 37 and falls largely within the Eastern Region of Kenya, but includes in the south-western corner a small part of the Rift Valley Region. Fieldwork connected with the survey was carried out between July 1958 and January 1959.

For administrative purposes the area is divided into three separate districts. The largest portion, being occupied mainly by *Boran* tribesmen, is administered from Isiolo, a township some thirty miles to the south-west; the south-western corner is inhabited by *Wameru* and is controlled by the District Commissioner at Meru; the *Samburu* country in the north-western corner of the area is administered from Maralal.

The Uaso Ngiro* (a *Samburu* name—it is known to the Boran as the Galana) is a permanent river fed by streams from Mt. Kenya and the Aberdare mountains. It runs centrally across the area from west to east, and ultimately dries up in the Lorian swamp some eighty miles east of the present area. South-east of Tumtu hill the river pours over a ledge of basalt at Chanler's Falls (named after their discoverer, W. A. Chanler), the water dropping 38 ft. in a single picturesque cascade (Plate I).

Maps

No reliable maps of the area were available at the time of the survey and field-sheets, on a scale of approximately 1:50,000, were prepared by photographing suitable mosaics of air photographs. There being insufficient ground-control, no absolute scale could be provided at the time, nor could any corrections be made for inevitable distortions. During the field-work, however, the existing control was supplemented by points resected and intersected on a plane-table and the final map was produced by photographically reducing, and where necessary adjusting, the mosaics. Due to the general low relief throughout the area distortion is small.

Formlines are based on spot-heights recorded with an aneroid barometer, a correction being made for diurnal variation. Where shown on the map these spot-heights have been given to the nearest 10 ft. To avoid confusion of detail, form lines have been largely omitted on the higher slopes of the volcanic vents. The vents are shown by an appropriate symbol indicating whether or not a crater is still recognizable, and where possible, a spot-height marks the highest point of the cone.

Place names were obtained mainly from *Boran* tribesmen, hence the lack of Meru names for features in the south-western corner of the area.

Communications

The southern half of the area is crossed from west to east by the main road linking Isiolo with Garba Tula and the more remote parts of the Eastern Region. The road is good by local standards, particularly the portion running across the sandy end-Tertiary peneplain, and the route is well served by two roadside bore-holes. In the south-western corner of the area a minor road affords access to the impressive, well-known Magado (Igembe) crater with its near-by small trading centre. A continuation of the same road leaves the area and leads north-westwards to Archer's Post, where the Uaso Ngiro is spanned by a bridge. A good track branches northwards from the main road near the Garba Tula bore-hole and then swings westwards, passing through Kurru Barrata and on to the wells at Muddo Yaka. Beyond Muddo Yaka the track is poorly defined but with care it can be followed across the lava country to its junction with the superior track linking Chanler's Falls and Archer's Post. From the Garba Tula bore-hole a minor road leads south-westwards to the boundary of the present area and thence to Kinna and Meru. North of the Uaso Ngiro the area is

*Also spelt Guaso Nyiro, Uaso Nyiro and Ewaso Ngiro.

crossed by a road connecting Archer's Post and Merti, the poorest section of the route being near Tumtu hill where a number of deep gullies have to be traversed. In common with other parts of the Eastern Region all roads are closed to traffic during the wet season.

Population

The area is inhabited by three distinct tribes, the largest portion being occupied by the nomadic, pastoral *Boran* who are to be found throughout the central and eastern parts. *Samburu* tribesmen (closely related to the *Masai* of southern Kenya) graze the extreme north-western corner of the area, adhering rigidly to the cut boundary separating them from the *Boran*; in contrast, the *Wa-Meru* intermingle freely with the *Boran* in the south-western parts of the area, sharing the important water-supply in Magado crater. Although the *Wa-Meru* are traditionally agriculturists, no cultivation is attempted in this arid part of their district.

Climate and Rainfall

The climate is hot and dry with two wet seasons, the "long rains" generally occurring between late March and the end of May, followed by a second rainy season between mid-October and December. No rainfall statistics are available for the Chanler's Falls area but Table I shows figures recorded up to 1958 from a number of stations surrounding the area, the nearest being Garba Tula.

TABLE I

Station	Latitude	Longitude	Altitude	Average Annual Rainfall	No. of Years Recorded
Isiolo, District Office ..	0° 21' N.	37° 35' E.	(Feet) 3,621	(Inches) 22.86	27
Birds Hill Ranch, Isiolo ..	0° 15' N.	37° 31' E.	5,025	24.15	7
Archer's Post	0° 37' N.	37° 40' E.	2,835	11.26	12
Garba Tula	0° 30' N.	38° 32' E.	1,500	13.60	6

(From records of the E.A. Meteorological Department, Nairobi)

The figures quoted for Archer's post and Garba Tula probably also apply approximately to the Chanler's Falls area.

II—PREVIOUS GEOLOGICAL WORK

The destination of the Uaso Ngiro river aroused considerable interest among many early travellers in Kenya and several expeditions were made towards its termination in the Lorian swamp.

The earliest recorded journey through the present area was made in 1892-93 by W. A. Chanler and Lt. von Hohnel in the course of an expedition towards Mt. Kenya and the unknown country to the north-east. A brief preliminary account of their travels was written by Chanler (1893) and included comments on the "Guaso Nyiro" which was said to flow in a gneiss bed except near "Chanler Falls" where the course lies in lava. The river was described as there pouring in two streams over the lava mass, the falls being some 50 feet high, thereafter flowing for two miles between sheer walls of black lava. It was found that near the Marisi el Lugwa Zambo Plateau (clearly that now known as Merti) the nature of the riverbed changes from gneiss to alluvial soil; the plateau itself was said to be purely volcanic, rising abruptly 500 feet from the plain. The account was illustrated by a map compiled by von Hohnel.

W. H. Broun visited the Lorian swamp in 1904 to confirm the belief that no effluent exists, his route taking him east of Mt. Kenya and the main Nyambeni range (referred to in his paper as the Embe or Jombeni mountains) and into the south-western corner of the present area where the party obtained water from the floor of Magado crater (known at the time as

Mgambe or Chiombe). Broun (1906, p.43) described Chiombe as "a typical cup-shaped crater with a fissure in its brim on the east side, altitude 2,800 ft. aneroid". From Magado the expedition headed north-north-westwards to the Uaso Ngiro near "Donio Longelli" (probably the hill on the western boundary of the present area now known as Boji) and then downstream along the right bank of the river to the Lorian swamp. Some 42 miles east of Donio Longelli, Broun noted (p.44) that "the lava-flow, which from the Tana everywhere forms the surface rock, ceases abruptly at a perpendicular basalt bluff 15 ft. high on the side of a ravine, issuing on the river". This point was almost certainly near Kubi Kalo, the end of a long tongue of basalt that follows the south bank of the river. From Donio Longelli to Kubi Kalo Broun recorded a fall in river level of 763 ft. in 42 miles (1 in 290), whereas downstream from Kubi Kalo to the Lorian swamp the fall was found to be 1 in 666; the change in gradient was attributed to the influence of "outpourings of lava which appear on both banks". The present survey showed that, apart from several insignificant outliers of lava near the north bank of the river and the more widespread sheets at Tumtu and Merti, the basalt is confined to the country south of the Uaso Ngiro. Broun noted in passing the 20-mile long and 300-ft. high "Erimba plateau" north of the river (obviously referring to the Merti plateau). On the return journey up the Uaso Ngiro from Lorian, the party came on (p. 48) "a remarkable fall 60 to 70 ft. high. Below the fall the stream passes through a gorge the sides rising sheer for about 60 to 70 ft., on the right being white trachyte, on the left a dark basaltic rock. The river (low water) fell over a ledge of basalt through narrow water-worn channels close to both banks, leaving the polished ledge of basalt in the centre dry; the extension of this polished ledge up-stream forms the bed of the river. This is probably the fall known as Chanler's."

In 1912-13, I. N. Dracopoli (1913) journeyed from Kismayu to the Lorian swamp and thence through the present area along the Uaso Ngiro. The "Marti" plateau was examined during the journey and said (p. 137) to be of volcanic origin, rising 603 ft. above the surrounding country to a maximum height of 1,607 ft. at the eastern end.

J. Parkinson (1920) prepared a report on the geology and geography of the northern parts of the then East Africa Protectorate based on surveys carried out during 1914-15. He classified (pp. 2-3) the country traversed into two natural sub-divisions: the Northern Frontier District composed of ancient crystalline rocks partly covered by lavas, and the alluvial plain of Northern Jubaland commencing at the Merti Plateau; the present area thus borders on both divisions. Parkinson described (p. 12) Chanler's Falls as a series of cascades cutting across the banded ortho-gneisses forming the bed and suggested that the river had been temporarily dammed by lava to form shallow lakes to the west of the falls. The volcanic rocks of northern Kenya were sub-divided (p. 5) into "older" and "newer" lavas, the olivine basalt at Chanler's Falls being grouped with the former. The Merti plateau was said (p. 11) to be composed of gneiss and capped by lava with beds of old alluvium, containing well-rounded quartz pebbles, occurring on its flanks. The cliffs at the eastern end of Merti were thought to be reminiscent of marine erosional features and the writer concluded that, since or at the time of the extrusion of the lava, the sea had reached Merti. A six-mile long exposure of fresh-looking olivine gabbro was reported (p. 28) from a locality west of Chanler's Falls (the exposure was said to be 15 miles from the Falls but the writer was probably referring to the occurrence at Tumtu hill). In this rock, the olivine was said to display serpentinization and the separation of iron oxides along cracks, with the diallage frequently showing peripheral alteration to yellowish green hornblende. Both minerals were occasionally seen with borders of pale green radiating actinolite. The feldspar was in part labradorite. In a later paper, Parkinson (1939) recorded information collected during subsequent travels in the country between the Lorian swamp and Isiolo. He re-examined the Merti plateau and found (p. 165) it to be composed of "compacted sand sufficiently solid to stand in a vertical face, very quartzose, and containing strings and occasional thin layers of quartz pebbles, which thickly strew the ground at the base of the cliff. Amongst them are a few well-foliated gneisses and pegmatites . . ." Mauve-coloured, rather argillaceous sandstone was found forming the lower part of the cliff, the plateau being covered by a layer of lava some 8-10 ft. thick that has preserved the underlying sediments. In the southern part of the present area Parkinson reported (p. 164) lake deposits near Garba Tula, followed by a lava plain from which rise the range of puy's forming the "Jombeni" hills.

During the Second World War Lt. H. D. Roberts carried out a geological reconnaissance of the Merti plateau and the country flanking the Uaso Ngiro river upstream to Archer's Post, most of the observations being made during road and track traverses. These rapid

examinations were undertaken to investigate for military purposes the water supplies of the area and an unpublished report, including notes on the physiography and general geology, was prepared in 1941. Commenting on the physiography of the region, Roberts attributed the uniform level of the country to pre-Tertiary peneplanation, with Timtu (Tumtu of the present survey) and other hills and inselbergs not having been reduced by the bevelling. An extensive mantle of conglomerate and sandstone, thought to have been produced during the peneplanation, is now preserved only beneath what Roberts regarded as a late Pleistocene lava flow capping the Merti plateau. The rock types encountered in the country covered by the survey were classified as follows:

1. Ancient Rocks

Hornblende schists and gneisses, garnet-hornblende schists, biotite schists, quartzites and micaceous quartzites were all thought to represent metamorphosed sediments; metamorphic rocks of igneous origin were said to include granite gneisses and biotite gneisses. Ancient igneous rocks were sub-divided into aplite and pegmatite veins with occasional garnets or pyrite, quartz veins bearing some malachite, and the gabbroid or doleritic intrusives of Tumtu and its satellites.

2. Pre-volcanic Sediments—Merti Beds

At Merti unfossiliferous conglomerates, grits, sandstones and marls were seen overlying an irregular surface of ancient gneiss and schist. Loosely consolidated sediments found at the foot of the Merti scarp were believed to have been formed by *in situ* weathering of the Merti Beds.

3. Volcanics

Lavas and agglomerates encountered south of the Uaso Ngiri were thought to be early Pleistocene in age, in contrast to what were regarded as later Pleistocene flows north of the river (including the lava at Merti).

4. Hydrothermal Superficial Deposits—Volcanic Sinter and Travertine

These deposits were examined south of the Uaso Ngiri and, within the present area, were noted particularly at Koru Barata (Kurru Barrata). Roberts recorded the occurrence of abundant fossil molluscs and pisolites but it is not clear whether any were seen in the Chanler's Falls area.

In 1943 Dixey (1948) travelled extensively in northern Kenya in the course of hydrographic surveys. Little attention was paid to the Basement System rocks but important preliminary contributions were made towards the study of the sediments and the various erosion surfaces in the Northern Province. Within the present area the Merti plateau attracted attention and was described (pp. 14–15) as being built up of Tertiary friable, pebbly sandstones capped by a conformable sheet of olivine basalt. The sediments were found to rest on a dissected Basement System surface, the sandstones being thin at the northern end but over 400 ft. thick at the eastern end of the plateau where the base is not exposed. The basalt was said to be 20 to 50 ft. thick, the top of the flow lying at an elevation of about 1,450 ft. and the base of the plateau at the eastern end at about 1,000 ft. A thin sprinkling of pebbles were found overlying the lava, suggesting that the flow was formerly overlain by sediments similar to those exposed in the scarp. The Basement System hills between Archer's Post and Kittermaster's Camp were said to be thickly overlain by coarse pebbles that were believed to be residual from sediments perhaps representing an extension of the Merti sandstones. Dixey visited Igembe crater (p. 7)—now better known as Magado—and described it as an explosion crater some 1,000 ft. deep and a mile across containing a shallow, slightly saline lake.

The sediments and volcanic rocks occurring on the isolated hill-tops at Merti and other localities in the Northern Frontier District (now part of the Eastern Region) were correlated by Dixey (p. 15) with Miocene sediments and volcanics in Turkana. The sub-Miocene surface, which had been recorded above the mid-Tertiary peneplain further to the west, was said to lie at a level intermediate between the mid-Tertiary and the Pliocene (end-Tertiary) bevels at the eastern end of the Merti plateau. The Uaso Ngiri river was thought (p. 4) to have considerably widened and deepened its valley during post-Tertiary sub-cycles of erosion.

III—PHYSIOGRAPHY

The area can be divided into five physiographic units. (Fig. 1):—

1. The foot-hills of the Nyambeni range.
2. Isolated hills representing remnants of the sub-Miocene peneplain.
3. The Merti plateau.
4. The dissected plains north and south of the Uaso Ngiro.
5. The Uaso Ngiro Valley.

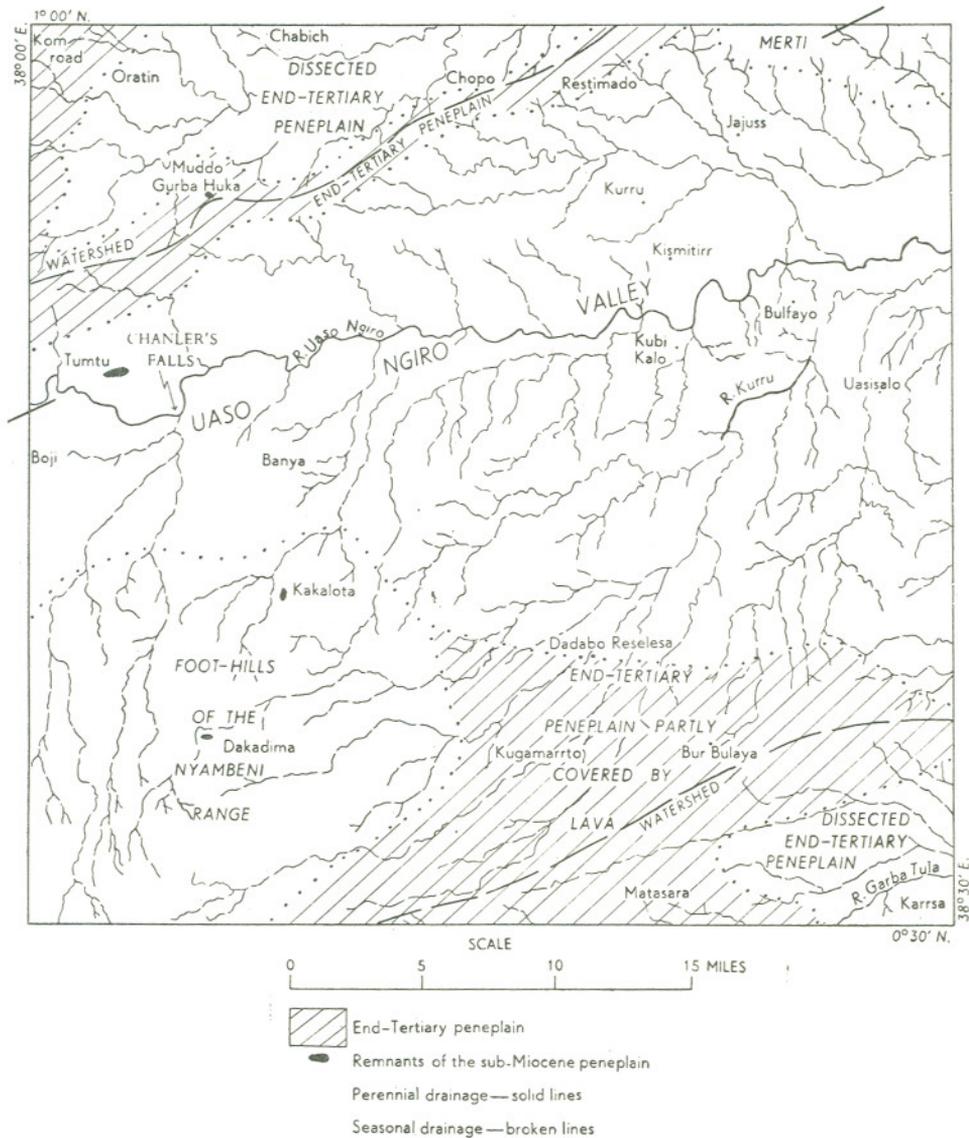


Fig. 1.—Physiographic map of the Chanler's Falls area.

A group of volcanic vents in the south-western corner of the area represent the foothills of the prominent Nyambeni range, a thick pile of lavas and cones that rise to over 8,200 ft. at the highest point. Within the Chanler's Falls area the volcanic rocks reach a maximum elevation of about 4,500 ft. at the southern boundary.

Large hills, other than those of volcanic origin, are rare; the summit heights are roughly co-planar and it is believed that the hills are the remnants of a once extensive sub-Miocene peneplain. The main non-volcanic masses are found in the western third of the area, the largest being Tumtu (3,176 ft.).

A portion of the western end of the 20 mile long, lava-capped Merti plateau lies in the north-eastern corner of the area and forms a prominent landmark, with the top of the plateau at nearly 2,000 ft. and bounded by scarps rising some 400 ft. above the surrounding plains.

With the exception of the nearly east-west trending Uaso Ngiro valley, the remainder of the area is composed of a vast flat plain partly underlain by lava and upon which are situated a number of tors, inselbergs and small residual hills. The broad Uaso Ngiro valley is bounded by such gentle slopes that its significance is not readily appreciated in distant view.

Drainage

The drainage pattern of the area is dominated by the Uaso Ngiro, a river that has achieved the early stages of maturity particularly towards the eastern boundary where the valley is occupied by alluvium. The river acquires considerable recharge during the wetter months of the year from seasonal watercourses that drain the north-eastern parts of the Nyambeni range and from an intricate pattern of sandy *luggas* that dissect the country north of the river. Underground drainage from the high rainfall areas to the south-west provides a valuable permanent source of water in bore-holes and springs in the arid districts south of the Uaso Ngiro. A watershed between Muddo Gurba Huka and Restimado, near the Merti plateau, separates the Uaso Ngiro drainage system from a north-easterly directed pattern that probably ultimately joins the main river further downstream beyond the present area. In the south-eastern part of the area another watershed divides the drainage in the vicinity of Bur Bulaya, but the Garba Tula stream and its tributaries also drain into the Uaso Ngiro further to the east. Near by however, Rix (report awaiting publication) has located the main Uaso Ngiro-Tana watershed within the Kinna area.

The formation some years ago of a five-mile long sand barrier in the lower course of the Uaso Ngiro created a critical situation by damming the river and causing the water to flow out from breaches in the banks leaving the river bed dry below the barrier. The plight of both tribesmen and animals suddenly deprived of water was described in an issue of the *East African Standard* of the 27th March 1953. The bar, formed by the deposition of sand from the exceptional flood waters of 1951, was situated near the eastern boundary of the present area and was built up largely as a result of the change in gradient of the river. Normal flow was restored by filling breaches in the river banks that had developed upstream from the sand barrier.

Erosion surfaces

Erosion bevels cannot be convincingly demonstrated within the Chanler's Falls area owing to a wide belt of dissection along the course of the Uaso Ngiro river and the existence of a cover of volcanic rocks that effectively conceals the pre-Pleistocene surface over about a third of the area.

Concordant summit heights of the few larger non-volcanic hill masses in and close to the area (consisting largely of ?Precambrian basic intrusive rocks) suggest the existence of an old erosion surface that now slopes gently to the east-north-east (Fig. 2). Tumtu, the highest non-volcanic hill in the area (3,176 ft.) has its summit standing some 200 ft. above the postulated surface and apparently remained as a residual on it. Pulfrey (1960, Fig. 3) has shown that this surface undoubtedly represents part of the extensive sub-Miocene erosion bevel, dated by the occurrence on it of lower Miocene sediments in other parts of the country. Within the Chanler's Falls area the bevel falls approximately 1,000 ft. between Tumtu and the western end of the Merti plateau where its continuation is found in hills of Basement System rocks (reaching 1,920 ft.) now buried beneath a thin cover of late Tertiary sediments

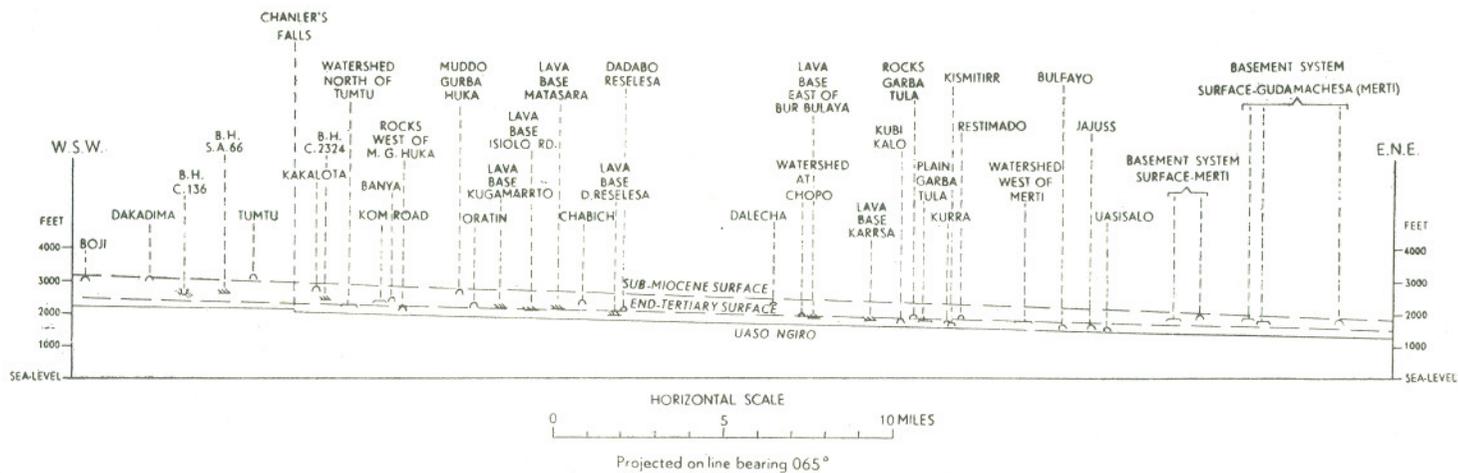


Fig. 2.—Section showing erosion levels deduced from projected ground levels and elevations of the lava base on a line bearing 065°.

and Pleistocene lava. This fall represents a slope of about 36 ft. per mile to the east-north-east, but it is believed that the gradient decreases to about 25 ft. per mile along the Merti plateau. Evidence at Merti is scant and further mapping of the eastern parts of the plateau will be required to confirm the slope of the sub-Miocene surface there.

Plotting of the elevation of the lava base in the southern third of the area (including information available from bore-holes) together with heights recorded from ground along the watersheds not covered by lava and a number of small isolated hills show that many of these points are co-planar. The surface is correlated with the end-Tertiary peneplain which is widely developed in the eastern half of Kenya. Fig. 2 shows that the surface within the Chanler's Falls area slopes to the east-north-east at about 26 ft. per mile. Heights of the base of the lava cannot be used indiscriminately to demonstrate the end-Tertiary erosion surface since widespread dissection of the peneplain had clearly taken place along an early Uaso Ngiro valley before the extrusion of the volcanic rocks. The latter are found at all levels to within a few feet of present river level, and the base plotted on Fig. 2 from a measurement at Dadabo Reselesa shows the initial slope of the sub-lava surface towards the Uaso Ngiro. A similar irregularity in the end-Tertiary peneplain is indicated by the lava base level at Karrsa where the volcanic rocks are underlain by Lower Pleistocene limestones partly filling a buried river valley (*see* page 36). The tongue of lava between Matasara and Karrsa is believed to have flowed along this valley at a level below the end-Tertiary surface. In addition to irregularities caused by dissection, the peneplain was also broken by a number of isolated hills and inselbergs, many representing much reduced remnants of the earlier sub-Miocene surface. Evidence of a small hill of Basement System rocks that was completely submerged by lava is provided by bore-hole S.A. 66 drilled at mile 46.5 beside the Isiolo-Wajir road. At that point gneiss was encountered only 20 ft. below the present lava surface, whereas three and a half miles to the east 117 ft of lava was proved by bore-hole C.2324, and a mile and a half west of S.A. 66 another bore-hole (C. 136) had not pierced the lava cover at 140 ft. below the surface.

