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MINISTRY OF NATURAL RESOURCES
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE GARBA TULA AREA

DEGREE SHEET 37, N.E. QUARTER
(With coloured geological map)

by

F. J. MATHESON, B.Sc., Ph.D., F.G.S.
Geologist

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MAP

Geological map of the Garba Tula area (Degree sheet 37, N.E. quarter); (Scale 1:125,000)	at end.
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ABSTRACT

This report describes an area of approximately 1,300 square miles in central Kenya. The area of the coloured geological map is bounded by latitudes $0^{\circ}30'N$ and $1^{\circ}00'N$ and longitudes $38^{\circ}30'E$ and $39^{\circ}00'E$, but the text and text figures extend the coverage to include the eastern part of the Merti Plateau.

The area is essentially composed of a flat plain, although the true end-Tertiary peneplain is recognized only on watersheds in the south.

The rocks in the west are gneisses and limestones of the Basement System, which was folded and metamorphosed, but in the eastern part sediments are developed. The oldest of these are sandstones, believed to be of Jurassic age, but the great majority are grits deposited during the Upper Pliocene. On the Merti Plateau the grits are capped by Tertiary lavas, and dykes related to these lavas cut the Basement System rocks. Faulting is of only minor importance.

An account is given of the petrography, stratigraphy, correlation and structures of the various rocks, and their economic prospects are assessed.

GEOLOGY OF THE GARBA TULA AREA

I—INTRODUCTION

General.—The area described in this report is the north-eastern quarter of Degree Sheet 37 (Kenya) which corresponds to the Directorate of Overseas Surveys Sheet No. 96. It is bounded by latitudes $0^{\circ}30'N$ and $1^{\circ}00'N$, and longitudes $38^{\circ}30'E$ and $39^{\circ}00'E$ covering an area of approximately 1,200 square miles. In addition the survey was extended into the south-east quarter of Degree Sheet 29 (Directorate of Overseas Surveys Sheet No. 87) to cover the eastern part of the Merti Plateau, which lies immediately to the north of the western part of the Garba Tula area (see Fig. 1).

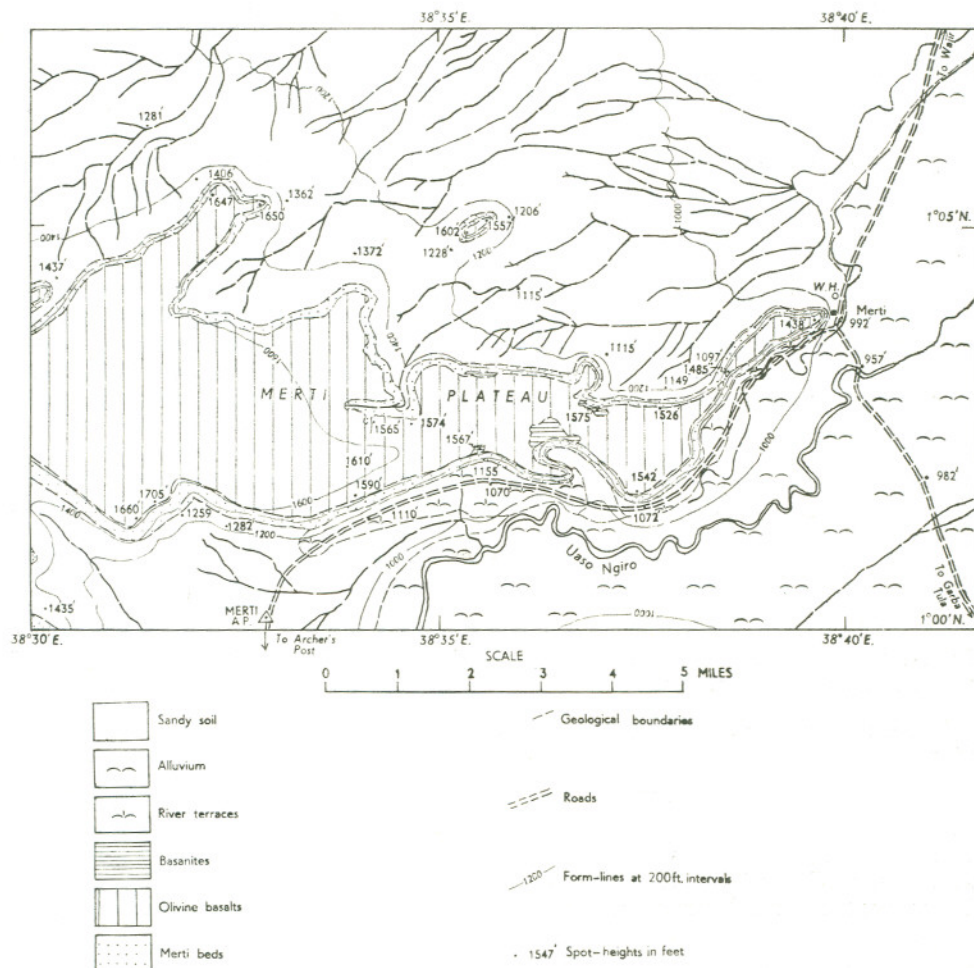


Fig. 1—Geological map of the eastern part of the Merti Plateau

The majority of the area falls within the Isiolo District of Eastern Province administered by the District Commissioner, Isiolo, who maintains an office and a rest-house at Garba Tula where the chief of the Boran is stationed. The extreme south-east, below the Galana Gof River, falls in the Garissa District of North-Eastern Province.