It will be seen from Fig. 2 that between the western boundary of the area and the Merti plateau the sub-Miocene and end-Tertiary surfaces are inclined towards each other, the former having the greater slope. Pulfrey (1960, Fig. 3), using all the information then available, plotted the morvan or line of intersection of these two surfaces forty miles east of Merti plateau, but in view of the apparent local decrease in slope of the sub-Miocene bevel along the Merti plateau it is impossible to deduce the position of the morvan from evidence obtained from the Chanler's Falls area alone.

IV—SUMMARY OF GEOLOGY

The rocks of the area fall into seven groups:—

1. Metamorphic rocks of the Basement System (Precambrian).
2. Metamorphosed basic and ultrabasic intrusives, and associated leucocratic rocks (?Precambrian).
3. Dykes (?Precambrian and Tertiary/Pleistocene).
4. Merti Beds (Tertiary).
5. Lower Pleistocene limestones and clays.
6. Tertiary to Pleistocene volcanic rocks.
7. Quaternary superficial deposits.

1. Basement System

The Basement System rocks in the area are mainly gneisses, granulites and migmatites, representing regionally metamorphosed and granitized sediments. These metasediments comprise garnetiferous and graphitic rocks of pelitic origin, biotite-bearing gneisses derived from semi-pelitic sediments, and quartzo-felspathic granulites and gneisses that represent metamorphosed psammitic sedimentary rocks. Crystalline limestones were not encountered during the survey, but local occurrences of calc-silicate granulites and gneisses, interbanded with the commoner metasediments, indicate the calcareous nature of some of the original beds. Widely developed migmatitic rocks display varying degrees of plastic deformation and demonstrate the introduction of material of granitic composition into the metasediments.

The migmatites can be subdivided into varieties having a semi-pelitic host rock, and those in which the host was of pelitic or calcareous origin. A paligenetic origin is assigned to rare occurrences of poorly foliated granitoid gneisses. Mylonitic gneisses are associated with fault zones in the north-eastern parts of the area.

2. Metamorphosed Basic and Ultrabasic Intrusives, and Associated Leucocratic Rocks

Rocks of the Basement System are intruded by a suite of metamorphosed hypersthene-bearing ultrabasic and basic plutonic rocks tentatively assigned to the Precambrian. Relatively unmodified cores of perknites, picrites, norites, hyperites, gabbros and bojites are surrounded by irregular envelopes of metagabbros, metanorites and ortho-amphibolites which display cross-cutting relationships towards the older Basement System rocks. Amongst the core rocks basic types predominate, but ultrabasic hypersthene and hornblende-pyroxene picrites have been recognized. The basic types are of variable composition and include both olivine-bearing and olivine-free varieties of norite and hyperite; hypersthene gabbros were all found to contain olivine and this mineral is also present in an occurrence of noritic bojite. Olivine is absent, however, in rare developments of hypersthene-free gabbro and in more common metagabbros. Anorthosites are present in layered gabbroic complexes, but the leucocratic rocks never appear in units large enough to show at the scale of the map. The rocks representing metamorphosed equivalents of the basic and ultrabasic rocks include amphibolites, plagioclase amphibolites, hornblende-pyroxene-scapolite gneisses and hornblende-biotite-pyroxene granulites.

The plutonic rocks and their metamorphic equivalents are cut by pegmatites, quartz veins, aplites and leucocratic ortho-granulites. The latter are of particular interest since they are virtually indistinguishable from some metasediments of the Basement System.

3. Dykes

The dyke rocks are divisible into older metadolerites, genetically associated with the basic and ultrabasic intrusives, and a set of younger dykes all composed of olivine basalt. The older dykes are probably of Precambrian age whilst the younger intrusives are referred to the late Tertiary or early Pleistocene.

4. Merti Beds

Coarse pebbly sandstones and conglomerates with a highly calcareous cement overlie Basement System rocks and are in turn capped by a thin flow of olivine basalt in the scarps bounding the Merti plateau. The sediments are unfossiliferous river deposits, probably attaining a maximum thickness of some 80 ft., and are referred to the late Tertiary in view of the altitudes of the occurrences. They are separated from deposits of similar aspect that were derived from the Merti Beds during subsequent weathering.

5. Lower Pleistocene Limestones and Clays

In the south-eastern and south-central parts of the area unfossiliferous clays and limestones underlie the Pleistocene lavas. These sediments were deposited on the end-Tertiary peneplain and are tentatively assigned to the lower Pleistocene. In the extreme south-east, bore-holes sited in areas of red soil beyond the limits of the lavas pierced limestones that evidently infill valleys in peneplained Basement System rocks. Marls located by drilling south of Boji hill, at the mid-western boundary of the Chanler's Falls area, are probably intercalated with Pleistocene lavas and may be younger than the limestones and clays farther south.

6. Tertiary to Pleistocene Volcanic Rocks

Volcanic rocks, which cover about a third of the area, are mainly of Pleistocene age, though olivine basalts capping the Merti plateau are assigned to the late Tertiary. The Pleistocene lavas are dominantly olivine basalts, but olivine melabasalts, olivine melanephelinites and rare olivine-bearing ultrabasic types were also encountered. A single flow of trachyandesite occurs in the south-western corner of the area. Volcanic vents are composed of tuffs, agglomerates and scoriaceous lavas; bedded tuffs were mapped near Magado.

7. Quaternary Superficial Deposits

Soils in the area include reddish brown sandy varieties that overlie Basement System rocks and form an unbroken cover across remnants of the end-Tertiary peneplain in the south-eastern districts. Similar deposits are developed north of the Uaso Ngiro near the Merti plateau. Coarse pinkish sands of pegmatitic origin flank basic intrusive rocks in the west-central parts of the area and chocolate-brown soils often overlie amphibolitic rocks in the northern half of the area. Dusty volcanic soils are widespread.

Deposits of tough calcrete and calcareous sinter were formed from spring waters rich in calcium and magnesium bicarbonates. Pebbly deposits at Merti were evidently derived from the Merti Beds exposed in the scarps of the plateau. The lower course of the Uaso Ngiro is marked by accumulations of alluvial silts and sands.

V—DETAILS OF GEOLOGY

1. Basement System

Metamorphosed semi-pelitic sediments dominate the Basement System succession in the Chanler's Falls area. They include biotite gneisses and granulites, and rarer occurrences of biotite-garnet gneisses, biotite-hornblende gneisses and porphyroblastic gneisses. Most of the migmatites in the area also were derived from semi-pelitic sediments, though some varieties are of pelitic or semi-calcareous origin. The process of migmatization was clearly selective, so that migmatites are now uniformly interstratified with other metasediments, and their position in the stratigraphical succession can generally be established.

The most reliable Basement System succession, involving rapidly alternating bands of biotite gneisses and hornblende-biotite migmatites, can be deduced from exposures north of the Uaso Ngiro, from the western boundary of the area eastwards to the meridian 38° 20' E. The rocks are folded into a series of open anticlines and synclines, in contrast to isoclinal structures which introduce correlation difficulties in the country south of the Uaso Ngiro.

Disregarding the intrusive rocks, the Basement System succession in the north-western and north-central parts of the area is as follows:—

	<i>Approx. thickness (feet)</i>
(9) Biotite gneisses, biotite granulites and porphyroblastic gneisses ..	4,000
(8) Hornblende-biotite migmatites	3,000
(7) Biotite gneisses	2,000
(6) Hornblende-biotite migmatites with lenticular biotite gneisses ..	5,000
(5) Biotite gneisses	2,000
(4) Hornblende-biotite migmatites	1,000
(3) Biotite gneisses	5,000
(2) Hornblende-biotite migmatites	1,000
(1) Biotite gneisses	2,000
TOTAL	25,000

The biotite gneisses and granulites (9) are those that outcrop in the Tumtu syncline and in the north-western corner of the area, whilst the oldest rocks in this succession are the gneisses that appear west of Manikadima in the core of the Matetendenava anticline (*see* section on the geological map). Biotite gneisses that occur at Manikamagado and Kararietu, in the Uaso Ngiro section, are provisionally correlated with (5).

East of meridian 38° 20' and north of the Uaso Ngiro the Basement System succession cannot be stated with certainty. The biotite gneisses and quartzo-felspathic granulites that outcrop between Garrbich and the Merti plateau are probably equivalent to biotite gneisses (5) in the succession quoted above. Migmatites at Garrbich, Jajuss and Merti contain calc-silicate granulites and gneisses; they are perhaps to be correlated with semi-pelitic migmatites (4) in the above succession. The stratigraphic position of graphitic gneisses at Buliss is uncertain.

South of the Uaso Nguro, between Muddo Yaka and Kulchar, Basement System metasediments are thrown into a series of tight isoclinal folds, and the following succession is likely to be less reliable than the one quoted above:

	<i>Approx. thickness (feet)</i>
(5) Semi-pelitic migmatites; pelitic or calcareous migmatites; rare calc-silicate granulites.	8,000
(4) Biotite gneisses; psammitic, semi-pelitic and pelitic granulites; porphyroblastic gneisses.	5,000
(3) Semi-pelitic migmatites	6,000
(2) Microcline porphyroblast gneisses	3,000
(1) Semi-pelitic migmatites and biotite-garnet gneisses	4,000
TOTAL	<u>26,000</u>

The microcline porphyroblast gneisses (2) of the Kurru anticline may be equivalent to the oldest gneisses in the first succession. The migmatites and calc-silicate rocks (5) of Tena, Kulchar and south of Kubi Kalo probably represent the continuation of migmatites at Garrich, Jajuss and Merti, where calc-silicate granulites and gneisses are also found; all these rocks are probably to be correlated with migmatites (4) of the first succession quoted.

Accepting these correlations, the generalized Basement System succession in the Chanler's Falls area is as follows:

	<i>Approx. thickness (feet)</i>
(4) Semi-pelitic gneisses, granulites and migmatites	16,000
(3) Semi-pelitic and calcareous or pelitic migmatites	8,000
(2) Semi-pelitic, pelitic and psammitic gneisses and granulites	5,000
(1) Semi-pelitic gneisses and migmatites	13,000
TOTAL	<u>42,000</u>

For descriptive purposes, the Basement System rocks are classified as follows:—

- (1) Metamorphosed calcareous sediments—
Calc-silicate granulites and gneisses.
- (2) Metamorphosed pelitic sediments—
(a) Garnetiferous quartz-felspar granulites.
(b) Graphitic gneisses.
- (3) Metamorphosed semi-pelitic sediments—
(a) Biotite gneisses and granulites.
(b) Biotite-garnet gneisses.
(c) Biotite-hornblende gneisses.
(d) Microcline porphyroblast gneisses.
- (4) Metamorphosed psammitic sediments—
(a) Quartz-felspar granulites.
(b) Quartz-felspar-biotite granulites.
(c) Quartz-felspar-magnetite gneisses.
- (5) Migmatites—
(a) Migmatites with semi-pelitic host rock.
(b) Migmatites with pelitic or calcareous host rock.
- (6) Granitoid gneisses.
- (7) Mylonites

(1) METAMORPHOSED CALCAREOUS SEDIMENTS

Although no crystalline limestones were encountered during the present survey, scattered occurrences of calc-silicate granulites and gneisses indicate the existence of impure calcareous beds in the original sedimentary succession. Furthermore, some migmatites in the south-eastern and east-central parts of the area contain hornblende, garnet and epidote (*see* p. 18) and were probably also derived from calcareous sediments. Only a single thin band of marble was mapped in the Kinna area (Rix, report awaiting publication) immediately south of the country covered by the present report, but crystalline limestones become more prominent members of the Basement System succession in parts of south-central, south-eastern and north-eastern Kenya.

Calc-silicate granulites and gneisses

With the exception of a single outcrop in the extreme north-west, calc-silicate rocks occur exclusively in the eastern third of the Chanler's Falls area. Dark calc-silicate granulites are poorly exposed along an interfluvial at Tena, and similar rocks were found as trains of boulders north of Kurru Barrata. Two miles south-east of Bulfayo calc-silicate granulites and hornblende-biotite migmatites form a small hill near the Uaso Ngiro; north of the river calc-silicate granulites and gneisses give rise to a more prominent feature at Jajuss. Further occurrences were found at Garrbich, Buliss and Gudamachesa, and underlying the Tertiary Merti Beds on the southern slopes of the Merti plateau. The latter outcrop is probably a continuation of the band exposed at Jajuss in the western limb of the anticline. A single thin band of garnet-epidote granulite was encountered in biotite gneisses in the extreme north-western corner of the area.

The rocks are typically dark, fine- to medium-grained granulites with a rather vitreous lustre and a purplish or greenish hue on fresh surfaces, but commonly weathering to pale shades of brown; some varieties exhibit a more gneissose texture. The principal constituents are pyroxene, plagioclase and garnet together with accessory sphene, scapolite, epidote, quartz, apatite and opaque ores.

The *pyroxene* has a variable composition in the specimens examined but usually falls within the diopside-hedenbergite range. In specimen 37/9* from Tena, the mineral is faintly pleochroic in olive-green a similar colour distinguishing the pyroxene in a specimen (37/220) collected east of Garrbich. More commonly the pyroxene is a brighter emerald-green as in 37/61 from north of Kurru Barrata and 37/208 from Jajuss. Colourless to neutral diopside characterises the calc-silicate granulite (37/206) from the Merti plateau and in this specimen the pyroxene shows alteration to brown amphibole. Rarely, the pyroxene exhibits marked pleochroism from brownish or yellowish green to deep green as in specimen 37/219 from Buliss. Occasional anomalous high maximum extinction angles measured in pyroxenes in some of these rocks probably represent measurements of the angle $a \wedge Z$ where a prominent parting parallel to (001) is developed.

The *plagioclase* (andesine-labradorite) is generally unaltered and displays both albite and pericline twinning (e.g. specimen 37/146, from a thin band of garnet-epidote granulite collected in the extreme north-western corner of the area). Salmon-pink *garnets* are abundant in the majority of the thin sections examined. They occur as xenoblastic granular aggregates, generally free from inclusions but sometimes intimately intergrown with pyroxene as in specimen 37/220, from a locality east of Garrbich. *Scapolite* is not uncommon as an accessory mineral. In specimen 37/327 collected from a small hill south-east of Bulfayo, scapolite forms an appreciable proportion of the rock, occurring in clear xenoblastic plates showing marginal alteration to fibrous aggregates of muscovite. *Calcite* is best developed in the calc-silicate granulites exposed north of the Uaso Ngiro, particularly at Gudamachesa (specimens 37/214 and 37/215) and east of Garrbich (specimen 37/220). In the latter rock large plates of calcite enclose garnet, olive-green pyroxene and bytownite.

A pyroxene-free, fine-grained, dark purplish grey granulite (specimen 37/195) exposed near Kittermaster's Camp south of Garrbich, shows pinkish brown garnets, iron ore and sphene, all intimately intergrown with clear bytownite. The sphene often forms a rim about opaque ore and is in turn bordered by garnet. Apatite is the chief accessory mineral.

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

(2) METAMORPHOSED PELITIC SEDIMENTS

Garnet-bearing granulites and gneisses of pelitic origin occur in the eastern parts of the area; less prominent graphitic gneisses are also considered as metamorphosed pelitic sediments. Sillimanite was found to be a widely distributed mineral in several areas south of the country covered by the present survey but the mineral was not identified in pelitic gneisses in the Chanler's Falls area, suggesting that there the highest grades of metamorphism were not attained. Sanders, (1954, pp. 12-13) reported occurrences of sillimanite in a variety of rock-types in the Kitui area and noted the existence of pseudo-sillimanite gneisses in which aggregates of sericite were believed to have formed by the alteration of sillimanite during the more advanced stages of granitization. No comparable occurrences of sericite were seen during the microscopic examination of rocks from the present area and it is considered unlikely that the absence of sillimanite can be explained by the intensity of granitization alone. Sillimanite-bearing gneisses were also reported from the Mwingi area (Crowther, 1957, p. 6) and from the North Kitui area (Dodson, 1955, p. 11), both tracts of country lying south of the present area. In the areas immediately adjacent to that under discussion, sillimanite is not a conspicuous mineral. Biotite gneisses containing quartz-muscovite *faserkiesel* with included needles of sillimanite were only rarely encountered to the west in the Archer's Post area (Jennings, report awaiting publication), and in the Kinna area (Rix, report awaiting publication) sillimanite is poorly developed.

(a) Garnetiferous quartz-felspar granulites

Garnetiferous granulites are confined to the eastern half of the area and outcrops were found both north and south of the Uaso Ngiro river. The rocks are generally well exposed, often forming rocky ridges and hills that become less prominent when traced southwards towards the sand-covered end-Tertiary peneplain, where the pelitic metasediments occupy occasional interfluvial in the north-south drainage pattern.

The granulites are medium- to coarse-grained rocks containing prominent red-brown garnets that seldom exceed 3mm. in diameter, together with variable proportions of magnetite. Pale brown weathered surfaces are spotted with dark garnets. The conspicuous appearance and form of outcrop make the rocks easily identified in the field, providing useful marker bands that assist in the elucidation of major structures. In a typical specimen (37/5) collected in the Tena district north-east of Bur Bulaya, the garnets are accompanied by rare flakes of muscovite. A thin section shows an inequigranular, sutured mosaic consisting of large plates of microcline replacing subordinate untwinned albite-oligoclase. Quartz occurs in xenoblastic grains, often enclosed by the potash feldspar, and the pale pink garnets commonly display cross-fractures and marginal incrustations of limonite and goethite. No muscovite was seen in the section. In specimen 37/8, also from Tena, salmon pink garnets occur as large irregular grains containing chadacrysts of quartz and showing alteration along cracks to limonite and goethite. The sodic plagioclase is generally in a more advanced stage of alteration than the potash feldspar, the latter apparently replacing plagioclase and quartz. Accessory sphene occurs in rounded grains together with opaque ore and epidote.

Hornblende is not a common constituent of the granulites, but in specimen 37/18 from Tena amphibole is visible in the hand-specimen. In thin section the hornblende, pleochroic from brownish green to very dark green, occurs both in the granular mosaic and also as inclusions in garnet, accompanied by quartz and iron ore; accessory apatite is present in rounded grains.

Although the garnetiferous granulites often form mappable bands over long distances gradations into different rock types were noticed at several localities. At Uasisalo, for instance, occurrences of pelitic rocks form small lenses in the generally garnet-free granulites that constitute the bulk of the hill, and south-west of Uasisalo, near the Kroftu water-course, a similar gradation evidently takes place along the strike. In the north-eastern corner of the area between Buliss and Gudamachesa, the garnetiferous granulites probably grade laterally into both graphitic gneisses and biotite-garnet gneisses.

(b) Graphitic gneisses

Graphitic gneisses were encountered only in the north-eastern corner of the area where the outcrops are largely confined to the country north of the Uaso Ngiro. In areas of poor exposure they are often the only rocks seen because they form conspicuous small rounded hills and ridges. The relationships between the graphitic bands and the neighbouring

rocks are frequently obscure, but at Gudamachesa, near the Merti plateau, the graphitic gneisses are seen intercalated in a sequence of pelitic garnetiferous granulites and semi-pelitic biotite-garnet gneisses. Nearby, calc-silicate granulites appear as a probable strike continuation of the graphitic rocks. Between Buliss and the Uaso Ngiro river quartzitic graphite-bearing rocks are associated with biotite-garnet gneisses and lenticular bands of calc-silicate granulite.

The graphitic gneisses are grey, brown or purplish medium-grained rocks with fine flakes of graphite often only visible on foliation planes. The purplish varieties owe their colour to the presence of garnet and are not unlike some of the calc-silicate granulites into which they appear to grade. In specimen 37/200 from Kimitirr (the most westerly occurrence of graphitic gneiss encountered in the area) a crude alignment of graphite is seen in a heteroblastic mosaic of quartz, plagioclase and colourless garnets. The feldspar, which is largely untwinned, is probably albite-oligoclase. Anhedronal garnet grains contain chadacrysts of quartz, graphite and feldspar. Specimen 37/205 was collected from a small development of graphitic gneiss at the foot of the Merti plateau. In this rock abundant fine graphite shows good parallel alignment in a mosaic of quartz and oligoclase with rutile, sphene, apatite and epidote present as accessories. A grey brown fibrous mineral is associated with the graphite. In specimen 37/186 from Buliss the graphite flakes are about 2mm. long and occur in a quartzitic band. In addition to quartz, graphite, sphene, opaque ore, apatite and zircon, a thin section shows two prominent unidentified minerals. One is pinkish brown, displays an interstitial habit and is marked by concentric structures. The mineral is almost isotropic and a microscopic examination of grains from the hand specimen shows that it also occurs in aggregates of octahedra. A second unidentified mineral occurs in small irregular patches associated with minute granules of rutile. The mineral is yellowish, has a refractive index lower than that of quartz and is apparently uniaxial and optically negative.

(3) METAMORPHOSED SEMI-PELITIC SEDIMENTS

Gneisses of semi-pelitic origin are extensively developed in the north-western and north-central parts of the area, and are well represented south of the Uaso Ngiro between the Banya hills and the Kurru anticline. Furthermore, inliers of porphyroblastic gneisses, locally breaking the cover of Pleistocene lavas, indicate an extension of metamorphosed semi-pelitic rocks beneath the volcanics. Biotite is a common constituent of the rocks, being accompanied locally by garnet and hornblende.

For descriptive purposes the semi-pelitic gneisses are classified as follows:—

- (a) Biotite gneisses and granulites.
- (b) Biotite-garnet gneisses.
- (c) Biotite-hornblende gneisses.
- (d) Microcline porphyroblast gneisses.

(a) *Biotite gneisses and granulites*

Biotite-bearing leucocratic gneisses and granulites are among the commonest Basement System rocks in the area. Exposures are generally controlled by the texture of the rocks, being of the flat-lying pavement type where the foliation is pronounced but forming small tors, inselbergs and whalebacks where a decrease in the biotite content results in granulitic textures. Though small feldspar porphyroblasts are occasionally present, the biotite gneisses sometimes exhibit a pseudo-porphyroblastic appearance, due to the sinuous nature of biotite-rich folia around aggregates of quartz and feldspar grains. On the other hand, where genuine coarse porphyroblastic textures are developed, the rocks are differentiated on the map as microcline porphyroblast gneisses.

In thin section the gneisses exhibit a granoblastic texture with microcline replacing quartz and oligoclase. Biotite is pleochroic from straw-yellow to dark brown and is often accompanied by a little muscovite. Opaque ore, apatite and zircon are the commonest accessory minerals, the latter two frequently occurring as inclusions in quartz.

Specimen 37/147, typical of biotite gneisses north of the Uaso Ngiro, was collected in the north-western corner of the area one mile west of Oratin. It is a medium-grained, leucocratic, well foliated rock with conspicuous biotite concentrated along foliation planes. In contrast, poorly defined foliation marks biotite-bearing rocks exposed south-west of Dadabo Dima, near the Isiolo-Wajir road. On the geological map these biotite granulites are not differentiated from more typical mica-free varieties. Specimen 37/26 from this locality is

a medium-grained greyish rock in which biotite and magnetite are sometimes concentrated in small areas on foliation planes to give a spotted appearance. Quartz and untwinned oligoclase are present in approximately equal proportions, accompanied by microcline and accessory constituents.

A less typical biotite granulite (37/230) from Ardadana, in the centre of the area, contains small garnets and is described below with the biotite-garnet gneisses. This rock clearly represents an intermediate member of a gradational sequence from biotite gneisses and granulites to richly garnetiferous varieties.

(b) *Biotite-garnet gneisses*

Biotite-garnet gneisses are not extensively developed and outcrops are largely confined to the eastern districts. At Tena, north-north-east of Bur Bulaya, medium-grained pink and brown dappled biotite gneisses contain occasional small feldspar porphyroblasts and form a lenticular band interstratified in a succession of granulites and migmatites. A thin section of the gneiss (37/19) shows greenish biotite, partly sericitized albite and pink garnets, the latter locally surrounded by borders of chloritic material. Muscovite is interleaved with some of the biotite flakes, and opaque ore and apatite are accessories. Quartz exhibits myrmekitic intergrowths with albite. Farther north in the core of the Kurru anticline garnet-bearing biotite gneisses or granulites are exposed in the Kurru stream. The rocks at this locality are rather fine-grained and poorly foliated in hand specimen (37/54), though a thin section shows a strong preferred orientation of biotite in a granoblastic mosaic of quartz and sodic oligoclase. The biotite, pleochroic from straw brown to dark brown, is accompanied by numerous small garnets and the accessory minerals are opaque ore, zircon and apatite.

Greyish mesotype rocks that outcrop at Gudamachesa near the Merti plateau are well foliated and contain biotite together with a sprinkling of small reddish garnets. These gneisses probably grade into both garnetiferous granulites and semi-pelitic biotite gneisses.

A garnetiferous biotite granulite (specimen 37/230) was encountered near Ardadana in the centre of the area. The rock is buff-coloured and poorly foliated, and in thin section shows small rounded garnets, quartz and sericitized oligoclase, the latter being partly replaced by microcline. Rare shreds of muscovite are interleaved with the more conspicuous biotite. Some myrmekite is present and the accessory minerals comprise opaque ore, grains of epidote and small plates of calcite.

(c) *Biotite-hornblende gneisses*

Although biotite-hornblende rocks are extremely well represented in the Basement System succession, most exposures display a typical migmatitic appearance with evidence of contorted banding and plastic deformation. Such rocks are therefore termed migmatites, and the term biotite-hornblende gneiss is reserved for rare occurrences of biotite gneiss in which amphibole attains the status of an essential mineral.

At Matetendenaya, some three miles east-south-east of Muddo Gurba Huka hill, moderately well foliated medium-grained mesotype rocks (37/162) containing both biotite and hornblende are intercalated in more normal leucocratic biotite gneisses. Blue-green hornblende, brown biotite and subordinate muscovite are poorly orientated in a xenoblastic mosaic of quartz, oligoclase and microcline. Opaque ore, sphene and apatite are accessory, the latter occurring largely as inclusions in quartz.

A mile and a half to the north-west, finely foliated medium-grained granulites (37/163) have a similar mineral composition but with biotite subordinate in amount to the amphibole. At this locality, however, the lenticular band is enclosed by biotite-hornblende migmatites and is perhaps merely a granulite rib.

(d) *Microcline porphyroblast gneisses*

Although found in widely separated parts of the area, outcrops of porphyroblastic gneisses are most prominent in the eastern portion, south of the Uaso Ng'iro. The rocks form two conspicuous inselbergs at Dadabo Dima, west of Bur Bulaya volcanic vents, the features being clearly visible from the Isiolo-Wajir road. Similar gneisses were encountered as inliers in the Pleistocene lavas a few miles further west, where the rocks outcrop in a line of rounded tors, whalebacks and inselbergs. The principal exposures are at Dadabo Reselesa, a lone pinnacle of rock best seen from the track between Kurru Barrata and Muddo Yaka. Less

conspicuous, because they are surrounded by a circle of volcanic cones, but still forming notable features, are the inliers of porphyroblastic gneisses at Dakadima in the south-western corner of the area. Rocks having a similar texture and composition admirably demonstrate the anticline north-north-east of Kurru Barrata, the gneisses forming a well defined semi-circle of crags marking the closure of the porphyroblastic band. Some three miles to the north-west, very similar rocks form the central portion of a small conical hill (Kubi Kalo) near the Uaso Ngiro. Elsewhere in the area the occurrences of porphyroblastic gneisses are not generally marked by prominent topographical features.

The microcline porphyroblast gneisses vary little in general appearance, being typically buff and pink medium-grained granitoid rocks containing prominent pale porphyroblasts of microcline or microcline micropertite half-an-inch in diameter; locally, the porphyroblasts are very much larger. Foliation is generally well defined, but with an increase in the proportion of potash feldspar the foliation becomes less distinct and the rocks grade into granitoid gneisses. Small segregations of ferro-magnesian minerals and iron ores often impart a dappled appearance to the exposures, and occasional small pegmatitic veins are to be seen. Hornblende occurs in subhedral crystals up to two and a half inches long in a thin *lit-par-lit* pegmatite in porphyroblast gneisses near the northern inselberg at Dadabo Dima.

In specimen 37/13 from Dadabo Dima, quartz and microcline form prominent porphyroblasts and the same minerals, together with magnetite, form the bulk of the groundmass. Hornblende and biotite were not cut by the thin section but both are visible in the hand specimen. Accessories include small colourless garnets, sphene in elongated and rounded grains, and apatite as inclusions in quartz. Porphyroblasts of microcline and microcline micropertite are visible in specimen 37/56 from Kubi Kalo. Albite-oligoclase occurs as clear unaltered grains in the groundmass, together with rare flakes of brown biotite, opaque ore, sphene and zircon. In the porphyroblastic gneisses (37/114) exposed in the Dakadima inlier in the south-western corner of the area, hornblende is prominent and shows pleochroism from brownish green to very dark green. Hornblende accompanies microcline micropertite as porphyroblasts in a specimen (37/224) of gneiss collected from exposures south of Dadabo Reselesa in the south-central portion of the area. The hornblende shows alteration to brown biotite, and accessories include colourless garnets, sphene, zircon and apatite.

For convenience, the microcline porphyroblast gneisses are all described here as metamorphosed semi-pelitic sediments, but they probably represent a variety of original sedimentary types that have undergone intense granitization. The presence of garnet and hornblende in some of the rocks perhaps indicates derivation from pelitic or semi-calcareous sediments.

(4) METAMORPHOSED PSAMMITIC SEDIMENTS

Quartzo-felspathic granulites and gneisses that are believed to be derived from psammitic sediments are well developed, particularly in the eastern parts of the area where they frequently form low ridges and tors. Pure quartzites were not seen in the present area and the rock types described below probably represent metamorphosed arkoses. All the rocks have undergone recrystallization together with some degree of granitization so that sedimentary structures have been obliterated. Field relationships, however, confirm that the granulites and gneisses represent sandy intercalations in the original sedimentary succession, the bands now being conformably interstratified with the metamorphic derivatives of pelitic, semi-pelitic and calcareous sediments.

The rocks are typically leucocratic, and medium- to coarse-grained, and they contain varying proportions of biotite and iron-ore. Textures are dominantly granulitic with local gradations into more gneissose members.

For descriptive purposes the following sub-division is convenient, though no separation is possible on the present scale of mapping:—

- (a) Quartz-felspar granulites.
- (b) Quartz-felspar-biotite granulites (in part).
- (c) Quartz-felspar-magnetite gneisses.

(a) Quartz-felspar granulites

These rocks are generally medium-grained, leucocratic and highly felspathic with a distinctive granulitic texture. They are buff-coloured or pale brown on fresh surfaces but frequently exhibit a brick-red rather mottled appearance when weathered. Magnetite, often

accompanied by subordinate ilmenite, is a common accessory mineral but mafic constituents make up a very small proportion of the rocks. Foliation is poorly defined and, even where observed, surfaces for reliable dip measurements have to be selected with caution owing to widespread slumping. With the introduction of biotite, particularly towards the margins of the bands, foliation becomes more pronounced and the rocks often grade through quartz-felspar-biotite granulites into leucocratic biotite gneisses. Inevitably, difficulty was experienced in separating for mapping purposes individual members of this gradational sequence. The quartz-felspar-biotite granulites have not been differentiated on the geological map, the more biotite-rich occurrences being grouped with the biotite gneisses and the highly quartzo-felspathic members with the quartz-felspar granulites.

In a typical specimen (37/60) of biotite-free granulite from Muddo Yaka, south of the Uaso Ngiro, microcline clearly replaces both quartz and sodic oligoclase but remains subordinate in amount to the plagioclase. Perthite, magnetite and possibly rutile are also present.

(b) *Quartz-felspar-biotite granulites*

The rocks are typically buff-coloured, medium-grained granulites containing a liberal sprinkling of biotite. In thin sections the rocks display a granulitic texture with quartz, oligoclase and biotite accompanied by varying proportions of microcline. They lack the marked foliation associated with the biotite gneisses and are more leucocratic than rocks previously described as biotite granulites.

In specimen 37/86, from an exposure north-east of the Banya hills, biotite is partly replaced by small shreds of muscovite, though some of the colourless mica seen in the thin section is almost uniaxial and may be bleached biotite; opaque ore is accessory. Farther east at the same locality the rocks grade into biotite-free granulites.

Near the eastern boundary of the area quartz-felspar-biotite granulites form a low hill at Rampsu, differential weathering of highly felspathic and more quartzitic horizons producing cave and pillar effects throughout the main exposures. In specimen 37/22 from this locality microcline is seen replacing both quartz and sodic oligoclase; microperthite is also present. The biotite is pleochroic from straw-brown to dark brown and zircon is accessory.

(c) *Quartz-felspar-magnetite gneisses*

The more gneissose members of the quartzo-felspathic group are less commonly developed than the granulites but they are more compact and more resistant to erosion so that they form prominent topographical features, as at Bulfayo hill (on which is situated Waso trigonometrical beacon) in the north-eastern corner of the area. The rocks owe their gneissose character mainly to the abundance and mode of occurrence of magnetite. Specimen 37/234 from the trigonometrical beacon on Bulfayo is a pink and buff coarse-grained rock in which foliation is defined by variation in grain size and by the distribution of magnetite. In thin section quartz, albite, microcline and magnetite form a heteroblastic texture. The chief accessories are a pale blue-green pyroxene and small yellowish rounded grains of sphene. Specimen 37/235 from the same locality is also rich in magnetite, the ore being concentrated in distinct laminae that enhance the foliation. In thin section this rock has a gneissose texture with quartz often occurring as porphyroblasts. Microcline is the dominant felspar but albite is also present. Opaque ore is prominent and sometimes encloses or is intergrown with occasional flakes of biotite. The accessory minerals are zircon and a faintly pleochroic green pyroxene having an extinction angle $c \wedge Z$ of 52° .

Similar quartz-felspar-magnetite gneisses (37/211) outcrop at the foot of the Merti plateau north of Jajuss. There the rocks are tough, compact and medium- to fine-grained with magnetite showing a preferred orientation. In thin section quartz, albite-oligoclase, microcline and opaque ore display a gneissose texture. Zircon and yellow rounded grains of sphene are the main accessories.

(5) MIGMATITES

The term migmatite is used here to describe a group of hornblendic rocks in which not only is there ample evidence of the introduction of material of granitic composition, but in which common contorted banding and ptymgatic veining (Plate III (b)) demonstrate varying degrees of plastic deformation. Contorted migmatites of this type are common enough members of the Basement System not to require any detailed account of field characteristics. The most prominent feature is a rapid alternation of mafic and leucocratic bands, individual

members varying in width from fractions of an inch to hundreds of feet. Amphibolitic *boudins* are often developed, with their long axes parallel to the foliation of the enclosing gneiss, and pegmatitic segregations are common (Plate III (a)). In many instances the orientation of pygmatic veins is without any major structural significance; on the other hand minor folds developed in the migmatites may be related to the major structural pattern of the area. It should be emphasized that exposures of the migmatites are often poor and only in the better river exposures is the true nature of the rock appreciated. This qualification is particularly important in view of the existence of complex ortho-amphibolites in the Chanler's Falls area. Both the ortho-gneisses and the Basement System hornblendic migmatites tend to be poorly exposed away from the Uaso Ngiro, and in deeply weathered small outcrops showing crumbly mafic granulitic rock, it is virtually impossible in the field to distinguish the two types; similarly, specimens from the more weathered exposures disintegrate readily and are often valueless for subsequent study. The presence of appreciable amounts of biotite accompanying the amphibole in the migmatites was believed to be indicative of a sedimentary Basement System origin, and this assumption has been largely justified by evidence seen in thin sections of the rocks.

The following two-fold subdivision of the hornblendic migmatites is based on the occasional appearance of megascopically visible garnets:—

- (a) Migmatites with semi-pelitic host rock.
- (b) Migmatites with pelitic or calcareous host rock.

(a) *Migmatites with semi-pelitic host rock*

These rocks are widely developed throughout the area, being best exposed in the central Uaso Ngiro river section where they occur in flat-lying outcrops more or less at water-level, often forming low islands in the stream. The migmatitic nature of the rocks is well displayed with both even and contorted banding and common amphibolitic schlieren. The darker bands are composed of mesotype, medium-grained, granular rock containing both hornblende and biotite; the ferromagnesian minerals are sometimes segregated into small clusters producing a mottled appearance. In specimen 37/99, taken from the migmatites exposed immediately below Chanler's Falls, small grains of pyrite are visible in the hand specimen.

Thin sections of typical rocks display a granular mosaic of hornblende, biotite, plagioclase, quartz and opaque ore minerals together with a variety of accessory minerals, commonly including apatite, epidote and zircon. The hornblende is pleochroic in shades of green and brownish green and biotite is normally subordinate in amount to the amphibole. Plagioclase has the composition of oligoclase in most of the slides examined but in specimen 37/117 from near Boji hill on the western boundary of the area the feldspar is andesine-labradorite. Leucocratic migmatites (37/135) exposed in the Uaso Ngiro south of Tumtu hill contain hornblende-biotite schlieren generally about four to six inches long. In the host rock some of the oligoclase is clearly of late growth, particularly near the small clusters of ferromagnesian components. Specimen 37/190 from Garrbich exhibits a marked heteroblastic texture with porphyroblasts of microcline quartz and oligoclase in a granular mosaic of the same minerals together with myrmekite and biotite; no hornblende was seen in the thin section of this rock.

Opaque ore and rounded grains and prismatic crystals of apatite are the commonest accessory minerals in the migmatites. Muscovite was occasionally seen interleaved with biotite as in specimen 37/33 from Tena, but is nowhere abundant. Spinel, zircon, epidote and calcite were seen in some of the specimens examined (e.g. 37/99 and 37/194, the latter being collected from a locality south of Garrbich).

(b) *Migmatites with pelitic or calcareous host rock*

Near the eastern boundary of the area south of the Uaso Ngiro the migmatites are commonly garnetiferous, suggesting that the host rocks represent metamorphosed pelitic or calcareous sediments in contrast to the presumed semi-pelitic host rocks in the migmatites described above.

The garnetiferous migmatites are best exposed in the Garba Tula watercourse at Karrsa, in the extreme south-eastern corner of the area, where occasional bands contain prominent idiomorphic garnets up to 1½ in. in diameter. The garnets are pink and translucent, or brownish and opaque; they are invariably shattered and sieved with inclusions of quartz and feldspar,

occasionally showing megascopic chloritic borders. The garnets are not restricted to either the mafic or felspathic bands in the migmatite, but the larger specimens generally occur in the conformable pegmatitic veins.

Further north garnetiferous migmatites were encountered at Dakaborr and east of Uasisalo hill, the rocks occupying the flat ground and also forming occasional small hills. At these localities the rocks are coarsely mottled and bear lenticular mafic segregations containing reddish garnets up to a tenth of an inch in diameter but generally half that size.

Thin sections of the migmatites display heteroblastic granular textures, the principal minerals being hornblende, biotite, quartz, plagioclase, microcline and garnet together with common accessory opaque ore and apatite. Less prominent accessory minerals include muscovite, epidote, chlorite and sphene. In a specimen (37/1) from a melanocratic band in migmatites exposed in the Garba Tula watercourse, biotite is subordinate in amount to strongly pleochroic, brownish green to dark green hornblende. The felspar is probably entirely oligoclase-andesine and apatite is a prominent accessory. No garnets were seen in this specimen but they are conspicuous in a leucocratic band (37/2) near by in which pink garnet accompanies sodic oligoclase, microcline and quartz. Occasionally biotite becomes the chief ferromagnesian mineral in the garnetiferous migmatites as in specimen 37/15 from the Garba Tula watercourse and 37/44 from the small hill of Dakaborr. In the former, clusters of small rounded crystals of epidote are seen as inclusions in microcline and quartz and more rarely in garnet; sphene occurs in rounded grains. In the migmatites (37/49) exposed north of Dakaborr, large flakes of biotite are pleochroic from straw-brown and reddish brown to dark brown and show the initial stages of alteration to muscovite. Reddish garnets, though not cut by the section, are prominent in the hand specimen.

(6) GRANITIC GNEISSES

Three small hills lying astride the Merti track at Buliss, near the eastern boundary of the area, are composed of poorly foliated rocks of granitic composition. The relationships between these hornblende-biotite granitoid gneisses and the surrounding metasediments are not seen, but the granitic rocks may be of paligenetic origin.

Specimen 37/185 from the western hill at Buliss is a poorly foliated, rather dark pink and grey mottled rock. In thin section it exhibits a granoblastic mosaic with quartz, felspar, hornblende and biotite as the essential constituents. The felspar is mainly microcline but untwinned sodic plagioclase is also present. The hornblende is pleochroic from yellow-green to dark green and occurs in large ragged crystals having an extinction $c \wedge Z = 27^\circ$. Prominent flakes of straw-brown to dark brown biotite have ragged terminations and are accompanied by subordinate muscovite. Accessory minerals include rounded grains and small prismatic crystals of zircon, rounded grains of apatite and scattered irregular grains of magnetite.

(7) MYLONITES

Mylonitic rocks, showing typical augen and cataclastic textures, were encountered at several localities in the north-eastern parts of the area. The occurrences, which are readily related to local faults, are not differentiated on the geological map.

The mylonites are well foliated, flaggy or fissile pink and grey rocks with rounded or lenticular aggregates of felspar drawn out in the plane of the foliation and extensively altered. The quartz is frequently grey and translucent and often stands out in small irregular patches to give rough weathered surfaces.

In the thin section of a specimen (37/197) of mylonitic quartz-felspar granulite collected near Kismetirr, west of Kittermaster's Camp, quartz and highly altered felspar form a coarse sutured mosaic. The felspar is largely unidentifiable but is in part oligoclase. Bent shreds of muscovite enclose trains of granular green epidote, and opaque ore is present in occasional irregular grains.

A mylonitic biotite gneiss (37/193) from a locality south of Garrbich contains small pink felspar augen, composed mainly of granular aggregates of turbid microcline. Subordinate oligoclase is generally fresher than the potash felspar, and numerous small shattered flakes of biotite are accompanied by irregular ore grains.

In specimen 37/199 from Kismetirr, drawn out lenticular aggregates of quartz and microcline are set in a finer granular mosaic of quartz, microcline, oligoclase, ore and scattered grains of pale green, non-pleochroic pyroxene. Rare mylonites also occur among the Basement System rocks at Gudamachesa, near the Merti plateau.

2. Metamorphosed Basic and Ultrabasic Intrusives, and Associated Leucocratic Rocks (?Precambrian)

The area is notable for its occurrences of metamorphosed basic and ultrabasic intrusives. Rocks of igneous aspect now appear as virtually unmodified cores within belts of foliated ortho-amphibolites and ortho-gneisses, formed by regional metamorphism of the intrusions. All the ultrabasic rocks, and most of the basic varieties, are hypersthene-bearing and are clearly related to the intrusive suites mapped in the Embu and Meru districts of Kenya. (Pulfrey, 1946; Schoeman, 1951, pp. 17-45; Bear, 1952, pp. 22-25). Similar metamorphosed basic and ultrabasic intrusive rocks were subsequently mapped in, for instance, the Archer's Post and Kora-Kalimangilu areas (Jennings, reports awaiting publication); in the Barchuma-Kom area (Dodson, report awaiting publication); and in the Buna-Korondil area (Williams, report awaiting publication), over 100 miles north-east of the Chanler's Falls area.

The intrusives are principally developed in the north-western parts of the Chanler's Falls area, where they occur in a broad zone that trends north-easterly to include Boji, Tuntu and Muddo Gurba Huka hills. Smaller intrusive masses were also found scattered throughout the northern two-thirds of the area, frequently showing a linear arrangement parallel to that of the Tuntu zone. It is of interest to note that the north-north-easterly trend of outcrops of the intrusive suite is paralleled by major faults in the area, by later cross-folds that affected the intrusive rocks, and by even later small dykes.

The ages of the basic and ultrabasic intrusive rocks are not demonstrated precisely by the present work. They display a discordant relationship towards Basement System metasediments; and ortho-amphibolites, derived from the intrusives, are overlain by late Tertiary sediments in the southern scarps of the Merti plateau. In view of the degree of metamorphism and the strongly folded nature of the rocks, however, the intrusive suite is referred to the Precambrian.

The intrusive types and associated rocks are conveniently classified as follows:—

- (1) Ultrabasic and basic igneous rocks, and metagabbros.
- (2) Ortho-amphibolites and ortho-gneisses.
- (3) Pegmatites, quartz veins and leucocratic ortho-granulites.

(1) ULTRABASIC AND BASIC IGNEOUS ROCKS, AND METAGABBROS

Constituent Minerals

The rocks in which igneous textures are preserved display a comparatively simple mineral composition, the majority being composed essentially of calcic plagioclase, hypersthene with or without a monoclinic pyroxene, and hornblende; many of the rocks carry olivine, and spinel is also a common constituent. Accessory ore minerals include both magnetite and pyrite.

The orthorhombic pyroxene was found to be *hypersthene* throughout the range of thin sections examined. Schoeman (1951, p. 20) recorded a similar invariable composition for the ortho-pyroxene in basic and ultrabasic intrusives in the Embu-Meru region, and Pulfrey (1946, p. 70) noted enstatite in only a single rock (a hornblendic websterite) during a detailed examination of hypersthene-bearing plutonic rocks from part of the same area. Bear (1952, p. 22) identified occasional crystals of enstatite in olivine-pleonaste norites from the area south-east of Embu, but quoted hypersthene as the dominant ortho-pyroxene.

The commonest pleochroism is from pale pink to pale green, or from pale pink to colourless, but sometimes the hypersthene is pleochroic in shades of pinkish brown and more rarely purplish brown. Estimated negative optic axial angles range from 80° to 85° , suggesting a content of about 20 per cent by weight FeSiO_3 (Poldervaart, 1950, p. 1,076). These optic axial angles contrast with values of 62° to 63° quoted by Pulfrey (*op. cit.* p. 20). Schiller structure is produced locally by closely spaced inclusions in the hypersthene. Extinction is usually parallel to prominent (110) cleavages, but occasionally the extinction direction is inclined to the trace of the cleavage. Johannsen (1937 Vol. III, p. 212) notes that oblique extinction will be seen in orthorhombic minerals when sections cut all three crystallographic axes.

The habit of the ortho-pyroxene is variable. Subhedral to anhedral crystals are typical of the norites, hyperites and gabbros, whereas the ultrabasic rocks are often coarser-grained, with hypersthene present in long blades or as large crystals enclosing hornblende. In olivine-bearing rocks hypersthene frequently forms a corona about olivine, occurring in a fine

granular or rather fibrous habit. When both ortho- and clino-pyroxenes are present in the same rock the orthorhombic mineral is generally the first to crystallize, but in a specimen of hypersthene olivine gabbro (37/121 from the Uaso Ngiri west of Tumtu) the hypersthene is seen fringing crystals of augite. Sometimes the ortho-pyroxene occurs in fine granular pseudomorphs after olivine.

The monoclinic pyroxene is commonly very pale green non-pleochroic *augite*; pale brown, neutral and purplish brown varieties were also observed. Measured extinction angles $c \wedge Z$ range from 38° to 55° and estimated optic axial angles are typically about 60° , though a range of 45° to 75° is likely. Schiller structure and prominent (100) diallage cleavage were observed in a number of thin sections. Marginal alteration to hornblende is not uncommon.

Pulfrey (1946, p. 71) suggested a correlation between the presence of spinel and the extinction angle in monoclinic pyroxenes in very similar plutonic rocks from the Meru district, noting that in the spinel-bearing types $c \wedge Z$ did not exceed 48° , and that in the spinel-free rocks the extinction was never less than 46° . No invariable relationship was observed in the rocks from the present area where, for instance, a spineliferous gabbro (specimen 37/121) is composed of augite showing $c \wedge Z = 55^\circ$, and the maximum extinction measured in a spinel-free uraltite gabbro (specimen 37/97) is 43° . On the other hand, from a random selection of sixteen slides only four showed clino-pyroxene with $c \wedge Z$ greater than 48° and, of these four, two contained no obvious spinel. Schoeman (1951, p. 20), during a further investigation of the basic and ultrabasic intrusives of the Embu-Meru area, also found some exceptions to the correlation suggested by Pulfrey; augite in a spinel-bearing olivine bojiite was seen to have $c \wedge Z = 57^\circ$ and in a spinel-free olivine norite the extinction was 33° . The exceptions led Schoeman to believe that factors other than the alumina content affect the value of the extinction angles of the monoclinic pyroxene.

Colourless *olivine* is a common and prominent constituent of the norites, hyperites and gabbros and is also present in one of the ultrabasic rocks—a hornblende-pyroxene picrite (specimen 37/29) collected from the core of the Kurru anticline. Estimated negative optic axial angles range from 80° to 90° , indicating a composition between Fa_{12} and Fa_{35} (Poldervaart, 1950, p. 1,073). In all the specimens examined, the olivine is characterized by irregular cracks marked by the preferential development of a reddish brown, yellow-brown or brown alteration product of apparently variable composition. Typically, the olivine alters to yellow-brown bowlingite that is occasionally pleochroic and has a refractive index lower than that of the olivine host. Not uncommonly, however, the secondary mineral is goethite with a refractive index higher than that of olivine. Throughout the range of thin sections examined, olivine is separated from plagioclase by a reaction rim producing a texture known as ocellar- or kelyphite-structure (Johannsen, 1937, Vol. III, p. 208). These rims consist either of a simple border of hypersthene with associated magnetite and spinel or, more commonly, of a double corona; treble coronal rims about olivine were rarely seen. The typical double corona consists of an inner zone of granular or fibrous pyroxene immediately adjacent to the olivine core, with an outer zone composed of pale green, feebly pleochroic amphibole sieved with dactylic growths of brighter green spinel. Clear-cut margins mark the contact between the amphibole and the neighbouring plagioclase. The composition of the pyroxene forming the inner zone is variable; most commonly it is weakly pleochroic hypersthene, but in many cases is a colourless to neutral monoclinic pyroxene. Examples of treble coronas are found in a noritic olivine bojiite (specimen 37/165) where large anhedral crystals of olivine are fringed by non-pleochroic hypersthene in the inner zone. Brown, non-spineliferous hornblende forms a discontinuous middle zone passing outwards into a rim of green amphibole enclosing fine growths of spinel.