Maps.—At the time of survey the only topographical map of the area was the 1:500,000 Garba Tula, E.A.F. No. 1705, which is on too large a scale for geological mapping. Accordingly geological data were plotted on an air photo mosaic supplied by the Directorate of Overseas Surveys, which was controlled by the author by Kodatrace strips prepared from the individual photographs. Over most of the area these photographs were taken at a scale of approximately 1:30,000 by No. 82 Squadron of the Royal Air Force in 1952, but the eastern fifth of the area was covered by 1:80,000 photographs, belonging to the V13A series, taken in 1957. A small gap in the 1:30,000 cover between Garba Tula and Benane was filled by 1:50,000 photographs taken by Spartan Air Services in 1957. The strips were controlled from the neighbouring 1:100,000 sheets of series Y633, which are Merti, No. 82, to the north and Muddo Gashi, No. 97, to the east. The four trigonometrical beacons within the area were used for further fixes, supplemented by Williams' plane-table points along the western boundary (Williams 1966)*. The low relief of the area precluded the resection of many new points by plane-table. Topographical detail is based on barometric spot-heights corrected for diurnal variations and standardized to existing values for trigonometrical beacons. Few place names were recorded since the Boran tend to use one name for a whole tract of country.

Geological mapping was based largely on river sections where exposures are often patchy, so bands have been linked across divides with little exposure. As a result soils are more widespread than shown on the geological map, where they are indicated only when there is no evidence as to the underlying solid rock.

Communications.—The main road from Isiolo to Wajir, which runs from east to west across the southern part of the area, is of earth and well maintained, but is closed to traffic during heavy rains. Garba Tula, to the south of the main road, is connected to it by two secondary roads, and other roads lead from Garba Tula to Kinna, Melka Lorni and Garissa. The Garissa road is also linked to the main road by a road running northwards from Benane, about ten miles east of Garba Tula. The new road to Merti branches from the main road about five miles north-east of Garba Tula and is in good condition because it runs along watersheds. The old Merti road, which leaves the main road north of Garba Tula, runs straight across country crossing many rivers, and is generally in poor condition, but was made passable to a Land-Rover during the survey. North of the Uaso Ngiro the road from Archer's Post to Merti runs between the Merti Plateau and the river, and has many gullies and wash-outs.

Cattle tracks and tracks cut by the Desert Locust Survey are often passable to a Land-Rover, while the larger sand rivers can be negotiated by the same vehicle and the whole of the eastern part of the area is motorable.

There are two airstrips, one at Garba Tula and the other about ten miles west of Merti.

Climate and Vegetation.—The climate is hot and arid with two periods of rainfall, during April and May and between October and December. Rainfall statistics have been kept at irregular intervals at Garba Tula, Merti, and Muddo Gashi, 48 miles east-north-east of Garba Tula. These statistics, recorded by the East African Meteorological Department, cover different years for the various stations, so no direct comparison can be made, but average annual rainfall is in the order of 14 in. (360mm.) at Garba Tula, 11.5 in. (290mm.) at Merti and 7.5 in. (190mm.) at Muddo Gashi. The rainfall recorded at Garba Tula is probably representative of the undulating western part of the area, whereas the figure for Muddo Gashi, although taken farther east, is likely to be typical of the lower, flatter, eastern plains. The relatively high precipitation at Merti is thought to be a local effect caused by the Merti Plateau.

*References are quoted on p. 29.

In the west the vegetation is characterized by stunted thorn trees, while the eastern plains are covered by grass with some small thorn trees. Along rivers the trees are larger and doum palms are common, especially towards the north-east.

Population and Fauna.—The area is populated entirely by the Boran tribe who are semi-nomadic, but inclined to settle near good water supplies. They depend on their animals for food and are well known for their good management of cattle. Sheep, goats and donkeys are numerous and camels are used for transport.

Elephants are numerous along the Uaso Ngiro at certain seasons and their tracks were occasionally found in other places. Reticulated giraffe, Grevy's zebra, oryx, dik-dik and Grant's gazelle, all of which are common, are typical of an arid environment. Of the predators, lion live near the Uaso Ngiro, while leopard and hyena often live near rocky outcrops. Many species of birds were seen.

Acknowledgements.—Sincere thanks are expressed to the District Commissioner, Isiolo, who gave permission to use his rest-house at Garba Tula for much of the survey.

II—PREVIOUS GEOLOGICAL WORK

Many early travellers passed along the Uaso Ngiro River in an endeavour to find its termination, but references to other parts of the area are few.

After his discovery of Chanler's Falls in 1892–93 W. A. Chanler, accompanied by Lt. Von Höhnel, followed the course of the Uaso Ngiro eastwards. In his account of their journey, which was illustrated by a map by Von Höhnel, Chanler (1893) noted that near the Merti Plateau (referred to as the Marisi El Lugwa Zambo Plateau), the river bed changes from gneiss to alluvium. He thought that Merti was purely volcanic in origin and noted that it rose 500 feet above the plain.

The next mention of Merti was by Count Wickenburg (1903, p. 198) who, during his journey from Djibouti to Lamu, passed to the north of the plateau and noted that it was capped by lava; he referred to it as the Siria Plateau.

When W. H. Brown (1906) visited the Lorian Swamp in 1904 to confirm the belief that no effluent exists, he passed along the Uaso Ngiro in both directions. He calculated the gradient of the river from near the hill of Kubi Kalo in the Chanler's Falls area (to the west of the present area) to the Lorian Swamp to be 1 in 666. He referred to Merti as the Erimba Plateau.

During 1912–13, I. N. Dracopoli travelled along the Uaso Ngiro when journeying from Kismayu. The "Marti" Plateau was examined and was said (Dracopoli, 1913, p. 137) to be of volcanic origin, rising 603 feet above the surrounding country, with an altitude of 1,607 feet at the eastern end.

The first comprehensive account of the geology of the area was included by J. Parkinson (1920) in his report on the geology and geography of the northern part of the East African Protectorate, which was based on surveys made during 1914–15. He divided the country into two natural subdivisions—(1) the Northern Frontier District composed of ancient crystalline rocks partly covered by lavas, and (2) the alluvial plain of Northern Jubaland commencing at the Merti Plateau. Hence the present area lies just south of his boundary between the two divisions. The Merti Plateau was said (*ibid.*, p. 11) to be composed of gneiss capped by lava, but beds of old alluvium, containing well-rounded quartz pebbles, were noted on its flanks. Parts of the cliffs at the eastern end of the plateau were thought to resemble stacks detached from the main mass by marine erosion, and Parkinson concluded that the sea had reached Merti since or at the time of the lava extrusion, and that the alluvial plain of Jubaland was the raised

sea floor. In a later paper on the volcanic history of South and East Africa, Parkinson (1922, p. 102) correlated the Merti lavas with those of the Dido Gullgullo to the north, which he thought might be included with the flows of the Kapiti Plains near Nairobi but were older than Marsabit volcano.

A further paper by Parkinson (1939) gives more information about Merti, which he found to be composed of sands which are arkosic in places. Erosion of the lava cap, some 8 to 10 feet in thickness, resulted in the presence of numerous blocks of lava on the slopes of the cliff. He recognized that the featureless plain of grey silt extended southwards from the Uaso Ngiri and that the Galana Gof was probably once a tributary of the Uaso Ngiri or perhaps flowed directly into the lake on the site of the Lorian Swamp. He concluded that the whole country had undergone considerable desiccation since the reports of the earlier explorers, describing it (*ibid*, p. 164) as "an arid waste, swept by constant dust storms and dotted only with a few gnarled and struggling trees".

During the Second World War unpublished military geological reports of several parts of Kenya were prepared with special regard to water supplies. Lt. H. D. Roberts (1941) traversed the old road from Merti to Garba Tula, giving the extent of the Uaso Ngiri flood plain as 16 miles from Merti before gneiss outcrops. He also noticed the area of black cotton soil just north of the Isiolo-Wajir road. He regarded the peneplanation as pre-Tertiary in age, with inselbergs standing above the surface. He attributed the production of the sandstones and conglomerates to the peneplanation and thought they were preserved by lava cappings on plateaux such as Merti, with the gravel and sand on the plains being erosional products of the sediments. Roberts classified the rock types as (1) Ancient rocks, recognizing several varieties of both orthogneisses and para-gneisses but not crystalline limestones, (2) pre-volcanic sediments-Merti Beds, (3) volcanics, placing the Merti flows in the later Pleistocene. He noted that the foliation of the gneisses generally strikes north-south, with steep dips to east or west. A fuller account was given of Merti in which it was stated that gneisses form part of the western end of the plateau but none can be seen in the east. Loosely consolidated sediments found at the foot of the scarp below the gneiss outcrop were believed to have been formed by *in situ* weathering of the Merti Beds.