Hornblende is a common constituent in nearly all the basic and ultrabasic rocks examined, but in most cases it is no easy matter to determine whether the mineral is of primary or secondary origin, since in both instances the habit is variable. A common occurrence is in the form of late magmatic reaction coronas about olivine and pyroxene, and more rarely surrounding grains of opaque ore. The hornblende in these coronas is usually pale green and either feebly pleochroic or non-pleochroic. Spinel is frequently found as minute dactylic growths in the amphibole, and the zones show clear-cut margins, particularly against felspar. Extinction angles $c \wedge Z$ measured on the pale green hornblende range from 25° to 33° . In addition to this spineliferous pale amphibole, brown hornblende is also a frequent essential constituent of the rocks, the two varieties often being seen in the same thin section. The brown

hornblende displays strong pleochroism from medium brown to pale olive green, or from pale yellow-brown to golden brown, or brown tinged with green. Extinction angles $c \wedge Z$ vary from 16° to 28° and are generally lower than values recorded from green hornblende in the same section. This is illustrated by the following examples:—

Specimen 37/130: Brown- 17° , Green- 26°

Specimen 37/171: Brown- 23° ; Green- 25°

Both specimens are of hypersthene gabbro, the latter bearing olivine whilst the former displays hypersthene pseudomorphs after olivine. Pulfrey (1946, p. 71) found that green hornblende in a hyperite from Inandago showed larger extinction $c \wedge Z$ than a brown variety in the same rock, but he noted that in detail there appeared to be no relation between the colour of the hornblende and the extinction angle.

A third, less common variety of hornblende displays pleochroism from bluish green to very pale green, has $-2V = c.60^\circ$ and $c \wedge Z = 27^\circ$. This amphibole is largely confined to the ultrabasic members of the suite and is well developed in an augitic hypersthene (specimen 37/46) and a hornblende hypersthene (specimen 37/198). It is also present in a melanocratic hypersthene olivine gabbro (specimen 37/121) where it is accompanied by hornblende that is pleochroic in shades of yellow-brown.

Plagioclase is usually unaltered and shows albite and pericline twinning; combined Carlsbad-albite twins are only rarely seen. The majority of the ultrabasic rocks contain no plagioclase, but in many of the gabbroic members plagioclase forms up to 80 per cent of the rock. Anorthosites, with more than 90 per cent plagioclase, are not developed on a large scale and occur as thin, rapidly alternating bands in the gabbros. The feldspar is typically labradorite with an average composition of An_{66} , but it ranges from sodic labradorite (An_{54}) to medium bytownite (An_{76}). In a specimen (37/136) of hypersthene olivine gabbro, the labradorite is accompanied by oligoclase that occurs as rounded clear blebs in clino-pyroxene. This probably marks the initial stage of a process of recrystallisation that is carried further in a metagabbro (specimen 37/164) where the feldspar is largely oligoclase; scapolite present in this specimen has probably formed from feldspar during the reconstitution. Calcic plagioclase in the metagabbros is occasionally sieved with inclusions of tremolite or hornblende. Alteration of the plagioclase is not widespread; where it does occur it takes the form of patchy sericitization, though in a noritic olivine bojiite (specimen 37/165) labradorite is replaced by minute prisms and grains of zoisite (*c.f.* Pulfrey, 1946, p. 70).

Nearly half the basic and ultrabasic rocks examined contain vivid green *spinel* (probably pleonaste) as a prominent accessory mineral. Very often it occurs in complex dactylic and vermicular growths in pale green hornblende, the latter forming reaction coronas around olivine and pyroxenes. More rarely spinel occurs in irregular interstitial grains outside the coronas, and in an augitic hypersthene (specimen 37/46) the spinel is present in striated crystals (*c.f.* Pulfrey, 1946, p. 73).

Opaque ore minerals are developed to some extent in all the rocks. Both *magnetite* and *pyrite* are usually to be seen in the same section, with the latter normally subordinate in amount to the oxide. Much of the magnetite is obviously produced during the alteration of the ferromagnesian constituents, but is also commonly present as interstitial irregular grains. Unconfirmed *chromite* (specimen 37/87) accompanies magnetite and pyrite in an olivine norite.

Biotite is a rare constituent of the basic and ultrabasic intrusives but prominent flakes occur in a coarse-grained hornblende-pyroxene picrite (specimen 37/29). *Calcite* is developed as small interstitial plates in several specimens, and in an olivine norite (specimen 37/90) a carbonate (?magnesian) traverses the rock in thin veinlets. Weakly pleochroic, pale green *tremolite* with $c \wedge Z = 14^\circ$ is accompanied by long prismatic crystals of *anthophyllite* in a specimen (37/137) of metagabbro. *Epidote* occurs in small prismatic crystals and rounded grains in the anorthositic portion of a banded uralite gabbro (specimen 37/97); interstitial, anhydrous plates of *scapolite* are present in this rock and also in several of the metagabbros. *Zoisite* has already been mentioned as an alteration product of plagioclase; more commonly the feldspar shows alteration to *sericite*. *Chlorite* is occasionally seen replacing pyroxene, and *bowlingite*, *goethite* and *iddingsite* formed during the alteration of olivine. *Apatite* occurs as rare inclusions in the pyroxene in an olivine hyperite (specimen 37/64), and *sphene* is a prominent accessory mineral in a metagabbro (specimen 37/164).

Classification of the Basic and Ultrabasic Intrusives

The following classification of the hypersthene-bearing basic and ultrabasic suite is based largely on the scheme adopted by Pulfrey (1946, p. 69) in descriptions of similar rocks from the Meru district of Kenya:—

- (a) Ultrabasic rocks—
 - (i) Hypersthenites.
 - (ii) Hornblende-pyroxene picrites.
- (b) Basic rocks—
 - (i) Olivine norites.
 - (ii) Metanorites.
 - (iii) Olivine hyperites.
 - (iv) Hyperites.
 - (v) Hypersthenic olivine gabbros.
 - (vi) Gabbros.
 - (vii) Metagabbros
 - (viii) Bojites
- (c) Anorthosites.

Metagabbros and a metanorite are included with the virtually unmetamorphosed rocks in the present discussion, since no clear distinction could be made in the field. On the other hand, a series of amphibolites, plagioclase amphibolites and hornblende gneisses that represent the more advanced stages of metamorphism of the intrusive rocks are omitted from the present classification and are described in a later section of the report (p. 30). Even in the early stages of metamorphism, represented by rocks that occur near the core of the original intrusion, the development of secondary amphiboles is widespread, often making it difficult or impossible to assess the magnitude of late-magmatic and post-magmatic changes in mineralogical composition. As a result, difficulties arise in the classification and nomenclature of the hornblende-rich rocks. Fig. 3 shows the distribution of the basic and ultrabasic intrusives, together with metagabbros and metanorites, but it should be noted that the finer subdivision of the rocks is based on evidence provided by a limited selection of specimens. Whilst every attempt was made to collect representative specimens, difficulties inevitably arose in the sampling of banded and variable rocks so that the illustration must be regarded rather as a specimen locality map. Occurrences of ortho-amphibolites are omitted from Fig. 3 since their distribution is clearly appreciated by reference to the coloured geological map.

(a) *Ultrabasic Rocks*

(i) *Hypersthenites*

These dense, felspar-free or felspar-poor coarse- to medium-grained rocks form only subordinate members of the intrusive suite. Four specimens were collected, two being hornblende, one containing augite in addition to hornblende, whilst the fourth was taken from a highly altered rock.

The *hornblende hypersthenites* are medium- to coarse-grained types mottled in shades of green, black and dark or reddish brown. In hand specimen 37/51 from Kulchar in the eastern part of the area brown hypersthene encloses dark aggregates of hornblende crystals. Specimen 37/198, collected from Kimitirr near Kittermaster's Camp, displays a coarse mosaic of dull green amphibole and brown hypersthene. Differential weathering of the two minerals produces a pitted appearance on exposed surfaces. In thin section the mineral composition is seen to be simple, with hypersthene and green hornblende forming the bulk of the rock. In specimen 37/51 hypersthene, pleochroic from pale pink to pale green, occurs in large crystals enclosing abundant subhedral amphibole, the enclosing pyroxene being represented by interstitial patches in optical continuity. Ore minerals, both magnetite and pyrite, are not abundant. Vivid green spinel is a prominent constituent of specimen 37/198, occurring as irregular grains and dactylic intergrowths in the hornblende, and more rarely as larger grains enclosed by the hypersthene. The accessory ore mineral is largely pyrite, and small ragged flakes of colourless mica are associated with occasional interstitial patches of calcite.

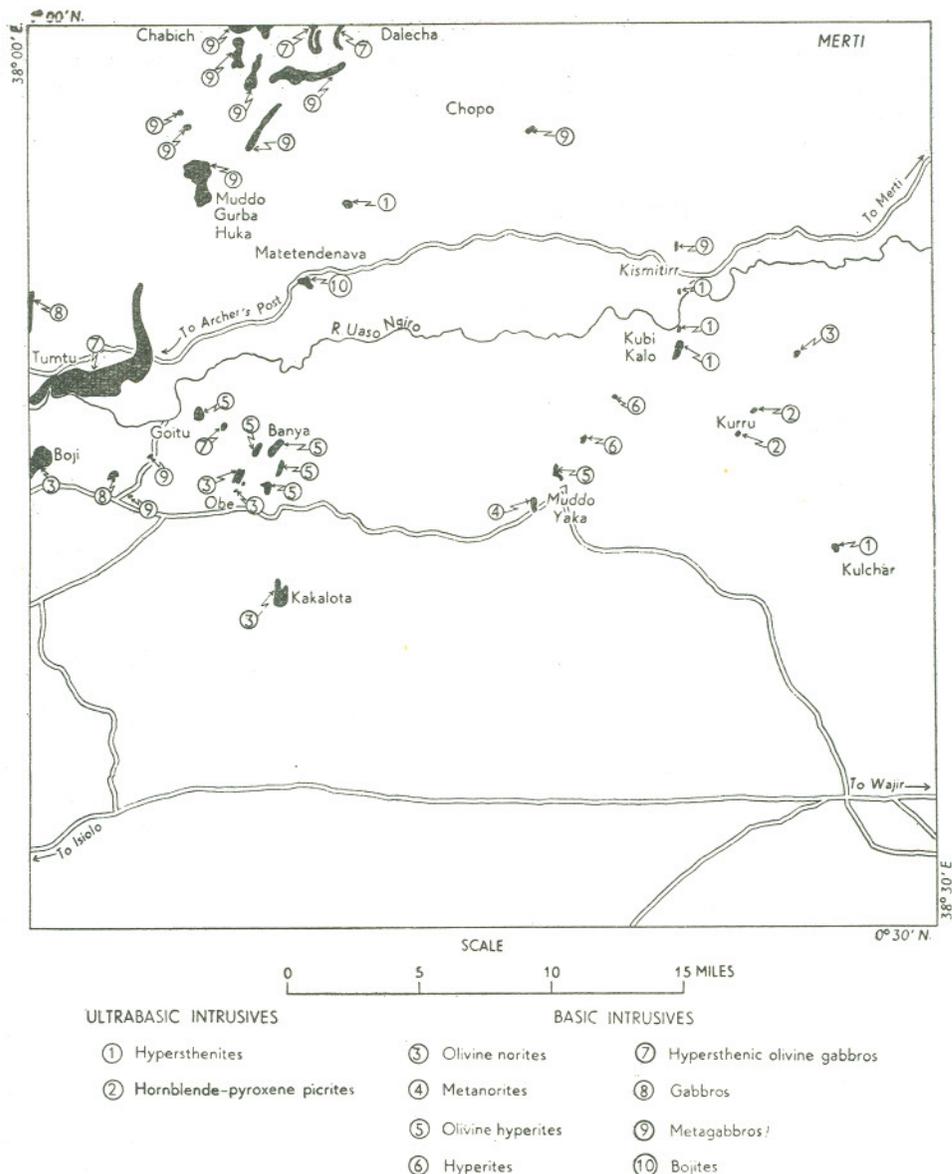


Fig. 3.—Distribution of the basic and ultrabasic plutonic rocks in the Chanler's Falls area.

A specimen of *hornblende augitic hypersthenite* (37/46) was collected from a small hill near Kubi Kalo and lies in the strike continuation of the ultrabasic rocks described above, the latter being exposed across the Uaso Ngiro less than a mile and a half away. The specimen from Kubi Kalo is a dark greenish black, medium-grained granular rock. A close examination of fresh surfaces shows indistinct mottling with local concentrations of pinkish hypersthene and small glassy grains of green spinel. Weathered surfaces have a mottled reddish brown and dull green appearance.

In thin section hypersthene and subordinate pale green, non-pleochroic augite form an equigranular mosaic; the ratio of clinopyroxene to hypersthene is insufficient to class the rock as a websterite. Hornblende is pleochroic from pale bluish green to a pale shade of green that is occasionally indistinguishable from that of the pyroxene. The amphibole is



Plate I—Chanler's Falls, Uaso Ngiro river



Plate II (a)—Magado crater from the eastern rim



Plate II (b)—The Uaso Ngiro river near Kubi Kalo



Plate II (c)—Tumtu hill, a metamorphosed basic intrusive mass



Plate III (a)—Pegmatite cutting hornblende-biotite migmatites. The dark lower portion of migmatite is hornblende-rich, the paler upper parts biotite-rich



Plate III (b)—Quartzo-felspathic ptynogenic vein in hornblende-biotite migmatites exposed in the Manikadima anticline



Plate III (c)—Porphyroblastic meta-dolerite dyke, north-west of Tuntu

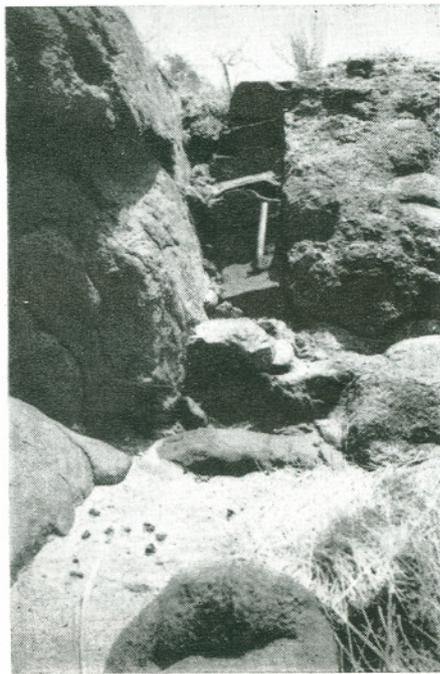


Plate III (d)—Metadolerite dyke cutting Basement System migmatites in the core of the Kurru anticline

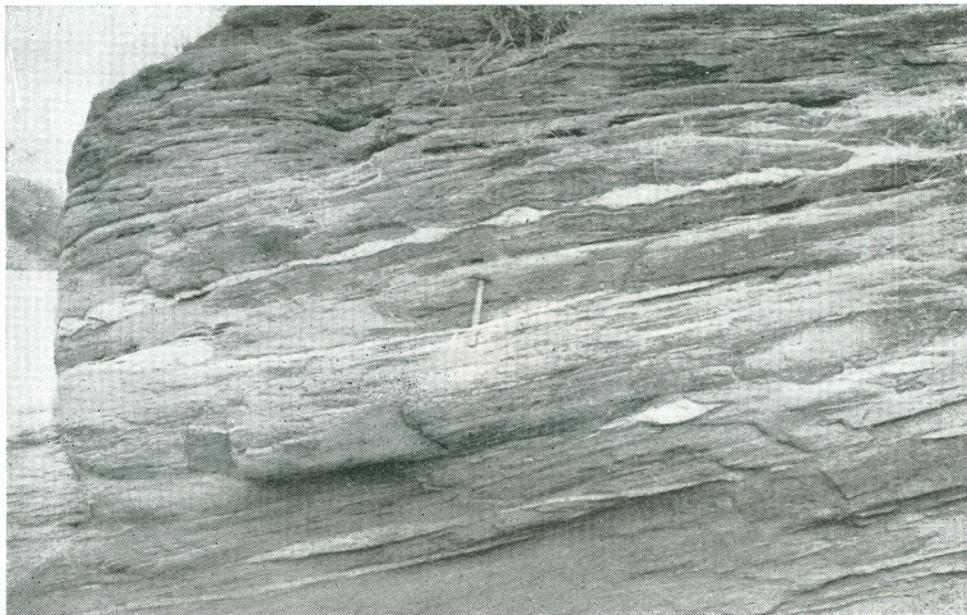


Plate IV (a)—Lenticular, conformable pegmatites in hornblende-biotite migmatites, Manikadima



Plate IV (b)—Pinkish pegmatites cutting migmatites north-west of Chopo

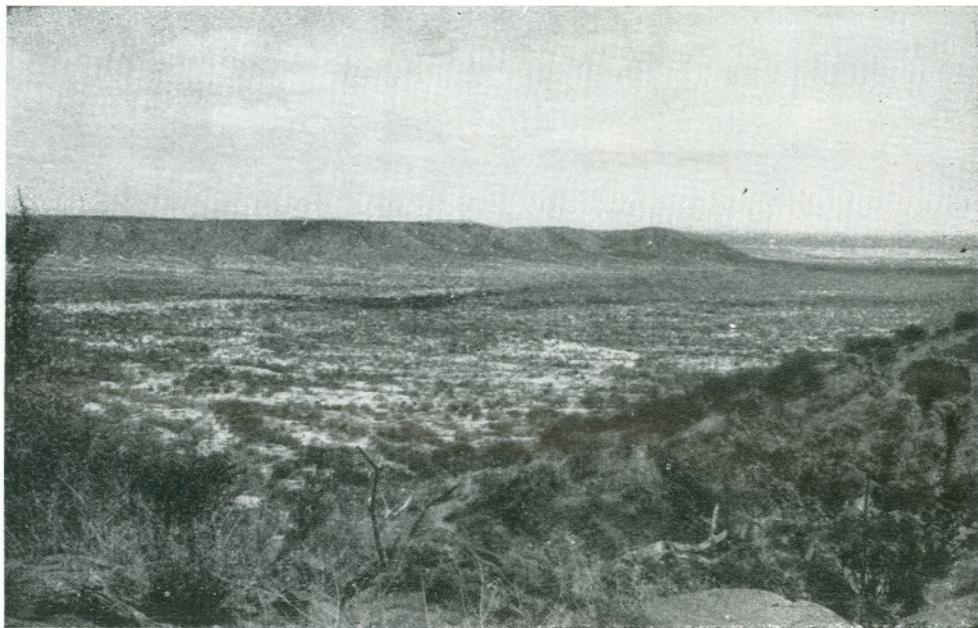


Plate V (a)—View eastwards across Gudamachesa valley, Merti



Plate V (b)—Monoclinial folds in hornblende-biotite migmatites, north-west of Chopo



Plate VI (a)—Cattle watering at the hot spring at Kurru Barrata, north of the Uaso Ngiro



Plate VI (b)—Crude trona workings on the crater floor at Magado



Plate VII (a)—Olivine basalt dykes cutting Basement System migmatites in the Uaso Ngiri at Manikamagado



Plate VII (b)—Columnar jointing in basalt near Chanler's Falls

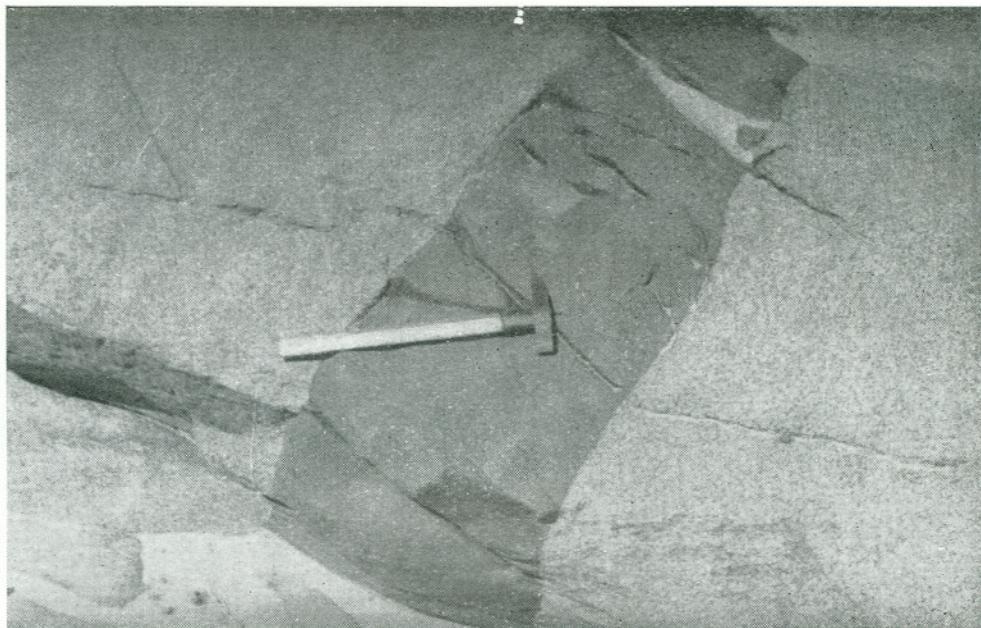


Plate VIII (a)—Metadolerite dyke in the Kurru anticline. Note the thin quartzo-felspathic vein cutting both the country-rock and the dyke



Plate VIII (b)—Metadolerite dyke cutting the Basement System migmatites at Manikamagado

probably in part secondary and forms a large proportion of the rock, though still subordinate in amount to the combined pyroxenes. Green spinel occurs in numerous irregular grains and is best developed in association with hornblende in which it occasionally forms fine dactylic intergrowths; large striated grains of spinel are common (*c.f.* Pulfrey, 1946, p. 73). Scattered grains of opaque ore include both magnetite and pyrite, and calcite forms occasional interstitial patches.

An altered hypersthene (or norite) was collected east of Matetendenava where it occurs as float blocks, together with fragments of plagioclase amphibolite. The friable rock (37/177) contains a large percentage of reddish brown earthy material bearing interlocking crystals of pale pyroxene; feldspar, if present originally, is now completely altered. Hypersthene is locally replaced by pale green chlorite, and by a semi-opaque reddish brown mineral.

(ii) *Hornblende-pyroxene picrites*

Small occurrences of coarse-grained ultrabasic rocks consisting dominantly of hornblende, ortho- and clino-pyroxene, and olivine were encountered in the core of the Kurru anticline. The rocks weather to perfectly rounded boulders several feet in diameter and are characterized in hand specimen by black glistening crystals of hornblende over three-quarters of an inch long.

Thin sections of specimen 37/29 show large anhedral crystals of strongly pleochroic primary hornblende (X=pale yellow-brown; Y=reddish brown; Z=dark reddish brown) containing numerous parallel rod-like inclusions of iron ore. The crystals poikilitically enclose ortho- and clino-pyroxene, olivine, ore and apatite. Neutral to very weakly pleochroic hypersthene and augite occur with olivine in groups of anhedral grains interstitial to the conspicuous hornblende crystals; the two pyroxenes are present in approximately equal proportions in the rock. Interstitial plagioclase, forming less than ten per cent of the rock, is mainly oligoclase, though local zoning to andesine was noted. Biotite, pleochroic from pale yellow-brown to deep red-brown, occurs in occasional interstitial flakes, and rare plates of calcite adopt a similar habit.

The rock is too coarse-grained to permit an accurate determination of the mode, but the following figures represent the average of measurements on several thin sections:—

Hornblende	..	..	..	50%
Hypersthene + augite	..	..	..	25%
Olivine	..	..	..	15%
Plagioclase	..	..	..	5%
Biotite	}	..	..	5%
Apatite				
Ore				
Calcite				

Some difficulty is experienced in providing a suitable name for the ultrabasic rocks at Kurru. Consisting mainly of hornblende, pyroxenes and olivine, they are olivine-bearing perknites, but this general term fails to stress the dominance of hornblende. The term melanocratic olivine-bojite might be considered, though strictly the sodic nature of the plagioclase precludes classification with bojites (*see* Pulfrey, 1946, p. 69). The rocks show affinities with cortlandtite (hornblende-hypersthene-peridotite), but the presence of subordinate plagioclase places them in the picrite field (*see* Hatch, Wells and Wells, 1961, p. 396), so that the Kurru rocks are probably best referred to as hornblende-pyroxene picrites.