Connected with the military geological reconnaissances was a hydrographical survey carried out over the entire Northern Province in 1943 by F. Dixey (1948). The sediments and physiography were his main concerns, with little attention being paid to the Basement System. On his map (Fig. 1 facing p. 18) he showed the entire Garba Tula area as being end-Tertiary in age, with a remnant of the sub-Miocene bevel preserved under the Merti lava. He described (pp. 14-15) the plateau as being built of Tertiary friable pebbly sandstones, over 400 feet thick at the eastern end where the base is not exposed, capped by a sheet of olivine basalt. The basalt was said to be 20 to 50 feet thick, with the top of the flow having an elevation of 1,450 feet at the eastern end of the plateau where the base is at about 1,000 feet. He suggested that the lava is conformable with the sediments because a thin sprinkling of pebbles resting on the basalt are similar to those found in the lower sediments. Dixey believed that a correlation might be made between the Merti Beds and the Miocene Turkana Grits of north-western Kenya, with the base of the sediments being exposed by post-Miocene dissection, especially during the Pliocene. He considered that the sub-Miocene bevel passes below the mid-Tertiary at the eastern end of the Merti but is above the Pliocene (end-Tertiary) peneplain. The Uaso Ngiri was thought to have considerably deepened and widened its valley during post-Tertiary sub-cycles of erosion.

In a report on the Northern Frontier Province and Samburu Water Development Scheme, Howard Humphries and Sons (1958, pp. 6-7 and p. 32) commented briefly on the geology, mentioning the Basement System, the sediments and the volcanic capping of Merti Plateau.

The area to the west of the Garba-Tula area was mapped by Williams (1966) and that to the south by Wright (awaiting publication).

III—PHYSIOGRAPHY

The area can be divided into four physiographical units as shown in Fig. 2.

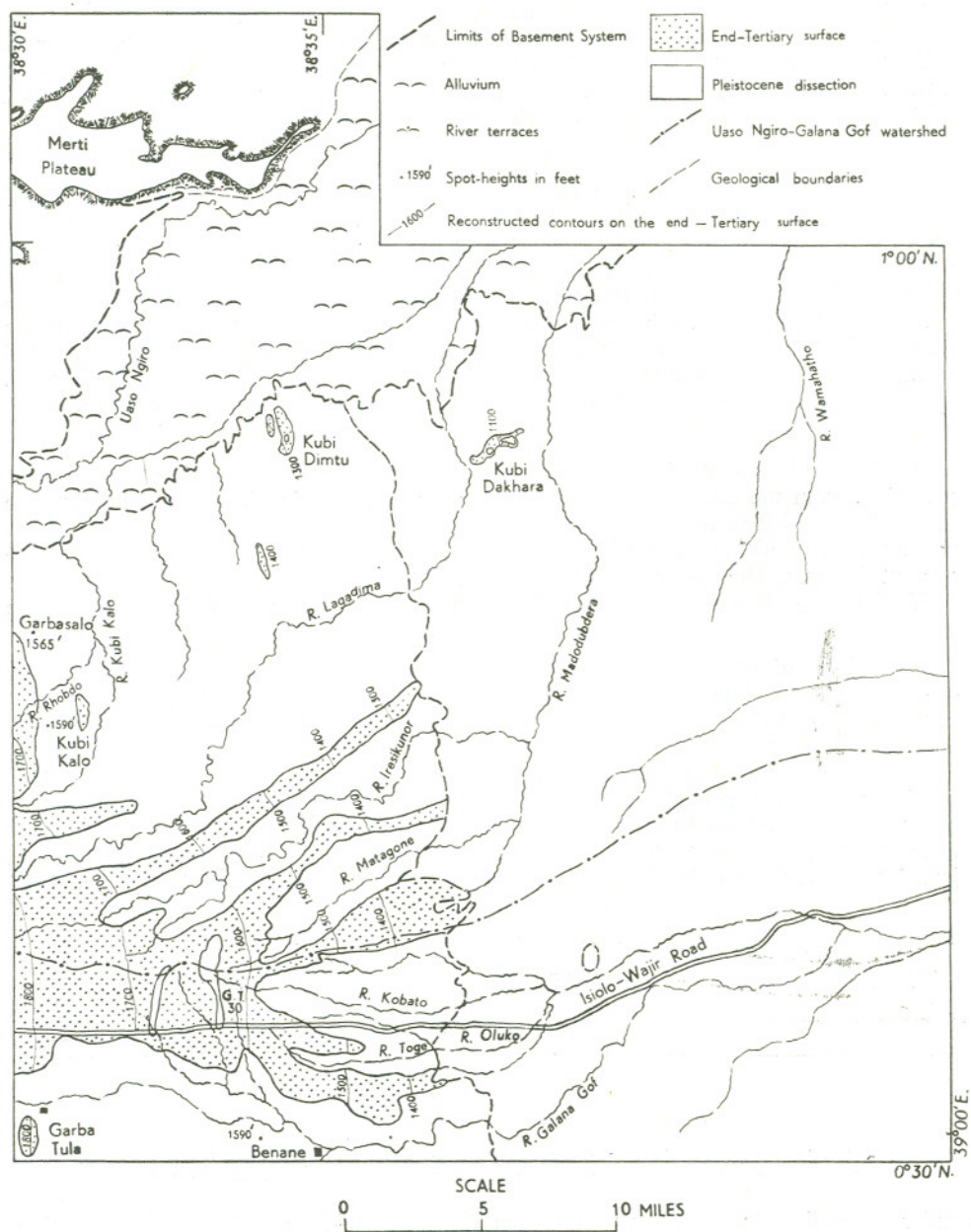


Fig. 2—Physiography and erosion surfaces, Garba Tula area

1. The undulating country in the west and south-west.
2. The eastern plains.
3. The Merti Plateau.
4. The Uaso Ngiro Valley.

The undulating country in the west and south-west is underlain by rocks of the Basement System, in which more resistant bands form low ridges. The eastern plains on the other hand are composed of sediments with a thick soil cover, and erosion has caused little relief. The Merti Plateau, although composed of sediments, has resisted erosion because of its capping of basalt. The Uaso Ngiro Valley is characterized by a wide belt of alluvium cut by many small tributaries and distributaries.

Drainage.—The drainage pattern of the area is dominated by the Uaso Ngiro River, which often flows when all other rivers are dry, due to high rainfall at its headwaters in the Aberdare Range and Mount Kenya. It has reached the stage of early maturity, for although flowing quickly, its course meanders through a wide belt of its own alluvium. When tributary streams reach the alluvium they often flow along its edge instead of cutting directly to the main river. The flow diminishes east of Merti, because of evaporation, before terminating in the Lorian Swamp. All the other rivers are part of the Uaso Ngiro drainage system, but the Galana Gof and its tributaries are separated from the Uaso Ngiro basin by a watershed along or to the north of the Isiolo-Wajir road. They too, flow into the Lorian Swamp, and can be considered to belong to the Uaso Ngiro system.

Erosion surfaces.—Williams (1966, p. 5) recognized remnants of the sub-Miocene peneplain from the accordance of summit heights of non-volcanic hills, including some under the Merti Plateau. These heights give a gradient of 36 feet per mile down to the east-north-east which, when projected into the Garba Tula area, passes above any of the present features. The eastern part of the Merti Plateau consists of sediments, with no residual hills of Basement System rocks, so no height for the sub-Miocene bevel can be given.

The heights of watersheds on the Basement System in the west and south-west are co-planar with a slope down to the east-north-east at 26 feet per mile. This bevel is correlated with the end-Tertiary peneplain which is widely developed in eastern Kenya. The tors and ridges of granitoid gneiss on the watersheds, such as trigonometrical point G.T. 30, seven miles east-north-east of Garba Tula, are thought to represent residuals on the end-Tertiary peneplain. It is believed that the tops of the crystalline limestones of Kubi Dimtu and the Jurassic sandstones of Kubi Dakhara also formed residuals, but their lower ridges agree with the height of the projected end-Tertiary bevel. When projected eastwards from the Basement System as shown in Fig. 3 the peneplain passes

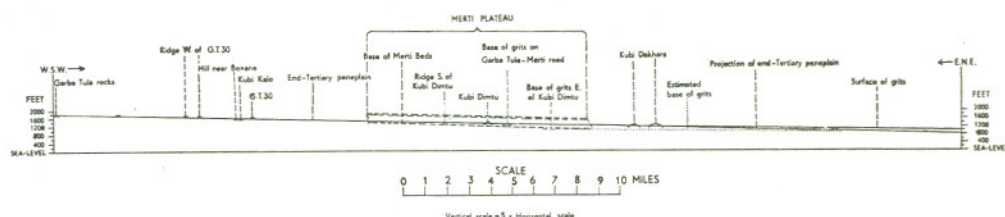


Fig. 3—Projection of minor summits and sediments to demonstrate erosion surfaces in the Garba Tula area

under the sediments, so it is probable that they were laid on a dissected end-Tertiary surface. Towards the Uaso Ngiro the amount of dissection of the end-Tertiary peneplain before the deposition of the sediments is seen to be over 100 feet, but farther south

it is slight and the present watersheds approximate to the bevel. The present flat surface of the sediments appears to be due to their uniform nature and fairly even thickness, which is controlled by their base on the end-Tertiary peneplain. The Uaso Ngiri has cut through the sediments to a level below the end-Tertiary surface since its maturation, but the base of the sediments is hidden by alluvium.

Pulfrey (1960, map at end) shows the morvan of the sub-Miocene and end-Tertiary peneplains passing through Muddo Gashi, about 20 miles farther east, so the separation of the two bevels is not great near the eastern boundary of the area.

IV—SUMMARY OF GEOLOGY

The rocks of the Basement System can be divided into two lithological groups. In the west they are characterized by numerous migmatites and granitoid gneisses with a strong development of garnet but towards the east, numerous bands of crystalline limestone make their appearance. Granitoid gneisses also occur to a small extent in the east where biotite gneisses are common, but hornblende and biotite-hornblende gneisses are typical of the western outcrops. All these rock types, with the exception of the granitoid gneisses, reveal a sedimentary origin, and even in the migmatites the introduction of granitic material has not obscured the metasedimentary character of the host rocks. The granitoid gneisses are thought to be of palaeogenetic origin and formed during the same period of granitization. The two subdivisions in the Basement System can be recognized in many parts of Kenya, where the upper calcareous sequence is referred to as the Turoka Series (Parkinson, 1913). The lower group, consisting of hornblende gneisses, migmatites and granitoid gneisses, is generally considered to be the older (e.g. Joubert, 1957, pp. 30-31), and their outcrop in the western part of the present area, where the dip tends to be easterly, supports this view. Poor exposure prevents any accuracy in estimating the thickness of the Basement System in the present area, but the lower group is thought to be about 30,000 feet, and the upper calcareous part approximately 10,000 feet.