(b) *Basic Rocks*

Intrusive rocks of gabbroic composition are far more widespread than the ultrabasic types described above. The majority of the relatively unmetamorphosed varieties contain prominent hypersthene and are often olivine-bearing. Classification depends largely on the ratio of orthopyroxene to clinopyroxene, with a further subdivision into olivine-free and olivine-bearing rocks (*see* Pulfrey, 1946, p. 69). In norites the orthopyroxene: clinopyroxene ratio is greater than 10:1, whereas in the gabbros (*sensu stricto*) it is less than 1:10. Ratios of 1:2 to 2:1 place the rocks in the hyperite class. Intermediate between hyperites and gabbros are the hyperthene gabbros. No augitic norites (*i.e.* types that fall between hyperites and norites) were identified during the present work. The term bojite is used to describe a gabbro with more than 50 per cent primary hornblende, but although amphibole-rich rocks are

abundant in the Chanler's Falls area, the term is used sparingly in view of the difficulty of differentiating with certainty primary and secondary hornblende. Metamorphosed intrusive rocks (metagabbros and a single metanorite) that retain an igneous appearance in hand specimen are included in the modified classification used in this report; the rocks are olivine-free and seldom contain hypersthene, although both minerals were possibly present in the types from which they were derived.

Difficulty was experienced in indicating on the geological map the range of gradational rock types constituting the intrusive suite. With very few exceptions, the variation that is seen even within individual exposures is too wide to permit mapping on the present scale, but it is felt that a distinction between basic and ultrabasic types is of value. Similarly, hypersthene-bearing basic rocks are differentiated from those in which ortho-pyroxene was not identified. This division is particularly useful in that it separates most of the relatively unmodified core rocks from marginal occurrences of metagabbro. It does not distinguish hypersthene-free gabbros (that are rare in the area) from metagabbros; nor does it separate metanorites (only one was identified) from unmetamorphosed hypersthene-bearing intrusives. Finally it must be stressed that the differentiation shown on the map is often based on the examination of a single rock specimen. As far as possible, specimens were collected to represent typical or dominant types seen within individual intrusive masses, but megascopic features such as colour and texture are frequently misleading, and there can be no guarantee that the rocks selected are in fact representative.

Although the basic intrusive rocks appear in widely scattered patches throughout the northern two-thirds of the area, they are best developed in a broad, north-north-easterly trending belt from Boji, through Tumtu and Muddo Gurba Huka hills to the northern boundary at Chabich. Evidence from air photographs suggests that the intrusives extend well beyond the northern limits of the Chanler's Falls area.

(i) *Olivine norites*

Three of the olivine-bearing gabbroic rocks collected have hypersthene greatly in excess of clinopyroxene, and fall within the norite class. They are all medium- to coarse-grained, greenish grey or brownish grey rocks. Specimens 37/87 and 37/90, from Kakalota and Obe respectively, contain feldspar having a violet-grey tint which increases the colour index of the rock, and both display pitted weathered surfaces; the pits have reddish brown cores with outer oil-green zones. Specimen 37/73, collected from an accumulation of boulders beside the Kurru watercourse near Bulfayo, is a more granular rock in which a little pyrite is visible in the hand specimen. At Kakalota and Obe the occurrences form small boulder-strewn hills that are made up of twin ridges separated by pegmatitic debris and sandy soils.

Thin sections show colourless olivines separated from labradorite by double reaction coronas, having an inner zone of fibrous or granular hypersthene and an outer rim of pale green amphibole, the latter bearing growths of spinel. In specimen 37/73 the amphibole has a bluish green or brownish tinge; brown, strongly pleochroic hornblende forms a granular fringe about hypersthene in specimens 37/87 and 37/90, in contrast to the pale amphibole in the coronas. Subordinate clinopyroxene accompanies hypersthene in two of the specimens examined. Pyrite and magnetite are the chief accessories, though chromite was seen in the thin section of specimen 37/87. A carbonate that occurs in thin veinlets in specimen 37/90 may be magnesite.

(ii) *Metanorites*

No unmetamorphosed, olivine-free norites were identified but a single specimen (37/59) of metanorite was collected from isolated rounded boulders found between the Archer's Post track and the Muddo Yaka watercourse. Fresh surfaces are black but on weathering the rocks assume a greyish brown colour, with mottling caused by crystals of dark pyroxene. Uralitization of hypersthene is accompanied by the separation of iron ore, and the ground-mass consists largely of hornblende, biotite and granular feldspar.

(iii) *Olivine hyperites*

Rocks in which hypersthene and augite are present in approximately equal amounts are not uncommon, and several occurrences were encountered south of the Uaso Ngiro. Olivine-bearing hyperites were collected from Muddo Yaka (in the central part of the area) and from small hills at Banya and Goitu (south-east of Tumtu). The rocks are coarse- to medium-grained and vary in colour from greenish grey to greenish black, the paler varieties

occasionally showing tinges of violet-grey across felspathic patches. Weathered surfaces are typically mottled in shades of brown, and display a rough pitted appearance as a result of the preferential alteration of olivines. The pits have earthy red-brown cores and fine green rims. The absence of prominent pitting is not necessarily indicative of a lack of olivine in the rock, for a specimen (37/92) of olivine hyperite from Goitu has a fairly even weathered surface.

Thin sections show the development of double coronas around olivine, an inner zone being either hypersthene or pale green, purplish brown or neutral clinopyroxene; when both pyroxenes are present in the coronal rim, hypersthene tends to develop immediately adjacent to the olivine. Outer zones of the coronas consist of pale green or pale brown amphibole invariably bearing fine growths of vivid green spinel. In specimen 37/92 the olivine is sometimes surrounded by pleochroic yellow-brown bowlingite. Strongly pleochroic brown hornblende is present in specimen 37/80, from the Banya hills, in contrast with pale green amphibole that is confined to the coronas. The plagioclase in the olivine hyperites is labradorite, and in an anorthositic specimen (37/83) from west Banya, forms nearly 80 per cent of the rock. Accessory magnetite occurs in small irregular grains in all the specimens examined and is usually accompanied by a little pyrite. Apatite is present as rare inclusions in pyroxene in the rock (37/64) from Muddo Yaka.

(iv) *Hyperites*

Only a single hyperitic specimen (37/65) was found to be olivine-free. It was collected from accumulations of boulders on a low hill north of the wells at Muddo Yaka, and is a medium-grained, greenish grey, rather granular rock. A thin section shows hypersthene and subordinate pale green diopsidic pyroxene, together with labradorite and an amphibole that is in part clearly secondary. Abundant green spinel occurs largely as vermicular intergrowths in the amphibole.

(v) *Hypersthenic olivine gabbros*

Five of the specimens examined, all collected in the north-western quarter of the area, are hypersthenic olivine gabbros. The rocks evidently form a large part of the Tumtu intrusion, with representatives at Goitu (near Chanler's Falls) and along the northern boundary of the area, east of Chabich.

In hand specimen the rocks are typically coarse- to medium-grained and dark greenish grey. They weather to shades of brown and greyish brown and often display a rough pitted appearance on exposed surfaces, similar to that described in the olivine hyperites. In thin sections the mineral composition and textures are also similar to those of the hyperitic rocks, from which they are separated only by a decrease in the ortho-pyroxene: clinopyroxene ratio. Specimen 37/136, collected near the trigonometrical beacon on Tumtu hill, is typical of the class. Olivine is surrounded by double reaction coronas, with colourless or neutral monoclinic pyroxene forming the inner zone and spineliferous pale green amphibole of the outer rim showing clear-cut margins against plagioclase. Augite exhibits a prominent cleavage parallel to (100) and is often pale brown and non-pleochroic; the subordinate hypersthene, on the other hand, is weakly pleochroic from pale pink to neutral. Strongly pleochroic brown hornblende is frequently seen fringing pyroxene, magnetite and spinel. Fresh labradorite displays both albite and pericline twinning, and oligoclase occurs as rare rounded blebs in clinopyroxene. The opaque ore is probably all magnetite. In specimen 37/130, from a watercourse north-east of Tumtu, granular hypersthene has formed at the expense of olivine and the aggregates are rimmed by spineliferous coronas. In most of the hypersthenic rocks examined orthopyroxene is enclosed by clinopyroxene, but in specimen 37/121, collected near the river west of Tumtu, hypersthene often fringes augite. Bytownite was identified in two specimens of hypersthenic olivine gabbro, 37/130 and 37/171, the latter being from boulders littering the ground east of Chabich on the northern boundary of the area; in all other members of the basic and ultrabasic suite labradorite was found to be the typical felspar.

(vi) *Gabbros*

Hypersthene-free gabbros are rare, and none of those collected contained olivine. A specimen (37/126) of hornblende gabbro from the boundary of the area north-west of Tumtu, is a medium-grained rock finely mottled in greenish grey and white. A thin section shows labradorite in association with granular aggregates of pale green monoclinic pyroxene and

hornblende, pleochroic from olive-green to brownish green or yellow-brown. The amphibole makes up about a third of the mafic constituents and much is seemingly of late magmatic origin. Magnetite occurs in irregular grains largely enclosed by the hornblende and is accompanied by subordinate pyrite.

An olivine-free uraltite gabbro (37/97) was collected from a small hill surrounded by lavas, east of Boji. Layering of the intrusive rocks is well displayed at this locality and is conspicuous even on weathered surfaces. Alternating mafic and leucocratic layers range from a quarter of an inch to an inch or two in width. The dominant minerals in the dark units are clinopyroxene, uraltite and labradorite; pyrite, magnetite, sphene and scapolite are the chief accessories. Rocks forming the leucocratic layers are described later as anorthosites.

(vii) *Metagabbros*

Specimens of metamorphosed gabbroic rocks were collected from widely scattered localities in the north-central and north-western parts of the area. They are often difficult to distinguish in the field from relatively unmetamorphosed intrusives, and like the latter occurrences are frequently marked by accumulations of rounded boulders forming hill features. The metagabbros represent an intermediate stage between unmodified rocks of igneous appearance, and amphibolitic granulites and gneisses of obvious metamorphic aspect.

The metagabbros are tough, greenish black, medium- or coarse-grained rocks with a rather granular texture. They have a mottled appearance that is best seen on weathered surfaces, where the pale brown colour of the altered felspar contrasts strongly with black clots and individual crystals of hornblende and pyroxene.

In thin sections the rocks are seen to have a rather simple mineral composition, the essential components being hornblende, monoclinic pyroxene and calcic plagioclase. Pale green or neutral augite or diopsidic augite frequently forms an irregular core to hornblende and all stages of uraltization are visible in the thin sections examined. No hypersthene was identified in the metagabbros, and olivine is also absent, but both these minerals were probably present in the original intrusive rocks, subsequently being converted to clinopyroxene and hornblende during metamorphism. The hornblende is pleochroic from yellow-brown to bright green or bluish green (specimen 37/47 from an occurrence north-east of Kubi Kalo) or from grass-green to bluish green (specimens 37/108 and 37/109 both from small occurrences of metagabbro near the Archer's Post track south-south-west of Chanler's Falls). The metagabbro from Muddo Gurba Huka (37/137) is characterised by the presence of pale green, feebly pleochroic tremolite together with long prismatic crystals and rhombic sections of very pale green or colourless anthophyllite. The plagioclase is typically labradorite-bytownite (An_{70}) and is occasionally sieved with minute inclusions of hornblende, as in specimen 37/174 from an outcrop north-west of the hot spring at Kurru, north of the Uaso Ngiro. In specimen 37/164, collected from the flat ground between the Madubakoni wells and the northern boundary of the area, the felspar is largely recrystallized, and is probably oligoclase. Anhedral grains of scapolite, abundant granules of sphene and a little interstitial calcite were seen in the same rock. Sphene is also present in specimen 37/108 in which it is accompanied by epidote and opaque ores, chiefly pyrite.

(viii) *Bojites*

Rocks containing primary hornblende as the dominant mafic constituent are probably less common in the present area than among the intrusives of the Meru and Embu districts (Pulfrey, 1946, pp. 78-81; Schoeman, 1951, pp. 31-32; Bear, 1952, p. 23). On the other hand, in many of the richly hornblendic gabbros it is difficult to assess accurately the proportion of primary amphibole, and it is possible that a number of the types described above should more correctly be termed bojites.

A specimen (37/165) from the roadside south of Matetendenava contains sufficient primary hornblende to warrant classification as a noritic olivine bojite. It is a coarse-grained rock displaying a reddish brown, green and white mottled appearance. Weathered surfaces are not distinctly pitted but show irregular patches with a reddish brown core and a thin oil-green rim; white or pale brown felspar is interstitial and encloses a little pyrite. In thin section, large anhedral grains of olivine display complex reaction coronas in which both brown and green hornblendes are prominent. Non-pleochroic hypersthene forms the inner zones of coronas with brown non-spineliferous hornblende separating the orthopyroxene from an

outer rim of green spinel-bearing hornblende. No clinopyroxene was identified. Labradorite exhibits local alteration to minute slender prisms and grains of zoisite and flecks of sericite. The opaque ore is mainly pyrite, but is not abundant; calcite occurs in small irregular patches enclosed by pyroxene.

(c) *Anorthosites*

No mappable units of anorthosite were found during the survey, but the felspathic rocks are prominent members in layered gabbroic complexes and are particularly well displayed in banded exposures at the western end of Tumtu hill. Small inclusions of greenish black ferromagnesian minerals are often found in the leucocratic layers, which are composed predominantly of calcic plagioclase having a distinctive pale violet-grey tinge.

In exposures on a small hill east of Boji thin anorthositic layers alternate rapidly with darker uraltite gabbros. A thin section of the rock (37/97) shows the anorthosite to be composed of labradorite, containing small rounded grains of sphene and rare crystals of epidote.

(2) ORTHO-AMPHIBOLITES AND ORTHO-GNEISSES

With few exceptions the basic and ultrabasic rocks described in the preceding pages are surrounded by belts of amphibolites and hornblendic gneisses that clearly represent the metamorphosed equivalents of the igneous rocks. These ortho-amphibolites and ortho-gneisses are locally indistinguishable in the field from some metasediments of the Basement System, so that the discordant nature of the intrusive suite is often somewhat blurred by the effects of metamorphism. Common *lit-par-lit* intrusion of the basic and ultrabasic rocks into already foliated Basement System gneisses has given rise to further confusion, ortho-amphibolites now appearing inter-banded on all scales in a succession of the older metasediments. The intrusive relationships are often necessarily simplified on the geological map to allow representation on the present scale of work. In detail, thin ribs and screens of Basement System gneisses are found within the outcrops of ortho-amphibolites and, conversely, amphibolitic veins and lenses penetrate areas mapped as unrelieved metasediments. In the north-western quarter of the area however, mappable screens of Basement System rocks were encountered within the broad amphibolitic belt that extends generally north-north-westerly from Tumtu hill, thus convincingly demonstrating the intrusive origin of the hornblendic rocks.

The ortho-amphibolites are best developed between Tumtu and Chabich and extend well beyond the northern boundary of the area. This belt encloses the main igneous masses at Tumtu and Muddo Gurba Huka, and probably continues southwards to Boji, although at the latter locality the amphibolites are obscured by a cover of Pleistocene lavas and Quaternary superficial deposits. Irregular patches of similar hornblendic rocks are also to be found further to the east, both north and south of the Uaso Ngiro river. At widely scattered localities within these outcrops there occur relatively unmodified igneous bodies, though the occurrences are smaller than those forming the hill masses to the west. Exposures of the amphibolites are frequently poor, and the rocks are often mantled by a thick cover of chocolate-brown soils. The more prominent soil accumulations are shown on the map, and the occurrences are briefly described in a later section of the report.

Throughout the exposures examined the amphibolites were found to be extensively intruded by networks of pegmatites (often having a coarse graphic texture), aplites, white quartz veins and granulitic rocks of granitic composition. No separation of the various elements is possible on the present scale of mapping, but it is important to stress the existence of these leucocratic members since locally they become dominant, as across the Kurru anticline, in the east-central part of the area.

Any apparent conformity with Basement System structures related to an early period of north-south or north-westerly trending folds is probably largely explained by *lit-par-lit* intrusion of the igneous rocks from which the amphibolites were derived, but north-north-easterly trending structures affecting both the Basement System rocks and the amphibolites (for example the Tumtu syncline) are believed to represent a post-intrusive, second phase of folding.

For descriptive purposes the ortho-amphibolites and ortho-gneisses are classified as follows:—

- (a) Amphibolites.
- (b) Plagioclase amphibolites.
- (c) Hornblende-pyroxene-scapolite gneisses.
- (d) Hornblende-biotite-pyroxene granulites.

(a) *Amphibolites*

Both pyroxene-bearing and pyroxene-free amphibolites are thought to have been derived from the plutonic rocks, the lack of pyroxene probably indicating a more advanced stage of metamorphism.

A typical specimen (37/42) from Chabich, in the east-central part of the area, is a finely foliated greenish black amphibolite. In thin section it shows abundant green hornblende forming a coarse heteroblastic mosaic with a little pyroxene, calcic labradorite and magnetite. The hornblende is pleochroic from yellow-brown to deep green, or from grass-green to brownish green and has $c \wedge Z = 27^\circ$. The pale green monoclinic pyroxene, with $c \wedge Z = 48^\circ$, frequently occurs as inclusions in the hornblende, but is also commonly developed in aggregates of xenoblastic grains between the amphibole crystals.

A banded pyroxene-free amphibolite (37/142) from the Uaso Ngiro east of Tumtu, contains hornblende crystals up to a quarter of an inch long in the mafic bands; a little pyrite is visible in the hand specimen. A fragmentary section of the mafic portion of the rock consists dominantly of green hornblende, together with largely untwinned plagioclase and accessory clinozoisite and apatite.

(b) *Plagioclase amphibolites*

Of more common occurrence than the mafic rocks described above, the plagioclase amphibolites are medium-grained, moderately foliated, dappled rocks. On weathered surfaces the amphibole often appears green and the feldspar assumes a translucent violet-grey tint.

In specimen 37/74 from the Uaso Ngiro river immediately south of Tumtu hill, the hornblende shows a fine granular habit in thin section and is apparently replacing pale green pyroxene. The latter is present as cores in the amphibole and has $c \wedge Z = 50^\circ$. Sodic labradorite is widely sericitized and sphene was seen as inclusions in the hornblende. In plagioclase amphibolites (37/140) exposed to the east-north-east of Tumtu, an amphibole tentatively identified as cummingtonite occurs in ragged crystals and granular aggregates. It exhibits pleochroism from very pale green to colourless, the margins of the crystals showing stronger pleochroism in pale shades of brown. The positive optic axial angle was estimated to be about 75° and $c \wedge Z = 16^\circ$. A little colourless pyroxene is probably present, and bright green spinel occurs in fine blebs and dactylic growths at the margins of the amphibole, particularly against labradorite.

A pyroxene-free plagioclase amphibolite (37/178) from a locality west of Restimado in the north-central part of the area, contains yellow-green to olive-green hornblende and labradorite, together with rather abundant interstitial xenomorphic grains of scapolite. Sphene occurs in small grains often enclosed by the hornblende or developed marginally to it, and oligoclase locally replaces labradorite.

(c) *Hornblende-pyroxene-scapolite gneisses*

The metamorphosed intrusive rocks frequently assume a more marked foliation than that seen in the plagioclase amphibolites, and feldspar often exceeds hornblende in amount. Typical ortho-gneisses (37/47) exposed near Kubi Kalo hill close to the Uaso Ngiro, are coarsely dappled in greenish black and white. Hornblende ($c \wedge Z = 27^\circ$) is pleochroic from yellow-brown to bright green or bluish green; it is probably partly recrystallized, but some is evidently developed after pale green augite ($c \wedge Z = 55^\circ$). Clear, completely recrystallized plagioclase (sodic labradorite) is accompanied by scapolite, and sericite is developed largely at plagioclase grain boundaries.

(d) *Hornblende-biotite-pyroxene granulites*

These rocks were only rarely encountered and are doubtfully included with the ortho-amphibolites and ortho-gneisses since biotite was not commonly found as an essential constituent of the metamorphosed intrusives.

Dark granular rocks (37/72) containing hornblende, biotite and plagioclase together with ragged crystals of pale green clinopyroxene (having $c \wedge Z = 46^\circ$) were seen in the core of the Kurru anticline, north of the stream that cuts across the structure. The appearance of biotite is perhaps related to the presence of that mineral as prominent flakes in the coarse ultrabasic hornblende-pyroxene picrites mapped within the anticline south of the Kurru stream.

(3) PEGMATITES, QUARTZ VEINS AND LEUCOCRATIC ORTHO-GRANULITES

Quartz veins and various leucocratic rocks of granitic composition (some showing the effects of regional metamorphism) are commonly found as minor intrusions associated with the basic and ultrabasic plutonic rocks and their metamorphosed equivalents. No attempt has been made on the present scale of mapping to separate individual occurrences of the pegmatites, aplites, and leucocratic ortho-granulites and ortho-gneisses from other members of the intrusive suite, though localities of some of the major quartz veins are indicated on the geological map.

Selections of the leucocratic rocks are most frequently encountered across outcrops of ortho-amphibolites. Locally pegmatites and ortho-granulites may even predominate, though in areas of poor exposure the proportion of amphibolitic rock is not easily assessed due to its greater susceptibility to weathering; in better exposed country, where the true proportions are seen, the host amphibolites are always the dominant rock types.

(a) *Pegmatites, aplites and quartz veins*

Pegmatites emplaced in hypersthene-bearing basic intrusives and ortho-amphibolites in the western parts of the area are pale off-white rocks composed of quartz, feldspar and iron ore. Garnet and muscovite are often present, the latter occurring in workable quantities at Boji, where beryl, columbite-tantalite, bismuth and tourmaline have also been recovered. Biotite is generally a rare constituent, but coarse pegmatites cutting ortho-amphibolites in a watercourse near the track north of Tumtu hill form a core to intrusive quartzo-felspathic granulites containing biotite. Coarse pink graphic pegmatites are best developed in the core of the Kurru anticline where they cut hornblende-pyroxene picrites and associated ortho-amphibolites. The pegmatites at this locality contain fragments of magnetite up to two inches in diameter. Numerous fine-grained aplitic rocks are clearly related to the pegmatites described above. Barren quartz veins are also widely distributed, but no major bodies were seen emplaced in Basement System rocks. Occurrences of major quartz veins are indicated by an appropriate symbol on the geological map.

(b) *Leucocratic ortho-granulites and ortho-gneisses*

Some exposures of basic intrusive rocks and associated ortho-amphibolites are cut by parallel ribs of leucocratic medium-grained granulites, often containing biotite and garnets and displaying weak foliation. Many superficially resemble Basement System granulites of sedimentary origin, but a detailed examination of riverside exposures west of Tumtu hill confirmed the intrusive form and post-gabbro age of the granulites. The country rocks at this locality are part of a layered gabbroic complex in which hypersthene olivine gabbros alternate rapidly with thin anorthosites. The granulites convincingly cut this igneous layering, and therefore cannot represent screens of Basement System rocks incorporated in the basic intrusion. The rocks are regarded as metamorphosed aplites, genetically related to the pegmatites described above.

Other occurrences of ortho-granulites and rarer quartzo-felspathic ortho-gneisses were encountered west and north-west of Tumtu. They vary in outcrop width from a few feet to several yards and all the exposures trend N.N.E.—S.S.W. A specimen (37/157) of granulite from a locality immediately west of Tumtu, contains microcline, quartz and subordinate oligoclase. A few small flakes of biotite are accompanied by a little chlorite, occasional irregular grains of magnetite, small prismatic crystals of zircon and a few grains of apatite. Specimen 37/158 from the same locality, has a similar composition but also includes rare shreds of muscovite. Granulites (37/131) cutting ortho-amphibolites in a watercourse north of Tumtu hill, contain small reddish brown garnets the size of a pin-head set in a granoblastic mosaic of microcline, quartz, oligoclase, muscovite, magnetite and zircon. Very similar garnetiferous ortho-granulites were described by Shackleton (1946, p. 18) from the country between Nanyuki and Maralal.

Rocks that differ slightly in appearance but which have essentially the same composition as those described above, are commonly developed in association with graphic pegmatites and quartz veins in the core of the Kurru anticline, and also farther east between Chabich and the Kroftu watercourse. Specimen 37/41 collected from Chabich, is a well foliated pink quartzo-felspathic gneiss containing a sprinkling of iron ore. Quartz is drawn out in lenses and thin stringers, and microcline forms occasional prominent porphyroblasts up to a quarter of an inch long. A thin section shows only microcline, quartz and magnetite.

3. Dykes

A number of minor basic intrusions were encountered in the eastern and central parts of the area, and a single occurrence was mapped near the western boundary. On petrological grounds these dykes are clearly divisible into two classes:—

- (1) Metadolerites.
- (2) Olivine basalts.

The older minor intrusives cut Basement System rocks but themselves display the effects of regional metamorphism and are petrologically related to the hypersthene-bearing Precambrian basic and ultrabasic plutonic rocks. The metadolerites are therefore probably of Precambrian age. In contrast, the olivine basalt dykes intrude Basement System rocks and probably also cut metamorphosed Precambrian major intrusives. In composition they are closely related to the Pleistocene volcanics which locally overlie them; the younger dykes are therefore probably of late Tertiary or early Pleistocene age.

The representation on the geological map of both sets of dykes is somewhat diagrammatic, the width being greatly exaggerated and small swarms often being indicated as a single occurrence.

(1) METADOLERITES

These intrusives are rare and were found only at three localities in the core of the Kurru anticline; at Manikamagado, where several small dykes are exposed about three-quarters of a mile north of the Uaso Ngiro; and north-west of Tumtu. At the latter locality the field relationships are not clear, but the occurrence has the appearance of being an off-shoot from metamorphosed basic intrusions of the Tumtu belt.