The boundaries and foliation in the Basement System generally strike north-south, the typical trend in the Mozambique belt to which they belong. The foliation, although mechanical in origin, parallels the lithological boundaries and hence the original sedimentary bedding planes. Major and minor structures, also trending north-south, were produced during orogenic folding, which was accompanied by regional metamorphism. Recrystallization was the main process in metamorphism, but granitization was widespread, especially towards the west.

After a long period of uplift and erosion there was a marine incursion in the early Jurassic which led to the deposition of sandstones. This incursion is probably the one responsible for the occurrence of Mesozoic sediments in north-eastern Kenya and the Coast Province, but Mesozoic rocks in the intervening ground are largely covered by later deposits. These rocks are well-compacted fine grained sandstones, which outcrop in the north of the area at Kubi Dakhara and the unnamed hill north of it. There are gentle anticlinal folds which carry them underneath the surrounding Upper Pliocene grits. They are similar in character to the Mansa Guda formation of north-eastern Kenya and the Duruma Sandstones of the coast, but are referred to the Jurassic rather than the Trias, because the only pointer as to their age is an outcrop of fossiliferous Jurassic limestone mapped by Dodson (Report No. 93) in the north-western corner of the Barchuma-Kom area, approximately 40 miles west-north-west of Kubi Dakhara, which is associated with identical sandstones.

A further period of uplift and erosion probably culminated in the maturation of the sub-Miocene peneplain, but a subsequent cycle of erosion removed all traces of that bevel in the Garba Tula area, although it is preserved in adjoining areas. During these periods of erosion the Jurassic rocks were largely removed and the later cycle resulted in the maturation of the end-Tertiary bevel, which formed the surface on which the Upper Pliocene sediments were deposited.

Grits and conglomerates with a calcareous matrix form the Merti Plateau, where they attain a thickness of 400 feet under the lava capping. Although unfossiliferous these sediments are placed in the Upper Pliocene since they rest on the end-Tertiary peneplain, which reached maturity in the middle of the Pliocene.

The chief outcrop of volcanic rocks is the capping of olivine basalt lava on the Merti Plateau, which is about 50 feet thick at its maximum. It is overlain locally by a basanite which forms small crags. Both flows are referred to the Pliocene because the lower one must have quickly followed the deposition of the Merti Beds to have prevented erosion of the friable grits. The upper basanite is thought to be part of the same episode of volcanicity, but may possibly belong to the Pleistocene activity centred on the Nyambeni range in the area to the south-west of the present map (Rix, 1967).

The dykes cutting the Basement System, apart from one lamprophyre, are composed of olivine basalt similar to that of the main flow on Merti.

Clays overlain by secondary (kunkar) limestone along the Galana Gof near Benane are tentatively placed in the Pleistocene. They formed in a small lake, dammed by a ridge of granitoid gneiss, which can be seen to have been recently breached by renewed down-cutting.

The red soils over the deeply weathered metamorphic rocks attain a considerable thickness in places, as shown by deep sections in some of the sand rivers. Brownish and black cotton soils are confined to areas of poor drainage. The grey sandy soils of the eastern plains are similar to black cotton soils with an admixture of sandy material, and west of El Dera Hill there is a large area of true black cotton soil. Kunkar limestone is in many places developed along rivers flowing over calcareous rocks in the Basement System. Sandy alluvium occurs along the larger river courses.

V—DETAILS OF GEOLOGY

1. Basement System

For descriptive purposes the rocks of the Basement System in the Garba Tula area are classified in the following groups:—

- (1) Metamorphosed calcareous sediments
 - (a) Crystalline limestones.
 - (b) Calc-silicate gneisses.
- (2) Metamorphosed semi-pelitic sediments
 - (a) Hornblende gneisses
 - (b) Biotite-hornblende gneisses
 - (c) Biotite gneisses
 - (d) Biotite-garnet gneisses
- (3) Metamorphosed psammitic sediments
 - (a) Quartz-felspar gneisses
 - (b) Quartzites
- (4) Migmatites
- (5) Anatectic or palingenetic rocks
 - (a) Granitoid gneisses
 - (b) Pegmatites
 - (c) Giant white quartz veins