Dykes of dark granular rock cut coarse mottled Basement System hornblende-biotite migmatites in the Kurru stream, where it flows eastwards across the core of the major anticline. The near vertical dykes are up to 18 in. wide and are particularly well preserved at the eastern side of the fold where they show sharp contacts with the country rock (Plate III, (c) and (d)). Thin quartzo-felspathic stringers (one is visible in the second photograph) frequently cut cleanly across the intrusions and into the country rock, with sharp changes in direction during the passage across the dykes. The dykes at this locality trend mainly N.E.-S.W., but smaller irregular off-shoots also vein the country rock. At Manikamagado several occurrences of older dyke rocks were encountered, and in appearance contrast strongly with near by later dykes of fresh olivine basalt. The relationships to the enclosing Basement System hornblende-biotite migmatites are not always clear, but at the western of the two occurrences marked on the map the cross-cutting attitude of the dyke is admirably demonstrated (Plate VIII (b)). Near by, trains of boulders indicate a multiple intrusion with a core of metadolerite flanked on both sides by fresh basaltic dykes. At the eastern locality in the Manikamagado district, the dyke apparently cuts across the strike of the host migmatite, but contacts are not exposed and the trend of the dyke is inferred from the orientation of a train of boulders. The dyke trend at Manikamagado is N.E.-S.W., the metadolerites displaying steep dips to the north-west. Close to the western boundary of the area near Tumtu, coarsely porphyroblastic dark granulites are exposed in a watercourse (Plate III (e)). During fieldwork these rocks were regarded as hybrids flanking Basement System microcline porphyroblast gneisses. Subsequent examination suggests however that the rocks represent a metamorphosed intrusion of original doleritic composition, probably genetically related to the nearby basic intrusives of Tumtu.

The metadolerites are black, dark greenish grey or brownish grey, medium-grained granulites. Three of the four specimens collected are porphyroblastic and contain pale grey crystals of feldspar which generally reach up to half an inch in length, though the photograph of the Tumtu occurrence shows unusually large porphyroblasts, more than an inch in length. The grey colour of the feldspars results in a higher colour-index than would be expected from the mineral composition of the rocks. Fine flecks of bronzy biotite impart a glistening appearance to fresh surfaces.

In thin section most of the metadolerites display porphyroblasts of plagioclase in a medium-grained, granular matrix. Hornblende and biotite are abundantly developed in all the specimens, the amphibole generally predominating. Both ortho- and clinopyroxenes have been identified in some rocks, and the accessory minerals comprise magnetite, pyrite, apatite, sphene and quartz.

Various stages in the progressive metamorphism of the older dykes are represented by four specimens collected. In specimen 37/179 from Manikamagado, crystals of schillerized, pleochroic hypersthene and grains of pale green diopsidic augite show replacement by green hornblende and by biotite. The zoned porphyroblasts are of andesine-labradorite. In specimen 37/37 from a dyke at Kurru, the pyroxene is entirely very pale green or neutral augite ($c \wedge Z = 54^\circ$) which occurs in granular aggregates surrounded and partly replaced by hornblende and biotite. Oligoclase is present in interstitial plates. Only a monoclinic variety of pyroxene was identified in specimen 37/155 from the Tumtu district, and the rock contains prominent oligoclase porphyroblasts in addition to interstitial oligoclase in the groundmass. Flakes of brown biotite are seen projecting into the porphyroblasts and occasionally are enclosed by the feldspar, which also bears intergrowths of quartz. Quartz also appears in the groundmass as xenomorphic interstitial grains. No pyroxene was identified in specimen 37/188 from Manikamagado, in which porphyroblasts of sodic labradorite have a turbid, finely spotted appearance and bear inclusions of biotite and hornblende. The feldspar is zoned and shows irregular borders against the groundmass, here composed of a granular mosaic of hornblende, biotite and oligoclase with accessory magnetite, apatite and sphene.

The metadolerites described above are mineralogically similar to the metamorphosed basic plutonic rocks in the Chanler's Falls area. The dykes cut the foliation of Basement System metasediments and were clearly emplaced after the Basement System metamorphism; this tends to confirm the post-Basement System age of the basic and ultrabasic intrusives.

Minor intrusives in the Embu-Meru area (Schoeman, 1951, pp. 45-46) were described as diorite-porphyrite and metadiorite-porphyrites, and from the descriptions have a number of features in common with the metadolerites of the present area, though no pyroxene was reported. Schoeman regarded the diorite-porphyrites as Archaean intrusives. Shackleton (1946, p.19) reported metadolerite sheets and dykes in Basement System rocks of the Nanyuki-Maralal area.

(2) OLIVINE BASALTS

Thin dykes of olivine basalt are confined to the north-eastern quarter of the area, and intrusion is clearly related to the local fault pattern. The dykes are best developed in a belt from Garrbich across the Uaso Ngiro to Dabasidi, and within this zone the dykes trend N.E.-S.W. A similar direction is retained by minor basaltic intrusions near Kubi Kalo, and between the Kurru anticline and Uasisalo. In contrast, small dykes encountered at Jajuss, near the base of the Merti plateau, and at Kulchar, south of Uasisalo, display a north-westerly trend.

The best exposures were seen in the river section at Manikamagado where basalt dykes, up to seven feet wide, occur in small swarms cutting the Basement System hornblende-biotite migmatites (Plate VII (a)). In areas of poorer exposure the dykes were mapped from persistent trains of basaltic fragments that can often be followed for several hundred yards, although the accumulation of rubble is seldom more than a few feet wide. South-east of the volcanic cones at Dabasidi a thin sill of basalt is conformable with the Basement System gneisses and undoubtedly represents an off-shoot from a dyke emplaced along a prominent north-easterly trending fault.

The younger dyke rocks are typically fine- to medium-grained, dark grey or bluish grey basalts weathering to shades of brown, and showing conchoidal fracture. With alteration the rocks become greenish grey due to the chloritization of the ferromagnesian components (e.g. specimen 37/52 from a dyke at Kulchar, in the east-central part of the area). Occasionally

the basalts are megascopically porphyritic as in the case of specimen 37/48 collected between Kurru and Uasisalo, in which fine plagioclase laths reach lengths of 2–3mm.; glassy olivines are prominent, locally attaining a diameter of 12 mm. The phenocrysts are set in a fine-grained dark blue-grey groundmass. The rocks often have a spotted appearance on fresh surfaces caused by abundant small calcite amygdalae (e.g. specimen 37/229 from the sill-like intrusion near Dabasidi). A little pyrite is visible in specimen 37/209 taken from a thin dyke near Jajuss at the western end of the Merti plateau.

In thin sections the rocks are characteristically holocrystalline and microporphyritic, with phenocrysts of olivine and, more rarely, of pyroxene and plagioclase. *Olivine*, with a high iron content indicated by the optically negative character, with $2V=75^\circ$ to 80° , is a prominent constituent of nearly all the unaltered specimens examined; in a non-porphyritic basalt (specimen 37/209 from Jajuss) however, it occurs as rather rare rounded grains. The mineral was not identified in chloritized rocks (specimens 37/52 and 37/183, from Kulchar and Garrich respectively) where it has probably undergone complete alteration. The olivine occurs in colourless to neutral subhedral, euhedral or rounded crystals; cracks and crystal outlines are often emphasized by a fine dusting of opaque ore. The large olivines seen in specimen 37/48 are found, in thin section, to be composed of aggregates of rounded grains.

The *pyroxene* is typically subhedral to anhedral brownish or purple-brown titanite. It is largely confined to the groundmass but occasionally forms small phenocrysts. The optic axial angle is commonly about 60° , but some pyroxene crystals in specimen 37/229 from Dabasidi are marked by an optic angle of about 30° , indicating an increase of the pigeonite molecule. Extinction $c \wedge Z$ varies from 41° to 48° in the slides examined, the lower values perhaps also indicating a pigeonitic composition. In specimen 37/180 from Manikamagado, clinopyroxene forms a granular corona about colourless olivine.

Plagioclase ranges in composition from andesine to labradorite, the latter being more common. Generally it is confined to the groundmass where it occurs as small laths showing both albite and Carlsbad twinning, but prominent euhedral phenocrysts of labradorite are visible in specimen 37/48.

Opaque ores are present as small irregular grains in all the rocks. The ore is most commonly magnetite but specimens 37/209 and 37/229 also contain subordinate pyrite. *Calcite* is widespread, largely in rounded amygdalae, where in one specimen (37/229) it is accompanied by a little *quartz*. *Chlorite*, pleochroic from yellowish to pale green, is a prominent mineral in the altered dyke rocks, and reddish brown oxidized material is abundant near a weathered surface cut by the thin section of specimen 37/48.

Several narrow dykes of olivine basalt, thought to be of Tertiary or Pleistocene age, were mapped by Dodson (1955, pp. 18–19) in the North Kitui area.

4. Merti Beds—(?) Late Tertiary

Coarse river gravels that overlie Basement System rocks in the upper parts of the scarps bounding the Merti plateau were named the Merti Beds (Roberts, 1941; Dixey, 1948, p. 9). The rocks are friable, coarse pebbly sandstones and conglomerates, containing well-rounded pebbles ranging up to 4 in. in diameter and consisting dominantly of quartz with subordinate feldspar, a few reddish garnets and occasional fragments of hornblende. The sediments are poorly sorted, and the cement is highly calcareous. An extensive search failed to reveal any fossil remains, but the absence of forms such as molluscs is not altogether surprising in view of the coarse grade of the deposits. The degree of rounding of the pebbles indicates an origin far removed from the present situation of the sediments.

The preservation of the Merti Beds along the length of the plateau is due to a capping of olivine basalt that is some 30 ft. to 35 ft. thick in the scarp, but probably attains twice that thickness towards the centre of the plateau. Exposures, particularly in the upper parts of the scarp, are generally rather poor, so that the base of the Merti Beds is not well defined, and occurrences of rounded pebbles are sometimes found below *in situ* exposures of Basement System rocks. Often the position of the junction can be estimated by noting the first appearance of sub-angular leucocratic rock fragments on descending the slopes. Accurate estimates of the top of the Merti Beds can be made even where exposure is poor since a change in gradient usually marks the position of the overlying basalt.

No Basement System rocks are exposed in the scarp at the western end of the Merti plateau, where 270 ft. of friable calcareous sediments are capped by 30 ft. of basalt. Rounded pebbles, mainly of quartz, are abundant and tend to become washed out from the pale marly matrix. The deeply gullied approach to the lower slopes of the scarp lies across calcareous deposits similar to those exposed in the scarp itself, though less well consolidated. Pebbly sediments containing pockets of white powdery kaolin infill the broad valley west of the plateau; they are exposed down to 1,580 ft. O.D. without the base being seen, i.e. 360 ft. below the level of the lava base (1,940 ft. O.D.) on the plateau.

Because of the difficulty in visualizing downcutting of Precambrian rocks to a point actually below the local level of the end-Tertiary peneplain and subsequent infilling by fluvial deposits up to altitudes corresponding to the sub-Miocene bevel, it seems more reasonable to regard the loosely consolidated material in and near the lower parts of the western Merti scarp as redeposited sediment derived from the Merti Beds. In fact it is likely that only about 80 ft. of the sediment immediately underlying the lava cap represents original Merti Beds. The loosely consolidated material lower down the slope and in the valley is regarded as a reworked deposit of Pleistocene to Recent age. It is of interest to note that Roberts (1941), during a visit to the plateau at a point east of the present area, attributed loosely consolidated sediments at the foot of the scarp to *in situ* weathering of the Merti Beds.

It seems, then, that the surface on which the Merti Beds were deposited may not have been as deeply dissected as previously postulated. The Basement System surface is certainly remarkably level from a point a mile and a half from the western scarp to the eastern boundary of the present area. Along this stretch of the plateau, a distance of some five and a half miles, the Basement surface falls only 50 ft., though at one point a "hill" of granulate is capped directly by lava.

In the absence of fossils, the age of the Merti Beds can be deduced only by reference to erosion surfaces. It has already been shown (p. 6) that the sub-Miocene bevel lies at about 1,920 ft. O.D. at the western end of the plateau, and that the end-Tertiary peneplain is represented by the watershed standing at some 1,800 ft. O.D. west of Merti. Accepting an average figure of 1,850 ft. for the base of the Merti Beds in the southern scarps, it is evident that the coarse river gravels were deposited during dissection of the sub-Miocene peneplain, i.e. during the late Tertiary.

5. Lower Pleistocene Limestones and Clays

Only locally in the Chanler's Falls area are sediments known to underlie Pleistocene volcanic rocks. At Boji*, beside the Isiolo-Wajir road, limestones with occasional pebble beds are exposed in a well 15 ft. deep south of the road. On the opposite side of the road off-white, unfossiliferous, porcellaneous limestones containing occasional rounded calcareous concretions are exposed to a depth of 6 ft. in pits. A single rounded basalt pebble was found at this locality and shows every indication of having been weathered out from the sediment. Half-a-mile south of the road olivine basalt forms a low scarp and probably overlies the limestone.

Seven and a half miles east of the above exposures a producing bore-hole (S.A. 10) was sited beyond the limits of the lava and on a plain of reddish brown sandy soil. The driller recorded the following succession:

Feet

- 0 to 3 Soil.
- 3 to 28 Decomposed limestone.
- 28 to 65 Limestone.
- 65 to 77 Hard limestone.
- 77 to 144 Gneiss.

Water was struck at 45 ft. from the surface and the water rest level is quoted as 41 ft. The plain at the bore-hole site is about 1,840 ft. O.D.

*This locality should not be confused with the hill of the same name near the western boundary of the area. The Boran use the term *boji* to describe "white limestone", and Boji hill received its name from the calcareous sediments flanking it to the west in the Archer's Post area.

Two other bore-holes, both now abandoned and plotted only approximately on the geological map, were drilled between S.A. 10 and Garba Tula, close to the track that joins the main road near the existing bore-hole. The following logs were recorded:

S.A. 18

Feet

- 0 to 3 Soil.
- 3 to 62 Limestone.
- 62 to 64 Gneiss.
- Water struck: 41 ft.
- Water rest level: 39 ft.

S.A. 32

Feet

- 0 to 2 Soil.
- 2 to 56 Limestone.
- 56 to 68 Gneiss.
- Water struck: 45 ft.
- Water rest level: 42 ft.

Exposures are extremely poor in this part of the area, but the thicknesses of the limestone pierced by the bore-holes are surprising. No sediments were seen between Basement System migmatites and the overlying basalt at Karrsa, less than a mile and a half south of the above two bore-hole sites, and the limestone probably infills a buried river valley. The tongue of lava between Matasara and Karrsa is suggestive of flow along a pre-existing valley with the subsequent development of small flanking streams (the Nderera and the Garba Tula).

These occurrences of limestones are all referred to the lower Pleistocene since they were deposited on the mildly dissected end-Tertiary peneplain and underlie Pleistocene volcanic rocks. If the pebble of basalt found at Boji was in fact derived from the sediments it suggests that deposition of limestone occurred after the start of the vulcanicity.

A bore-hole (C. 2324) at Kubi Turkana, in the south-central part of the area, showed 16 ft. of brown and greyish clays between the base of the lava and the underlying Basement System rocks (see page 39). These clays are probably lower Pleistocene deposits.

Marls more than 40 ft. thick were proved by drilling immediately south of Boji hill at the western boundary of the area (see p. 40). The sediments evidently infill an old course of the Uaso Ngiro and are tentatively referred to the Pleistocene.

6. Tertiary to Pleistocene Volcanic Rocks

Olivine basalts capping the Merti Beds are tentatively referred to the late-Tertiary, because they evidently preserved the sediments during the end-Tertiary cycle of peneplanation. The lavas are petrologically similar to Pleistocene olivine basalts and, for descriptive purposes, are treated below with Pleistocene rocks.

About a third of the area is immediately underlain by volcanic rocks of Pleistocene age, that flowed across a previously dissected end-Tertiary peneplain to cover wide tracts of country south of the Uaso Ngiro. Volcanic vents are largely concentrated in the south-western corner of the area, where they form the foothills of the Nyambeni range. With few exceptions, no convincing evidence was discovered to determine the relative ages of the lava flows and the vents, but it is believed that many of the latter were active during a late explosive phase of the vulcanicity. In river gorges the height of the top of the lava above the present day level of the Uaso Ngiro (about 50 ft. in periods of normal flow) provides some measure of the degree of downcutting since extrusion of the flows. From such evidence it is assumed that the upper time limit of the vulcanicity was probably late Pleistocene, though a flow of trachy-andesites near the southern boundary of the area may be of Recent age.

For petrographic purposes, the volcanic rocks are conveniently classified as follows:—

- (1) Olivine basalts.
- (2) Olivine melabasalts.
- (3) Olivine melanephelinites and rare ultrabasic lavas
- (4) Trachyandesites.
- (5) Tuffs, agglomerates and scoriaceous lavas of the volcanic vents.

(1) OLIVINE BASALTS

With the exception of trachyandesites in the south-western corner of the area and very minor occurrences of melanephelinites, melabasalts and ultrabasic rocks, all the lavas mapped are porphyritic olivine basalts that weather in shades of grey and brown. Both olivine and pyroxene commonly occur as phenocrysts, set in a fine blue-grey or purplish grey groundmass. Specimen 37/225, collected from the roadside near Kubi Aru, contains augite phenocrysts half an inch across, together with pale green glassy olivines up to half that size. On the other hand, small phenocrysts of yellow-green olivine are only occasionally accompanied by megascopic pyroxene in the Tertiary basalts from the Merti plateau (specimen 37/202). Many of the basalts are vesicular and some contain amygdalae of calcite and zeolites.

In thin sections, colourless olivine occurs largely as euhedral phenocrysts showing varying degrees of alteration to reddish brown or yellow-brown iddingsite; the mineral is optically negative with optic axial angles ranging from 80° to 90° . Small anhedral grains of olivine are occasionally found in the groundmass (e.g. in specimen 37/4, from a locality four miles south-east of Bur Bulaya). Purple-brown titanite, with $c \wedge Z = 48^\circ$ to 59° , is often present as phenocrysts, but is universally developed as granules in the base. In specimen 37/225 some sections of pyroxene show optic axial angles estimated to be about 45° , indicating an approach to a pigeonitic composition. Plagioclase only rarely occurs in phenocryst form and is usually only present in fine laths throughout the groundmass, where it has a composition in the andesine-labradorite range. Fine granular opaque ore is ubiquitous, and analcite is sometimes seen in the groundmass, adopting an interstitial habit (e.g. specimen 37/112 from a flow two miles east of Magado).

(2) OLIVINE MELABASALTS

With a diminishing proportion of feldspar, the olivine basalts grade locally into olivine-bearing melabasalts; these melabasalts are not differentiated on the geological map. Specimen 37/11, from a locality two miles east of Bur Bulaya, is a fine-grained, dark blue-grey rock containing irregular vesicles and occasional phenocrysts of black pyroxene up to 0.4 of an inch across. The lava weathers to a purplish brown colour. In thin section the specimen shows euhedral phenocrysts of clear olivine and pale brown augite, the latter with $c \wedge Z = 52^\circ$ and exhibiting marked zonal structures. Fine feldspar laths of undetermined composition are scattered throughout a groundmass consisting dominantly of granular pyroxene and opaque ore. Carbonate is present in amygdalae.

A purplish brown lava (specimen 37/226) from Kugamarro, near the Isiolo-Wajir road, contains black pyroxene phenocrysts up to 0.1 in. long together with small reddish brown patches arising from the alteration of olivines. Calcite is the chief constituent of numerous amygdalae. The thin section shows phenocrysts of yellowish pyroxene, altered olivine and rare plagioclase in a fine, dark, granular groundmass. The pyroxene has $c \wedge Z = 54^\circ$ and an optic axial angle of about 45° , indicating a composition between augite and pigeonite. Zoning is prominent, and twinning is sometimes seen in the phenocrysts. Olivine is largely altered to opaque iron oxides that appear bright reddish brown in reflected light, but cores of unaltered olivine are visible in some pseudomorphs. The plagioclase in the phenocrysts is probably andesine; no feldspar was confirmed in the groundmass, which is apparently composed of fine granular pyroxene and iron ore. Analcite is associated with calcite in amygdalae.

(3) OLIVINE MELANEPHELINITES AND RARE ULTRABASIC LAVAS

A single specimen (37/118) of lava having an ultrabasic composition was collected from the bed of the Uaso Ngiro river about 20 yards upstream from Chanler's Falls. The black compact rock contains prominent pale green phenocrysts of olivine up to 0.2 of an inch in

diameter. In thin section it exhibits a marked porphyritic texture with phenocrysts of titan-augite accompanying more common olivines, the latter showing partial alteration to iddingsite. No feldspar or feldspathoid is visible in the holocrystalline groundmass, which consists entirely of granular titan-augite and subordinate iron ore. Small amygdalae are probably composed mainly of carbonate.

At the request of the author, Mr. P. Rix later collected two more specimens from the same locality as that of 37/118; both contain interstitial nepheline, so that the lava in the river-bed above Chanler's Falls is probably mainly olivine melanephelinite. Neither melanephelinites nor the ultrabasic lavas are differentiated from neighbouring olivine basalts on the geological map.

Lavas having the composition and texture of the rock described above are evidently extremely rare. Gass (1958) described ultrabasic pillow lavas from Cyprus but the rocks there differ considerably from those encountered during the present survey. The Cyprus lavas, where holocrystalline, contain serpentinized olivine phenocrysts set in a groundmass that consists mainly of anorthite, diopside and hypersthene and the rocks were believed to have originated by crystallization from a peridotite melt. The ultrabasic lava at Chanler's Falls, on the other hand, clearly represents a portion of an olivine melanephelinite locally free of nepheline.

(4) TRACHYANDESITES

A single late flow of lava, extruded from Choro vent in the south-western corner of the area, has a distinctive appearance in hand specimen, and the extent of the flow is clearly defined on air photographs. The rocks, which are typically greenish grey, fine-grained, and non-porphyritic, exhibit a conchoidal fracture and contain vesicles up to an inch and a half long. In thin section specimen 37/223 displays a trachytic, micro-porphyritic texture. Pale brown pyroxene is characterized by small extinction angles ($c \wedge Z$). Most of the pyroxene is optically positive, though rare optically negative sections suggest that the monoclinic pyroxene is accompanied by a little hypersthene. Feldspar is present both in the groundmass and as microphenocrysts. Mostly it is optically positive with a refractive index slightly higher than that of balsam and shows indistinct lamellar twinning, the extinction on which suggests a composition near oligoclase. Some of the feldspar, however, has $-2V = c.50^\circ$ and refractive index approximately equal to that of balsam; it may be potash oligoclase or anorthoclase. Accessory minerals include opaque ore and a little analcite.

(5) TUFFS, AGGLOMERATES AND SCORIACEOUS LAVAS OF THE VOLCANIC VENTS

Volcanic vents, often having well preserved craters, are largely confined to the south-western corner of the area, forming the foot-hills of the Nyambeni range. The vents show no marked linear arrangement although they clearly lie mainly within a zone of faulting in the underlying Basement System rocks. These faults, often intruded by thin basalt dykes, trend generally north-north-eastwards and the zone of weakness evidently controlled the orientation of the Nyambeni range.

The vents are composed of accumulations of friable, loosely consolidated tuffs, together with scoriaceous lavas and scattered occurrences of coarse agglomerates bearing fragments of Basement System rocks brought up from depth. Volcanic bombs frequently litter the surfaces of the cones. The agglomerates vary widely both in the size and composition of the constituent fragments. Fragments of Basement System origin are most commonly composed of leucocratic biotite gneiss, hornblende-biotite gneiss or migmatite, but amphibolite and pegmatite were also seen. At Magado crater, one block of biotite gneiss from an agglomerate measures three and a half feet in diameter. To the east, near Dakadima, similar large blocks of gneiss are accompanied by fragments of basalt, volcanic glass and occasional olivine crystals up to two inches in diameter.

The vents are often surrounded by lavas but aprons of tuffs and ashes from the cones generally obscure the relationships between the various rock types. Indications of lava flows derived from craters are rare, so that the cones may have been built up during an explosive phase that succeeded the extrusion of the bulk of the olivine basalt; the state of preservation of the majority of the craters also indicates a late formation. Bedded tuffs between Magado and the southern boundary of the area at Yakabuti and Kirongo are, however, overlain to the west by basalt, and the trachyandesites from Choro crater clearly overlie both tuffs and basalts.

Thickness of the volcanic rocks from bore-hole evidence

Several bore-holes drilled beside the Isiolo-Wajir road provide evidence of the depth of the volcanic cover near the southern boundary of the area, where the lavas attain a maximum thickness. The long tongues of basalt that extend north-eastwards from the foot-hills of the Nyambeni range down to the banks of the Uaso Ngiro and to Kurru, represent the remains of flows that poured into a pre-existing broad river valley. The effect on Pleistocene drainage is discussed in later pages of the report.

A producing bore-hole (C.2324), was drilled at the roadside at Kubi Turkana (mile 50 from Isiolo), between several small volcanic vents, and pierced the lava cover. The driller recorded the following log:

Feet

- 0 to 59 Lava pebbles, sand and earth.
- 59 to 117 Lava boulders, decomposed lava.
- 117 to 120 Brown clay.
- 121 to 133 Greyish clay.
- 134 to 143 Decomposed biotite schist.
- 143 to 170 Basement Complex.

Water was struck at 134 ft. below the surface (i.e at the base of the clay formation) and rose to a rest level at 118 ft. (at the base of the lava). The ground surface at the bore-hole site is about 2,480 ft. O.D.