(6) Metamorphosed intrusive rocks

(a) Plagioclase amphibolites

(b) Amphibolites

(1) METAMORPHOSED CALCAREOUS SEDIMENTS

(a) *Crystalline Limestones*

Massive white crystalline limestones are best developed at Kubi Dimtu in the northern part of the area, but also form thin bands to the south and west. The majority of the thinner outcrops however, are pink in colour and outcrop only east of a line running approximately north-north-east from Benane. The pink limestones are often sheathed by calc-silicate gneisses, some of which are similar to the amphibolites of presumed igneous origin. Limestone horizons can often be traced across divides when other rocks are masked by soil and can be seen only in the river valleys. The limestones are 300 feet in thickness at Kubi Dimtu, where they stand 300 feet above the surrounding plains. Southwards from Kubi Dimtu the limestones thin to 200 feet but still build a low ridge. The other horizons mapped are much thinner, rarely attaining a thickness of 20 feet except at fold closures. Layering in individual limestones usually consists of alternating layers of varying shades of one colour rather than different colours, but may also be produced by variations in the degree of crystallinity or by bands of graphite or calc-silicates. These internal layers, which vary in thickness from a fraction of an inch to several feet, are parallel to the boundaries and the foliation within the surrounding gneisses.

In thin section the great majority of the limestones contain diopside, but specimens 37/659* and 37/720, from south of the river Matagone and north of the Kobato River respectively, are pyroxene-free. Both are formed of a mosaic in which calcite grains are more abundant than those of dolomite, and rounded quartz, feldspar and chlorite are accessory.

Diopside is more common in the white limestones of Kubi Dimtu where it is often chloritized, than in the pink limestones. In specimen 37/756 from the north end of Kubi Dimtu there are thick white bands alternating with thinner cream ones. Under the microscope the white layers are seen to be a pure calcite mosaic, while the cream ones contain in addition to calcite many rounded grains of chloritized diopside. Quartz, feldspar and magnetite accompany the diopside as accessories. In 37/763, from the low ridge extending southwards from Kubi Dimtu, chloritized diopside grains are scattered irregularly through the calcite mosaic, in which a little dolomite is also present.

The pink limestones, such as 37/646 from the Oluko River and 37/719 from north of the Kobato River, are predominantly composed of a calcite mosaic with subsidiary dolomite. In 37/646 diopside, which is chloritized along cracks, forms knots and lenses, and the crystals contain accessory quartz and sphene, but in 37/719 the diopside is scattered throughout the carbonate mosaic. The calcite twin-planes are locally bent in 37/646. Specimens 37/653 and 37/707 from the Matagone River and south of the Lagadima River respectively, are similar in general appearance, but much of the diopside is bright green in colour, and sphene is abundant as an accessory.

An unusual limestone from east of Kubi Kalo is represented by 37/697, which is a medium-grained, pink rock with numerous flakes of brown mica, determined as phlogopite in thin section.

(b) *Calc-silicate gneisses*

These rocks are often associated with the limestones, to which they sometimes form sheaths, but also form separate bands. Their close relationship with the limestones is shown by a limestone horizon outcropping in the rivers Matagone and Kaboto, which

*Numbers 37/659, etc., refer to specimens in the regional collection of the Geological Survey, Nairobi.

is represented by a calc-silicate band in an intervening river. Except for one band on the rivers Iresikunor and Lagadima, their outcrops are small, and are usually lensoid. They are compact, fine-grained rocks which are dark green in colour and have only faint foliation.

Petrologically the calc-silicate gneisses can be divided into two groups, the calc-silicate gneisses proper and amphibolites of sedimentary origin. Examples of the first group are specimens 37/624 and 37/699 from the Galana Gof and south-east of Garbasalo respectively, both of which have a speckled appearance. In thin section diopside is the most abundant mafic mineral seen and is associated with greenish hornblende which is often enclosed by the pyroxene. In 37/624 the leucocratic minerals are quartz and altered felspar (probably oligoclase) with some calcite, but calcite predominates in 37/699. Sphene, magnetite and apatite are accessory, the sphene sometimes forming quite large crystals. A migmatized calc-silicate gneiss is represented by 37/744, from the north bank of the Uaso Ngiro, in which microcline is the only felspar, while quartz forms only a few small crystals. Hornblende is more abundant than diopside and epidote is accessory.

The amphibolites of sedimentary origin are included with the calc-silicate gneisses because they contain calcite and are associated with limestones. A typical example is 37/634, from north of Benane, which has the pepper-and-salt texture characteristic of plagioclase amphibolites. Under the microscope the dominant mineral is seen to be hornblende, which is pleochroic from light to dark green. Some calcite is associated with the plagioclase, which was determined as andesine, and both are often interstitial to hornblende. Magnetite, sphene and apatite are accessory and chlorite secondary.

Estimated volumetric modes of these rocks are as follows:—

					<i>Percentages</i>			
					37/624	37/699	37/744	37/634
Diopside	..	..	..	..	30	43	12	10
Hornblende	..	..	..	..	10	12	27	44
Plagioclase	..	..	..	..	18	—	—	31
Microcline	..	..	..	..	—	—	48	—
Quartz	..	..	..	..	23	5	10	—
Calcite	..	..	..	..	14	35	—	10
Sphene	..	..	..	..	3	4	2	1
Magnetite	..	..	..	..	1	—	—	2
Apatite	..	..	..	..	1	1	1	1

37/624 Calc-silicate gneiss, Galana Gof.