An abandoned bore-hole (S.A. 66) had been drilled previously at the roadside three and a half miles to the west (the site is shown approximately on the geological map) and there Basement System rocks were encountered beneath only a thin cover of lava boulders, indicating a buried inselberg on the end-Tertiary peneplain. The following details were recorded by the driller:

Feet

- 0 to 3 Soil.
- 3 to 20 Lava boulders.
- 20 to 300 Gneiss.

Water was struck at 194 ft. and rose to a rest level at 160 ft. from the surface (here about 2,700 ft. O.D.).

A mile and a half to the west (at mile 45 from Isiolo) two unsuccessful bore-holes (C. 136) failed to pierce the lavas. The positions can only be indicated approximately on the map since the site was not located precisely during the survey. The first hole was abandoned in lava boulders at 82 ft. below the surface (here probably a little over 2,700 ft. O.D.); the second bore-hole failed to penetrate the volcanic cover and was also abandoned in lava boulders at a depth of 140 ft. No water was struck during either drilling operation.

An unsuccessful bore-hole (C.91) was abandoned in basalt at 182 ft. below the surface near the Isiolo road about six miles beyond the boundary of the present area.

The above evidence shows that the Pleistocene basalts flowed across a near-planar surface in the southern parts of the Chanler's Falls area, but that towards the centre of the area this surface (the end-Tertiary peneplain) had already undergone dissection by a primitive Uaso Ngiro river before the extrusion of the bulk of the basalt. Bore-hole records show that the lava is locally more than 180 ft. thick at the present day.

Influence of the lava on the course of the Uaso Ngiro

From the extent of the present lava outcrops it is clear that some flows of basalt actually reached the Pleistocene Uaso Ngiro. Although the overall effect was a general northward migration of the river course in its broad valley, in places the lava dammed the river, forcing the water to flow across the volcanic rocks in its return to a previous course downstream. There is some evidence of a major change in the river course in the neighbourhood of Tumtu and Boji hills, near the western boundary of the area. A hole drilled to 40 ft. from the surface beside the track immediately south of the main conical hill at Boji (just beyond the confines of the present area) failed to locate either the basic intrusive rocks forming the hill or

Basement System rocks. Instead, the drill passed through a series of whitish and pale buff-coloured marls until the hole was abandoned in wet, clayey calcareous mud. A single basalt boulder was encountered at a depth of 36 ft. It is believed that the marls infill an old river course that carried the Uaso Ngiro around the southern end of Boji hill and thence generally north-eastwards in the direction of the present day Chanler's Falls. Damming of the old river bed east of Boji resulted in the deposition of calcareous muds upstream from the lava, occasional lava boulders being incorporated in the sediments. Subsequently, more extensive flows of basalt buried the silted-up river valley between Boji and a point east of Tumtu, causing the river to seek a new outlet between the two hills; it flowed largely along the northern edge of the lava, but locally adopted a course in the volcanic rocks.

Contacts between the lava and the underlying Basement System rocks are consistently exposed a few feet above river level *both* upstream and downstream from Chanler's Falls, though at the Falls the Uaso Ngiro drops 38 ft. through lavas without the Basement being exposed. There are no signs of faulting to explain the sudden elevation of the lava base, so the evidence is taken to indicate the existence of a marked step in the sub-lava surface at this locality. The step probably marks the point of return of the river to its original course, following a forced detour caused by damming by lava somewhere upstream; the step was itself subsequently buried by later lava flows.

Above the Falls the river flows in olivine melanephelinites and ultrabasic lavas for several hundred yards, but with continued backcutting the Basement System rocks at the step will eventually become exposed. The falls have already migrated upstream a distance of at least a mile and three-quarters since extrusion of the lavas in Pleistocene times, and the river has cut down through some 50 ft. of volcanic rocks.

7. Quaternary Superficial Deposits

A wide variety of superficial deposits were encountered during the survey. They were formed by the continued weathering of contrasting rock types and fall generally into the following groups:—

- (1) Reddish brown sandy soils.
- (2) Chocolate-brown soils.
- (3) Volcanic soils.
- (4) Calcrete and calcareous sinter.
- (5) Pebbly deposits derived from the Merti Beds.
- (6) Alluvial silts.

(1) REDDISH BROWN SANDY SOILS

These soils are best developed across the remnants of the end-Tertiary peneplain, particularly between Rapsuu and the Isiolo-Wajir road where the superficial cover is unbroken over wide tracts of country. South of the main road, between the lava outcrop and Garba Tula, the sandy soils are also well represented, but there the cover is generally thinner, and bears occasional float blocks from the more resistant of the underlying formations. Poor drainage conditions in the neighbourhood of the Kinna track have led to the formation of darker swamp soils. Small surface concentrations of black sand, often several inches thick, consist almost entirely of magnetite—a common accessory mineral in many of the rock types examined in the area. Irregular masses of *kunkar* limestone are commonly found in the reddish brown soils on the end-Tertiary peneplain. In addition to the occurrences shown on the geological map sandy soils are associated with most of the Basement System rocks, but exposures are generally convincing enough to allow solid mapping. Where derived *in situ* from the highly quartzo-felspathic members of the Basement System, the deposits are often paler in colour than the peneplain sandy soils.

Course pinkish sands and sandy soils frequently surround the occurrences of basic intrusive rocks between Boji hill and the Banya, Obe and Kakalota masses. Felspar fragments are common in these deposits, suggesting that they are largely derived from pegmatites associated with the intrusive bodies. The sands contain fragments of magnetite up to an inch in diameter, beryl and less commonly columbite-tantalite. Small quartz crystals are occasionally found. Similar pale sands (but bearing only magnetite) were often found overlying pegmatite-injected amphibolites north of the Uaso Ngiro river, and also across poorly exposed ortho-granulites and ortho-gneisses east of the Kurru anticline. Coarse sands containing abundant magnetite are associated with coarse graphic pegmatites, quartz veins and picrite boulders in the core of the Kurru anticline.

(2) CHOCOLATE-BROWN SOILS

At several localities north of the Uaso Ngiro river the underlying geology is obscured by thick accumulations of rich chocolate-brown coloured soils. From evidence seen elsewhere in the area, these soils are believed to be derived from the weathering of amphibolitic rocks, and they probably overlie outcrops of ortho-amphibolites formed by the metamorphism of basic intrusive rocks. These soils form a poor surface for motorable tracks.

(3) VOLCANIC SOILS

The volcanic soils are fine dusty deposits ranging in colour from brick-red to grey or black. They often bear boulders and pebbles of basalt together with occurrences of *kunkar* limestone. Like the chocolate-brown deposits, the volcanic soils provide poor surfaces for roads and tracks.

(4) CALCRETE AND CALCAREOUS SINTER

Calcareous superficial deposits were found principally near Chanler's Falls, where the deposits overlie lava; occasional pebbles of basalt are found in the limestones. Calcareous sinter is associated with permanent springs near the Falls and may still be forming. In the analysis of spring water from this locality (page 51) no figures are available for the proportions of calcium and magnesium, but in view of the high magnesium values recorded in spring waters from the neighbouring Archer's Post area, the calcrete probably contains a correspondingly high percentage of magnesium carbonate.

(5) PEBBLY DEPOSITS DERIVED FROM THE MERTI BEDS

The significance of reworked sediments at the western end of the Merti plateau has already been discussed in a previous section of the report (page 35). The loosely consolidated pebbly deposits, containing occasional small pockets of kaolin, were evidently derived from the cemented river gravels (Merti Beds) exposed in the upper parts of the scarp. Erosion and redeposition of the sediments probably commenced during the early Pleistocene and continues to the present day. No basalt pebbles were found in any of the reworked beds to provide conclusive proof of a secondary origin.

(6) ALLUVIAL SILTS

Deposits of silt and sand in the lower course of the Uaso Ngiro mark a change in gradient of the river east of Kubi Kalo and Kismitirr (*see* Fig. 2). The alluvial deposits terminate a near-continuous series of rock exposures in the bed of the river upstream from Kubi Kalo.

VI—METAMORPHISM AND GRANITIZATION

The area is thought to have suffered two independent phases of regional metamorphism that are tentatively correlated with two periods of folding. The oldest rocks in the area are Basement System metasediments that had undergone metamorphism and intense north-south folding prior to the intrusion into them, probably during Precambrian times, of a suite of hypersthene-bearing basic and ultrabasic plutonic rocks and hypersthene-bearing dolerite dykes; locally the dykes cut across the foliation in Basement System rocks (*see* p. 32). All the intrusive rocks were themselves subsequently metamorphosed to produce extensive belts of foliated ortho-amphibolites and ortho-gneisses; then folding occurred along north-northeasterly trending axes. Metamorphism of the plutonic rocks proceeded inwards from the margins of individual masses, the process being incomplete so that virtually unmodified cores of perknites, picrites, norites and gabbros are now found within the belts of ortho-amphibolites. The effects of the second metamorphic phase on the already metamorphosed rocks of the Basement System are not readily appreciated.

Metamorphosed pelitic sediments of the Basement System occur in the eastern parts of the area but the zone minerals sillimanite and kyanite were not seen during the survey. Almandine garnet is present in pelitic quartzo-felspathic granulites and graphitic gneisses in some metamorphosed semi-pelitic sediments, and also in some migmatites that are thought to be derived from pelitic or calcareous sediments. Garnet is also present in association with diopsidic pyroxene, plagioclase in the range andesine-labradorite, and often calcite and scapolite in calc-silicate granulites. The metamorphosed semi-pelitic sediments contain biotite, and often muscovite, in association with quartz and oligoclase. Garnet, when present, sometimes displays the effects of retrogressive metamorphism in being surrounded by

kelyphitic borders of chlorite. Hornblende is not widely developed outside the migmatites of semi-pelitic origin, and epidote and calcite are rare accessories. Metamorphosed psammitic sediments contain quartz and oligoclase in association with varying amounts of biotite, magnetite and microcline.

The following then are the typical mineral assemblages that occur in Basement System metasediments:—

Calcareous:—

Calcite-diopside-garnet-plagioclase-quartz-epidote-scapolite.

Pelitic and semi-pelitic:—

Quartz-garnet-biotite-muscovite-plagioclase (–epidote).

Quartz-garnet-biotite-plagioclase-hornblende.

Quartz-garnet-plagioclase (–hornblende-muscovite-epidote).

Quartz-biotite-muscovite-plagioclase.

Psammitic:—

Quartz-biotite-plagioclase-microcline.

The plagioclase is andesine-labradorite in calcareous rocks, and oligoclase in pelitic, semi-pelitic and psammitic types.

The rocks clearly fall within the almandine-amphibolite facies of Turner and Verhoogen (1960, pp. 544–553), with the association of diopside, garnet and an intermediate plagioclase in calcareous rocks indicating a grade of metamorphism equivalent to either the staurolite-almandine or the kyanite-almandine-muscovite subfacies. Lack of anorthite and the presence of epidote in the calcareous assemblage makes it unlikely that correlation with the sillimanite-almandine-muscovite subfacies can be considered. Pelitic, semi-pelitic and psammitic assemblages also indicate a metamorphic grade corresponding to the lower half of the almandine-amphibolite facies; temperatures are likely to have been in the region of 550° to 650°C., and pressures approximately 4,000 to 6,000 bars.

Microcline replaces quartz and sodic plagioclase in many of the above rocks and the process of potash metasomatism is carried further in microcline porphyroblast gneisses and in migmatites. Later stages of granitization are represented by granitoid gneisses at Buliss, though these poorly foliated rocks may have been formed through the medium of a granitic magma, generated locally by the fusion of pre-existing rocks.

All stages of metamorphism of the basic and ultrabasic intrusives are represented in the area. The core rocks show only late-stage magmatic changes, with common uralitization of the pyroxenes and the formation of reaction coronas about olivine. These indications of autometamorphism are overshadowed by more advanced alteration in the metagabbros, in which olivine and hypersthene are typically absent. The process of progressive amphibolitization is carried to extremes in the suite of ortho-amphibolites and ortho-gneisses, in which pyroxene is either absent or is present only as cores to the hornblende and in which recrystallization is often prominent. Similar metamorphic changes occur in metadolerites, the rocks ranging from hypersthene-bearing types to varieties in which no pyroxene remains.

The following mineral assemblages were recorded in metamorphosed intrusive rocks:—

Ortho-amphibolites and ortho-gneisses:—

Hornblende-plagioclase (–scapolite-epidote).

Cummingtonite (?)—plagioclase.

Metagabbros:—

Hornblende-plagioclase.

Tremolite-anthophyllite-plagioclase.

Metadolerites:—

Hornblende-biotite-plagioclase (–quartz).

The plagioclase in all the above assemblages is commonly labradorite. The presence of pyroxene in some of the rocks denotes lack of equilibrium, and is disregarded.

These assemblages indicate a grade of metamorphism corresponding to some part of the almandine-amphibolite facies, i.e. approximately equivalent to that shown by Basement System metasediments. No aureoles of contact metamorphism are recognizable around major intrusions; it seems likely, therefore, that the second episode of metamorphism distinguished in the Chanler's Falls area was more intense than the earlier phase, and that it corresponds to the high-grade regional metamorphism commonly reported during studies of Basement System rocks in many parts of the country.

VII—STRUCTURE

Although a detailed structural analysis of the complexly folded Basement System rocks was beyond the scope of the present work, sufficient evidence was recorded in the course of the survey to demonstrate the general structure. A large part of the area is mantled by Pleistocene lavas, and although the underlying rocks appear as isolated inliers it is impossible to assess with certainty the significance of structural data collected from these widely separated outcrops. In contrast, the nearly continuous section exposed along the Uaso Ngiro, supplemented by scattered but generally adequate exposures north and to a lesser extent south of the river, greatly assisted in the interpretation of the Basement System structures in the northern half of the area.

Among the Basement System rocks foliation is best displayed by semi-pelitic types, in which biotite is a common constituent. In these gneisses lineation is defined by the orientation of mica flakes on foliation planes. In the rocks of psammitic origin foliation naturally becomes less distinct with a decrease in the mica content. Furthermore, the form of outcrop, with a common disintegration into large blocks, often prevents a true assessment of the dip and strike. Lineation in the granulites frequently takes the form of fine striations along foliation planes. Care has been exercised in the interpretation of structural data records from the post-Basement System ortho-amphibolites and ortho-gneisses, since these rocks originated by the metamorphism of both discordant and concordant intrusive bodies. Many of the lineations shown within ortho-amphibolite outcrops were recorded from biotite-rich bands, believed to represent screens of Basement gneiss inseparable on this scale of mapping from the enclosing hornblende rocks of intrusive origin.

Major Folds

The major structural elements in the area are shown in Fig. 4.

In the eastern part of the area, the axes of the major folds trend generally north-south, the structures being overturned south of the Uaso Ngiro but becoming more open north of the river. This fact is clearly illustrated in Fig. 5.

Stereogram B, showing structural information recorded from the Kurru, Tena, Uasisalo and Rapsuu districts, indicates that the folds are overturned to the east with a gentle plunge on a bearing a few degrees west of north. In stereogram D, representing a sub-area between the Uaso Ngiro and the Merti plateau, the poles to foliation planes are scattered about a great circle, showing the major folds to be open structures. Lineations suggest that the plunge is perhaps a little steeper than that seen south of the river but that the axial trend of the folds is similar. The slight scatter of the foliation poles is probably related to local swinging of the fold axes. In the vicinity of Bulfayo, immediately south of the Uaso Ngiro, lineations plunge to the south and south-south-east (stereogram C), illustrating a major structural depression and culmination near the river. This reversal of the axial plunge of the folds is also demonstrated by the outcrop shapes between Kurru and Garribich, particularly by the sinuous trace of the band of quartz-felspar granulite and gneiss that forms Bulfayo hill; the same band widens considerably north of the river partly as a result of the plunge culmination. The depression north of Uasisalo causes a divergence in the bands forming the Kroftu anticline, and is also responsible for the S-shaped outcrop of the granulites at Uasisalo hill.

At Gudamachesa, in the north-eastern corner of the area, the structure is probably also complicated by culminations and depressions (stereogram E) but exposures are poor across the lower ground and there is insufficient structural evidence to establish the style of folding. At one locality calc-silicate granulites display complex small-scale folds with axes plunging both to the south-west and to the north-east.

In the south-eastern corner of the area exposures in the Garba Tula watercourse show steep dips both to the east and west, a single lineation suggesting that the major folds plunge locally to the north-north-east.

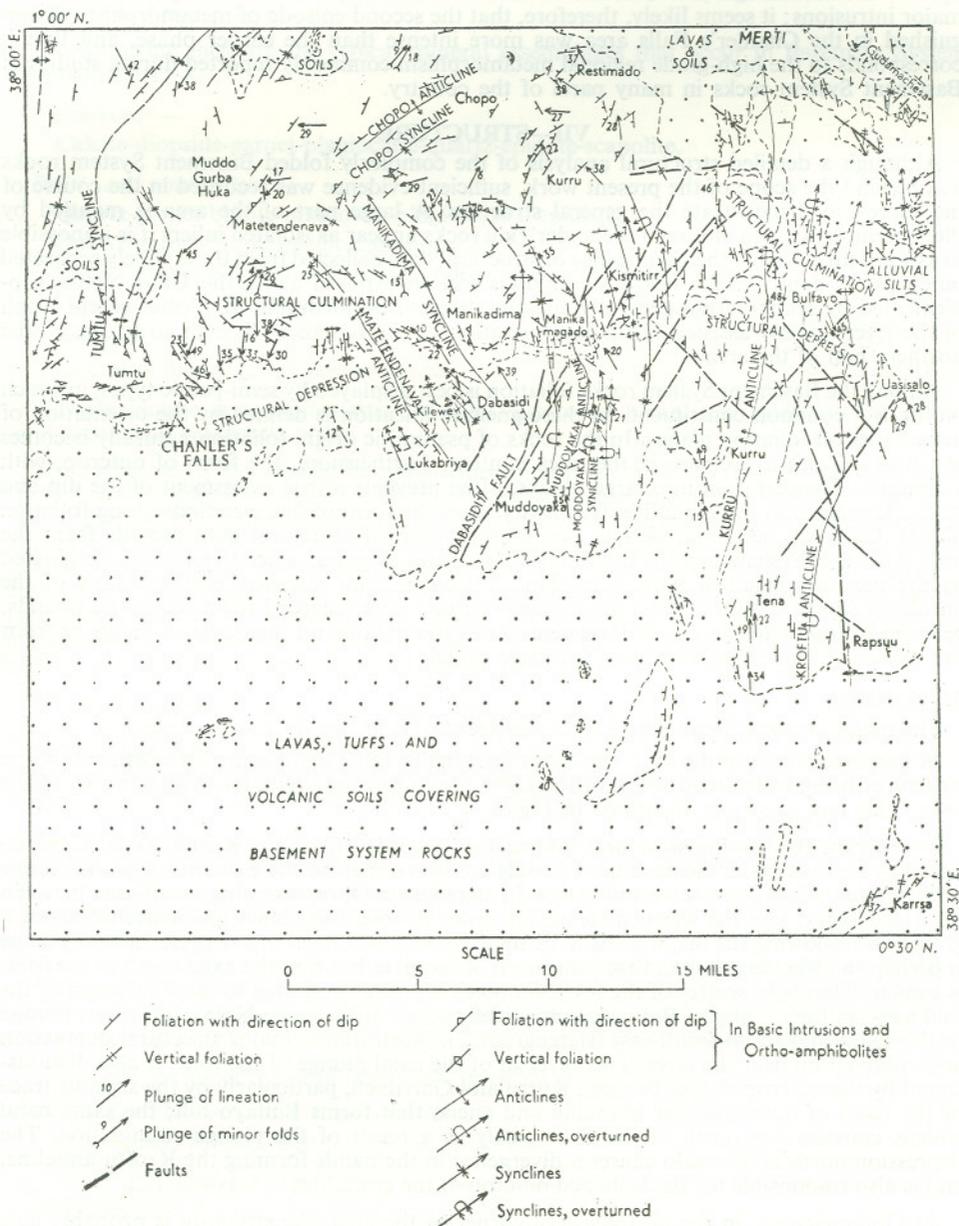


Fig. 4.—Structural map of the Chanler's Falls area.

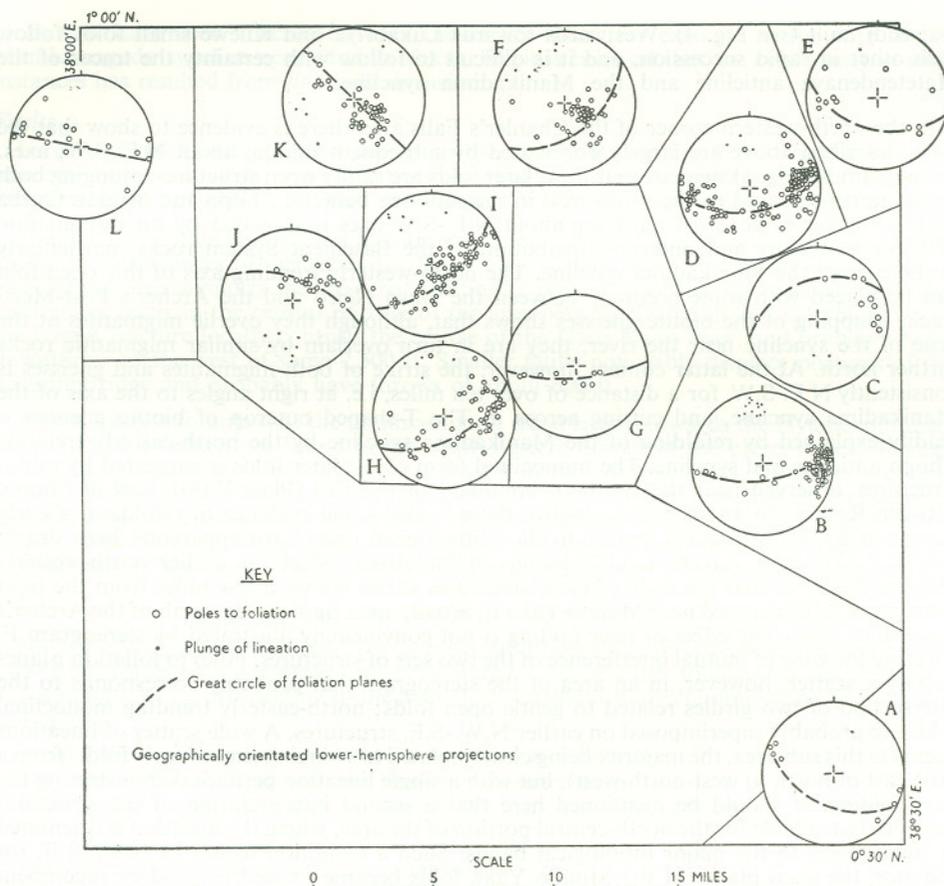


Fig. 5.—Stereographic projections of structural data recorded in the Basement System rocks of the Chanler's Falls area. The stereograms are arranged to show the disposition of sub-areas.

Towards the centre of the area a marked change occurs in the trends of the major folds, there being a gradual swing in the axes from the north-south orientation described above to a north-westerly direction. Stereograms G, H and I (representing the sub-areas at Muddo Yaka, Kilewe and Manikadima respectively) illustrate the swing, and show that it is accompanied by a change in the style of the major folds from overturned to more open structures with moderately dipping limbs. Throughout the swing a north to north-westerly plunge is retained. The most striking north-westerly trending major folds were mapped north of the Uaso Ngiri. Biotite gneisses, forming the core of the Manikadima syncline, outcrop in a broad zone across the Archer's Post Merti road, displaying dips that show the open nature of the fold. The synclinal structure is also demonstrated by migmatites exposed along the river. The complementary Matetendenava anticline is also an open fold, in which a widening of the outcrop on the western limb is caused by subsidiary flexures superimposed on the major structure; these smaller folds are seen both in the river exposures and also in the biotite gneisses at Lukabriya, south of the Uaso Ngiri. East of the Manikadima syncline folds at Manikamagado, Kurru and Kimitirr have more northerly axial trends, and at the last two localities become overturned to the east.

Difficulty was experienced in relating the clearly defined and rather simple fold pattern north of the Uaso Ngiri to more complex structures mapped south of the river between Muddo Yaka and Lukabriya. Although exposure deteriorates away from the river, sufficient evidence was recorded to illustrate the axial swing from north to north-west, and to differentiate a number of large-scale folds. At Muddo Yaka these are overturned and have closely appressed limbs; the Muddo Yaka anticline and syncline have been identified north of the Uaso Ngiri, some distortion of the traces of the folds probably being attributable to the

Dabasidi fault (*see* Fig. 4). Westwards towards Lukabriya and Kilewe small folds follow each other in rapid succession, and it is difficult to follow with certainty the traces of the Matetendenava anticline and the Manikadima syncline.

In the north-western corner of the Chanler's Falls area there is evidence to show that the folds described above are largely obliterated by subsequent folding about N.E.-S.W. axes. Stereogram K (Fig. 5) suggests that these later folds are rather open structures, plunging both to the north-east and to the south-west in the sub-area between Chopo and Muddo Gurba Huka. Further evidence of refolding about N.E.-S.W. axes is provided by an examination of the stratigraphy and outcrop distribution of the Basement System rocks, particularly in the core of the Manikadima syncline. The north-westerly trending axis of this open fold can be placed with some accuracy between the Uaso Ngiro and the Archer's Post-Merti track. Mapping of the biotite gneisses shows that, although they overlain migmatites at the nose of the syncline near the river, they are in turn overlain by similar migmatitic rocks further north. At the latter contact, however, the strike of both migmatites and gneisses is consistently N.E.-S.W. for a distance of over ten miles, i.e. at right angles to the axis of the Manikadima syncline, and cutting across it. The T-shaped outcrop of biotite gneisses is readily explained by refolding of the Manikadima syncline by the north-easterly trending Chopo anticline and syncline. The monoclinial form of the later folds is suggested by minor structures observed near the northern boundary of the area (Plate V (b)). East of Chopo, between Restimado and the Uaso Ngiro, there is also some evidence of refolding of early Basement System structures, and individual lithological units have apparently been drawn out in a N.E.-S.W. direction. Undulations in the strike reflect the earlier north-westerly trending folds, so that the style of these structures varies within a few miles from the tight overturned folds mapped near Muddo Yaka to broad, open ripples seen north of the Archer's Post-Merti road. The effect of later folding is not convincingly illustrated by stereogram F. covering the zone of mutual interference of the two sets of structures. Poles to foliation planes display a scatter, however, in an area of the stereogram that probably corresponds to the intersection of two girdles related to gentle open folds; north-easterly trending monoclinial folds are probably superimposed on earlier N.W.-S.E. structures. A wide scatter of lineations occurs in this sub-area, the majority being clearly related to swinging axes of early folds (from a little east of north to west-north-west), but with a single lineation perhaps demonstrating the later folding. It should be mentioned here that a second interpretation of the structural evidence is available for the north-central portion of the area, where the lineation is orientated at right-angles to the major lithological bands. Such a condition would be realized if, for instance, the axial planes of the Muddo Yaka folds became twisted to produce recumbent structures with north-westerly trending axes in the Restimado district. This solution has been rejected in view of the evidence of major cross-folds provided by stereogram K.

The southerly plunging folds in the sub-area between Chanler's Falls and Manikadima (stereogram J) are probably related to the later period of deformation, though no conclusive evidence is available. The axes trend N.N.E.-S.S.W., and similar trending folds were mapped near the western boundary of the area, but there the axes are apparently horizontal (stereogram L). The trace of the Tumtu open syncline swings from north-south to a more north-easterly orientation at the northern boundary of the area.

The structural evidence shows that, in the Basement System rocks of the Chanler's Falls area, north-south trending isoclinal folds (the Mozambiquian trend) are modified by later N.E.-S.W. structures. Two periods of folding in Basement System rocks were also recognized in the Mara River-Sianna area (Williams, 1964, pp. 33-41) and the Loita Hills area (Saggerson 1966) of south-western Kenya; but there early N.E.-S.W. structures were refolded about N.W.-S.E. axes. A similar relationship is reported in southern and eastern Kenya, where folds on the Mozambiquian trend (N.W.-S.E. to N.-S.) were preceded by N.E.-S.W. structures (Saggerson *et. al.*, 1960, pp. 344-345). The second folds in the Chanler's Falls area are, therefore, evidently later than the two dominant fold trends so far recognized in the Basement System rocks of Kenya.

The line of the Tumtu syncline marks the maximum development in the area of post-Basement System intrusive rocks (including a series of foliated ortho-amphibolites of gabbroic and noritic origin). These intrusive rocks have clearly been folded by the Tumtu syncline, and were probably emplaced after the first period of folding and before the second. Locally the ortho-amphibolites display a conformable relationship to Basement System

rocks that have been affected by only the earlier folds (for example in the core of the Manikamagado syncline near Muddo Yaka), but it is believed that the conformity in such instances has resulted from *lit-par-lit* intrusion.

Faults

Large-scale faults are confined mainly to the eastern half of the area, where they trend generally north-eastwards and north-north-eastwards. A limited number of fractures cross the main trends at right-angles, and rare east-west and north-south faults were also mapped.

The faults are often emphasized by intrusions along them of thin basaltic dykes and, more rarely, by occurrences of metadolerites. The rarity of these minor intrusives in the western parts of the area supports the view that faulting, if present, is of less significance. The main fault zones occur in the central portion of the area between Dabasidi and Garrbich, where the largest fracture locally controls the course of the Uaso Ngiro river, and probably has a downthrow to the west of some 2,500 ft. Smaller faults noticeably displace portions of the Kimitirr ridge and probably have throws of about 600 ft.

It is of interest to note that the dominant fault trend strikes towards the Nyambeni range, the foot-hills of which are found in the south-western corner of the present area. Though in detail there is no apparent linear arrangement of the volcanic vents, the faults probably control the orientation of the main range. Some of the faults are probably of Precambrian age, in view of the control afforded to metamorphosed dykes; others displace ortho-amphibolites of Precambrian age, so that later movements may have taken place along original lines of weakness. No trace of faulting was found in the Tertiary-Pleistocene lavas.

VIII—ECONOMIC GEOLOGY

No deposits of economic value (based on current prices) were discovered during the present survey but traces of a number of minerals were found, and the following account is given as a guide to future prospecting in the area. The distribution of economic minerals is shown in Fig. 6.

Minerals occurrences are conveniently classified as follows:—

1. Minerals associated with the Basement System rocks.
2. Minerals associated with the basic and ultrabasic intrusive rocks.
3. Minerals associated with the volcanic rocks.
4. Minerals associated with the sediments.
5. Water supplies.

(1) MINERALS ASSOCIATED WITH THE BASEMENT SYSTEM ROCKS

Few traces of economic minerals were found in the Basement System rocks, and it is considered unlikely that further prospecting will reveal deposits of importance.

Garnets are abundantly developed in migmatites exposed in the Garba Tula watercourse at Karrsa. Near the eastern boundary of the area garnets tend to be confined to leucocratic bands in the migmatites and rarely exceed a quarter of an inch in diameter, but upstream both the mafic and quartzo-felspathic bands contain conspicuous reddish garnets. In one zone about 200 yds. wide, striking across the watercourse, the garnets range up to an inch and a quarter in diameter and are easily extracted from the weathered hornblendic portions of the rock. Idioblastic crystals vary in colour from translucent pink to opaque brown, and display megascopic kelyphitic borders of chlorite. All the crystals are shattered and bear chadacrysts of quartz and feldspar, rendering them unsuitable for use as abrasives. No flawless, gem quality stones were seen during the survey.

Graphite occurs in limited quantities in the north-eastern corner of the area, but the mineral appears only in tough quartzo-felspathic gneisses so that milling costs would be prohibitive. Formations immediately flanking the graphitic gneisses are generally unexposed and should there be an appreciable rise in the demand and current price of graphite it is possible that prospecting might reveal marginal schistose bands of economic value. *Magnetite* is an abundant constituent of some quartzo-felspathic gneisses, but no concentrations of economic importance were encountered. *Kyanite* was not seen during the survey, but the mineral might be expected to occur in pelitic gneisses in view of the grade of metamorphism of Basement System rocks (see p. 41).

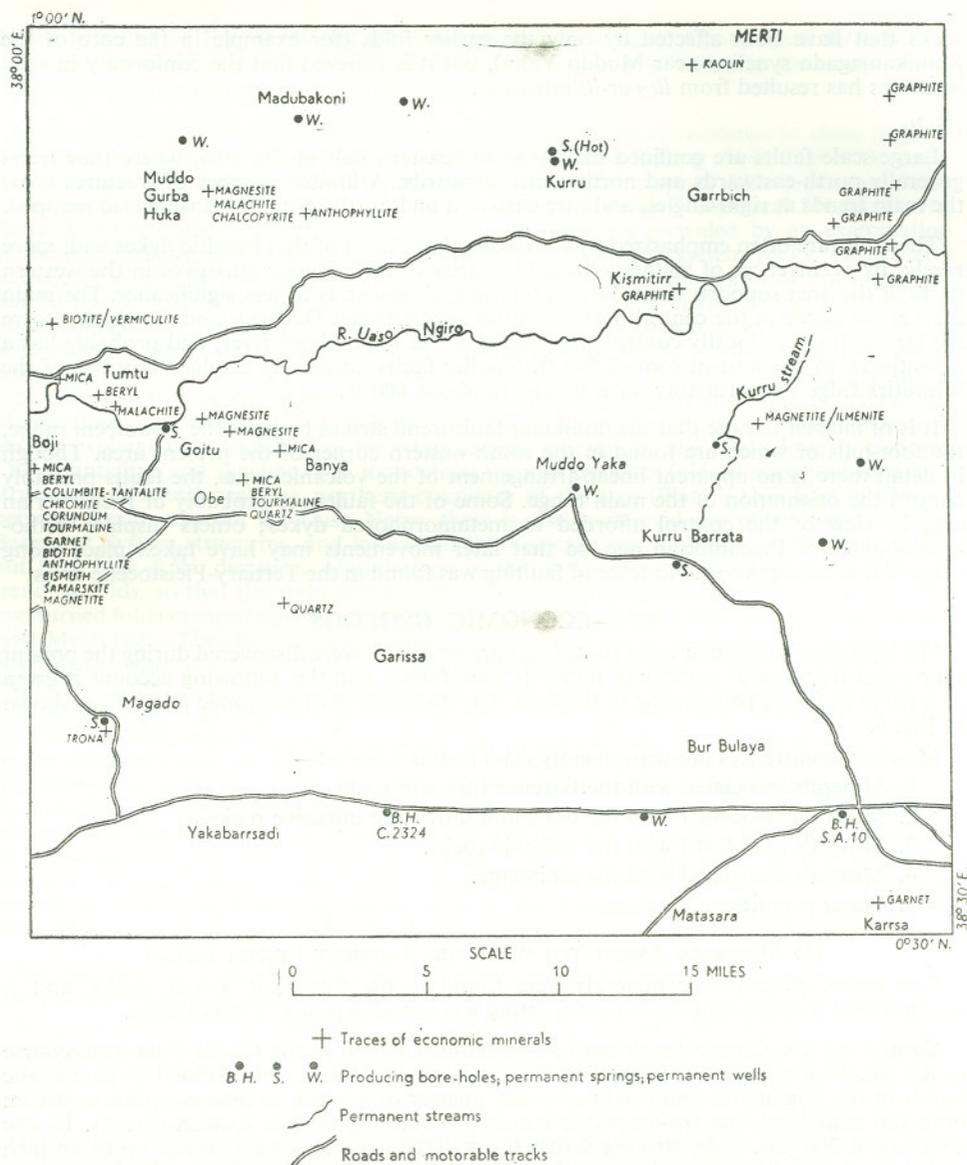


Fig. 6.—The distribution of economic minerals in the Chanler's Falls area.

(2) MINERALS ASSOCIATED WITH THE BASIC AND ULTRABASIC INTRUSIVE ROCKS

Mica

During the present survey occurrences of good quality muscovite were being examined by Mr. J. J. Davies at Boji, a small hill mass lying astride the western boundary of the area near the Uaso Ngiro. The mica was found in pegmatites cutting the olivine- and hypersthene-bearing basic and ultrabasic intrusive rocks that form the bulk of the hill.

In May 1959 Davies was granted Exclusive Prospecting Licence No. 136 covering approximately 2.4 square miles, the boundary being defined (Official Gazette Notice No. 1919 of the 6th May 1959) as commencing at a point which is on a bearing of 132 degrees and about 700 yds. from the trigonometrical beacon on Boji; thence generally westerly along the Shaffa Dinka and Chanler's Falls road for a distance of 2,295 yds.; thence on a bearing of 40 degrees for a distance of 4,420 yds.; thence on a bearing of 130 degrees for a distance of

1,870 yds.; thence on a bearing of 220 degrees for a distance of 3,400 yds. to the point of commencement. Part of this claim thus falls within the present area. The main excavation to investigate the mica occurrence was carried out on the north-western slopes of the prominent conical hill at Boji and consequently the workings are situated within the Archer's Post area (Jennings, report awaiting publication). During the early months of the investigation a small quantity of mica was recovered, but the licence was relinquished in September 1959.

Muscovite-bearing pegmatites were encountered at a number of other localities in the area, notably at the western end of Tumtu hill and cutting basic intrusives at the Banya and Obe hills, but nowhere were the surface indications as promising as at Boji. Between the two spurs at the northern end of Obe hill thin books of muscovite yielded flakes up to six inches long, but no trenching was undertaken to prove the quality and quantity at depth. The early abandonment of the Boji prospect must unfortunately be regarded as a poor omen for the chances of large-scale mica production in the area.

Beryl

Crystals of beryl, weighing several pounds each, were recovered by Davies from pegmatitic scree and wash on the lower eastern slopes of Boji hill. Numerous smaller fragments were also collected, but trenching failed to establish the source of the beryl. Small crystals and fragments of the mineral were picked up by the writer during the present survey, but nowhere was the beryl found *in situ*. Other than Boji, the principal localities yielding beryl are the southern slopes of Tumtu hill and the eastern flank of the main hill at Obe. In both cases beryl was found lying loose in gravels and soils of pegmatitic origin.

The mineral is commonly opaque blue, but a little green beryl was collected at Boji. Completely flawless crystals were not seen, but a transparent pale blue fragment from Obe suggests that an extensive search might reveal stones of gem quality.

Other Minerals

In addition to muscovite and beryl a number of other minerals of possible economic importance occur in, or associated with, the basic and ultrabasic intrusives of the Chanler's Falls area, but they are likely to remain unexploited in view of the high cost of transport to the nearest railhead.

Magnesite was encountered in thin veins cutting many of the intrusive bodies, and also in large fragments that probably originated in the same fashion, though the source is unexposed. At Goitu, near Chanler's Falls, numerous magnesite fragments are strewn across the upper parts of small hills of olivine hyperite; some of the calcrete near the base is probably also rich in magnesium carbonate. Similarly, magnesite is a rather common mineral at Muddo Gurba Huka, a prominent double hill of metagabbro north of the Uaso Ngiro. The occurrences were not considered to be of economic value.

Fragments of *magnetite* and *ilmenite* up to two in. long occur in pegmatites associated with both gabbroic intrusives and ortho-amphibolites. In the core of the Kurru anticline small outcrops of hornblende-pyroxene picrite are flanked by coarse graphic pegmatites carrying irregular masses of magnetite one or two inches across. Fragments found around Boji, Obe and Banya hills probably also originated from pegmatites cutting the basic rocks. No economic concentrations of iron ore were seen during the survey. Occasional fragments of *columbite-tantalite* have been recovered from the pegmatitic debris around the lower slopes of Boji hill; one piece was found to have a specific gravity of 6.2. The mineral is easily mistaken for the more common iron ores in the field.

Other minerals collected from Boji, during excavations to investigate mica and beryl occurrences, include *chromite*, blue and white *corundum*, *anthophyllite*, *garnet*, *biotite*, *tourmaline*, *malachite* and several traces of native *bismuth*. A little anthophyllite was also found associated with dark amphibolites north-east of Matetendenava. Garnets occur in pegmatites and aplites at many localities in the north-western quarter of the area. Biotite occasionally has a greasy appearance, but even inelastic flakes do not exhibit the exfoliation on heating that characterises vermiculite. Tourmaline crystals in vein quartz were found at Obe, and minute needles in occasional small *quartz crystals* from Kakalota hill are probably also of tourmaline. Malachite occurs in small quantities on the southern flank of Tumtu hill, and also at Muddo Gurba Huka where the carbonate is accompanied by thin veins of

chalcopyrite. Sulphides (mainly *pyrite*, but perhaps including *chalcopyrite*) were identified among the accessory ore minerals in thin sections of many ultrabasic and basic intrusive rocks and their metamorphosed equivalents. No economic deposits of any of the above minerals were seen during the survey, but it is possible that detailed prospecting might reveal workable concentrations.

(3) MINERALS ASSOCIATED WITH THE VOLCANIC ROCKS

Few economic minerals, other than water, can be expected from the volcanic rocks of the area. *Olivine* is a common constituent of the basalts and often weathers out to form small concentrations, together with augite and iron ores, in watercourses draining the lava country. None of these concentrates are likely to prove of value.

In the crater floor at Magado crude *trona* is recovered by the Wameru and exported to other parts of the reserve. The material is first prepared by puddling the clays forming the crater floor (Plate VI (b)), the mud then being sun dried and wrapped in leaves ready for removal. The clayey *trona* is in great demand by many of the surrounding tribes, both for consumption in small pinches with chewing tobacco and also for culinary use.

A sample of the prepared *trona* was sent to the Mines and Geological Department, Nairobi in 1955 by Mrs. Joy Adamson of Isiolo. A qualitative chemical analysis was carried out with the following result:—

“The sample contains water-soluble alkali salts including sodium and potassium carbonates, bicarbonates, chlorides and a small amount of sulphates. The alkali metal is mainly sodium”.

Anal. W. P. Horne

A further sample (37/115) was collected during the present survey from one of the holes in the crater floor, near the lake. An analysis showed the following:—

	Per cent
Na ₂ CO ₃	8.06
NaHCO ₃	15.46
Na ₂ SO ₄	0.68
NaCl	5.08
Balance insoluble in water	

Anal. W. P. Horne.

The above figures were said to be approximate only and all are likely to be low owing to the persistence of suspension and great difficulty in filtering during the analysis. The insoluble portion of the sample is evidently a fine clay.

A second sample sent in by Mrs. Adamson came from the bed of Magado crater lake. This silt was said by the *Boran* tribesmen to be poisonous. An analysis was carried out and the following report was received from the Government Chemist's Department, Nairobi:—

“No arsenic or other heavy metal—antimony, silver, mercury or bismuth—was detected.”

Anal. F. McNaughton.

(4) MINERALS ASSOCIATED WITH THE SEDIMENTS

Small pockets of white powdery *Kaolin* were found in reworked Merti Beds exposed in a watercourse near the western scarp of the Merti plateau. Even in the event of large deposits being proved, transport costs would probably render the occurrence uneconomic.

Limestone, in the form of calcareous sinter and calcrete, is sporadically developed. Judging by the composition of present spring water in the Archer's Post area, the calcrete is likely to contain a high proportion of magnesium.

(5) WATER SUPPLIES

Although the Chanler's Falls area is more fortunate than many other parts of northern Kenya in being traversed by a permanent river, serious water-supply problems exist in the country far removed from the Uaso Ngiro, and even along the river close control of the

numbers of stock and the rotation of grazing areas has been advocated (Howard Humphries, 1959, pp. 34-36) to reduce the present serious rate of erosion due to overstocking. A number of permanent springs, together with widely scattered permanent wells and two bore-holes, do much to alleviate water-supply problems.

Uaso Ngiro

No detailed flow figures for the Uaso Ngiro are available from stations situated within the present area, but Table II presents a comparison of recordings made in 1958 at Archer's Post (some 30 miles upstream from Chanler's Falls) and Habaswein (about 80 miles downstream from the eastern boundary of the area). The figures from these two stations should be accepted with caution since, for instance, inaccuracies have been reported as a result of silting of the weir at Archer's Post. The figures do, however, illustrate the appreciable loss of water between the two stations. In view of the danger of causing considerable hardship to the tribesmen living along the lower stretches of the Uaso Ngiro by over-drawing of water from the headwaters of the river, a minimum flow of $42\frac{1}{2}$ cusecs. is maintained at Archer's Post by controlled take-off upstream.

TABLE II.—FLOW FIGURES RECORDED AT TWO STATIONS ON THE UASO NGIRO RIVER IN 1958

ARCHER'S POST			HABASWEIN	
Month	Total Cusec. days	Total acre feet	Total Cusec. days	Total acre feet
January.. ..	7,433	14,743	No records	No records
February	15,388*	30,522*	No records	No records
March	9,218*	18,284*	7,564	15,003
April	9,420*	18,685*	5,018	9,954
May	24,465*	48,526*	7,564	15,003
June	11,857*	23,518*	6,714	13,316
July	23,822*	47,251*	7,432	14,742
August	29,426*	58,366*	7,842	15,555
September	17,866	35,437	7,320	14,519
October.. .. .	11,728	23,262	5,794	11,492
November	9,044	17,939	2,063	4,092
December	17,662*	35,033*	5,704	11,314

*Plus excess not measured.

(From records of the Ministry of Works, Nairobi).

Springs

There are five permanent springs in the Chanler's Falls area, four being situated south of the Uaso Ngiro. A clear spring, flowing from tough calcareous sinter overlying basalt, provides a steady recharge to the river a few hundred yards upstream from Chanler's Falls. A water sample (37/120), taken as close as possible to the source of the spring, was analysed with the following result:—

Turbidity	.. .. .	None
Colour	.. .. .	Clear
Odour	.. .. .	None
Suspended Matter	.. .. .	Considerable amount of organic matter.
pH	.. .. .	7.5

Alkalinity: (as CaCO ₃)		Parts per million
Carbonate	.. .. .	nil
Bicarbonate	.. .. .	910
Ammonia: Saline	.. .. .	0.04
Albuminoid	.. .. .	1.04
Oxygen absorbed—4 hrs. at 80°F.	.. .. .	2.87
Chlorides: (as Cl)	.. .. .	38
Sulphates: (as SO ₄)	.. .. .	28
Nitrites: (as NO ₂)	.. .. .	present
Nitrates: (as NO ₃)	.. .. .	present
Calcium: (as Ca)	.. .. .	not determined
Magnesium: (as Mg)	.. .. .	not determined
Iron: (as Fe)	.. .. .	3.0
Silica: (as SiO ₂)	.. .. .	72
Total Hardness: (Soap)	.. .. .	40
Total Solids: .. .. .	.. .. .	1120
Fluorides: (as F)	.. .. .	1.8

Comments:—

The water shows evidence of organic contamination and would have to be boiled or chlorinated prior to human consumption.

The fluoride content also exceeds the desirable upper limit of 1.5 p.p.m. for potable water. In the present case however, the water is not likely to have any ill effects.

*Anal. D. B. Patrick,
Government Chemist's Department, Nairobi.*

The organic contamination results from the uncontrolled watering of stock at the spring, and would be considerably higher in the deep pools where water is normally drawn for human consumption. In common with other springs, simple fencing of the source and greater control over stock would improve the quality of water reserved for human consumption. Fences would have to be stoutly constructed to discourage game animals from drinking near the source.

A small permanent spring at Kurru Barrata (Plate VI (a)), near the Garba Tula-Muddo Yaka track, provides an important watering place midway between the main road and the Uaso Ngiro. The water flows sporadically (the flow increasing noticeably during cloudy, overcast weather) in the Kurru watercourse down to its confluence with the Muddo Yaka; there the added recharge from nearby springs creates a more permanent stream across the Kurru anticline, which subsequently dries up in a sandy *lugga* immediately east of the fold.

Small springs below general ground level at Magado supply a shallow lake on the floor of the crater (Plate II (a)) and provide an important water supply for the entire south-western corner of the area. The lake is saline and is undoubtedly contaminated both by the trona content of the crater floor (*see* page 50) and by organic matter, but the main spring is fresh enough for human consumption.

North of the Uaso Ngiro warm water issues from a single spring in Basement System migmatites at Kurru (Plate VI (a)); the temperature of the water was estimated to be between 50° and 60° C. A few gas bubbles were seen escaping at the source but the gas flow is sporadic and insufficient to sample.

The water at Kurru is badly contaminated up to its source as a result of poor organization and control over stock. At present cattle and camels drink from an inadequate trough filled by baling water from the spring. Yet again, the tribesmen would benefit by the construction of a tank, with the spring itself fenced off to supply human needs only. The Kurru spring is easily accessible from the main Merti track and a motorable route could be found with little difficulty.

Bore-holes

Excellent supplies of fresh water are available from bore-holes situated at Kubi Turkana ("Kula Mawe") and near the Garba Tula turn-off, both beside the Isiolo-Wajir road.

At Kubi Turkana (C. 2324) water was struck at 134 ft. below the surface, at the contact between a bed of greyish clay and underlying decomposed biotite schists of the Basement System. The clay is overlain by 117 ft. of lava, and the water rest level coincides with the lava base. In the bore-hole near Garba Tula (S.A. 10) water was struck 45 ft. from the surface, in a bed of limestone overlying Basement gneisses. The water rest level was reported to be at 41 ft. (some 36 ft. above the limestone-gneiss contact).

Records exist of four other bore-holes in the area, all being situated near the two mentioned above. These abandoned sites have been plotted on the geological map from the best information available. C. 136, at mile 45 on the Isiolo-Garba Tula road, represents two holes that failed to pierce the lava cover; the first was drilled to 82 ft. and the second to 140 ft., no water being struck. A mile and a half to the east (S.A. 66) water was encountered at 194 ft. from the surface, the rest level rising to 160 ft. The lava-Basement System contact was said to lie at only 20 ft. at this locality. The remaining two bore-holes (S.A. 18 and S.A. 32) were drilled near S.A. 10 in the Garba Tula district, the lithology and the position of the water-table being similar to that reported above for S.A. 10.

The underground water supplies proved by these bore-holes undoubtedly represent sub-surface drainage from the high rainfall areas of the Nyambeni range.

Wells

Numerous shallow wells have been dug by the local tribesmen both north and south of the Uaso Ng'iro. The majority are situated in large seasonal sandy *luggas*, water being retained by clay beds or by natural rock bars. An interesting permanent well at Boji, near the Isiolo-Wajir road, deserves individual mention, being sited in calcareous sediments that apparently underlie the main lava flows (*see* page 35); the well is about 15 ft deep.

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