37/699 Calc-silicate gneiss, south-east of Garbasalo.

37/744 Felspathized calc-silicate gneiss, north bank of the Uaso Ngiro.

37/634 Plagioclase amphibolite, north of Benane.

(2) METAMORPHOSED SEMI-PELITIC SEDIMENTS

(a) Hornblende gneisses

Hornblende gneisses are best developed in the west of the area where they are associated with numerous granitoid gneisses, but are not so common as the hornblende-biotite gneisses. They are fine-grained, dark rocks with more pronounced foliation than the calc-silicate gneisses, due to the presence of leucocratic bands. They can be divided into two main groups on the presence or absence of diopside, and garnetiferous varieties are included since they outcrop in small lenses included in larger bands of hornblende gneiss. Hornblende is the only mafic mineral in 37/616 from south of the Iresikunor River and

37/651 from north of the Kobato River, the latter from a thin band enclosed by biotite gneisses. The hornblende is subordinate to the leucocratic minerals, of which oligoclase is the most abundant, with subsidiary quartz and orthoclase. Magnetite, epidote and apatite are accessory.

When diopside is present, as in specimen 37/696 from east of Garbasalo and 37/745 from the north bank of the Uaso Ngiri, it is less common than hornblende and often forms cores in the amphibole. The proportion of ferromagnesian minerals is greater than in the diopside-free hornblende gneisses but the leucocratic constituents are the same. Sphene makes its appearance as an accessory. The introduction of garnet in specimens 37/628 from the Galana Gof and 37/698 from east of Kubi Kalo makes no difference to the general mineralogy. The garnets, occurring in the hornblende layers, are small, and although they contain numerous quartz inclusions they show no sign of rotation. Some estimated volumetric modes of the hornblende gneisses are given below:

			<i>Percentages</i>					
			37/616	37/651	37/696	37/745	37/628	37/698
Hornblende	..	..	25	20	43	34	40	34
Diopside	..	..	—	—	12	17	—	8
Garnet	..	..	—	—	—	—	6	10
Quartz	..	..	18	20	10	9	13	12
Orthoclase	..	..	12	11	7	8	7	10
Plagioclase	..	..	40	44	25	26	30	22
Magnetite	..	..	2	2	2	2	2	3
Sphene	..	..	—	—	—	3	—	—
Epidote	..	..	2	2	—	—	1	—
Apatite	..	..	1	1	1	1	1	1

37/616 Hornblende gneiss, south of the Iresikunor River.

37/651 Hornblende gneiss, north of the Kobato River.

37/696 Hornblende-diopside gneiss, east of Garbasalo.

37/745 Hornblende-diopside gneiss, north bank of the Uaso Ngiri.

37/628 Hornblende-garnet gneiss, Galana Gof.

37/698 Hornblende-garnet gneiss, east of Kubi Kalo.

(b) *Biotite-hornblende gneisses*

This group forms much of the western part of the Basement System, and some bands outcrop in the calcareous sequence farther east. The rocks are fine or medium-grained and dark in colour, and have a better foliation than the hornblende gneisses because the biotite emphasizes the dark bands.

The petrology of the biotite-hornblende gneisses is similar to that of the hornblende gneisses except that biotite replaces some of the hornblende. The proportion of biotite is about equal to that of hornblende in typical specimens, such as 37/607 from the Galana Gof and 37/709 from the Iresikunor River, but in others either mineral may be dominant.

(c) *Biotite gneisses*

These rocks are best developed in the east, where they form most of the country rock between the calcareous members, but they also outcrop in thinner bands towards the west of the area. They are fairly uniformly medium-grained, and their biotite content varies between 5 and 20 per cent. When the proportion of biotite falls below 5 per cent they grade into the quartz-felspar gneisses. Grey is their normal colour, but some are cream, and feldspathization tends to produce a pink shade due to weathering of microcline.

Typical examples are 37/645 from the Toge River and 37/766 from south-west of Kubi Dimtu. In the former the biotite forms bands interlayered with quartz-feldspathic bands, but the biotite of the latter, which is accompanied by some muscovite, is scattered throughout the slide. Oligoclase is the most abundant leucocratic mineral with subsidiary orthoclase and quartz. Magnetite, epidote and zircon are accessory. In 37/645 there are later feldspathic bands almost entirely composed of microcline, but in specimens 37/710 and 37/717, from the rivers Iresikunor and Matagone respectively, feldspathization has proceeded further. The former is pink in colour and the latter cream, and in both biotite occurs as scattered flakes rather than in distinct bands. Microcline is the dominant feldspar, with a little oligoclase, and some orthoclase remains in 37/717, in which quartz is subsidiary. In 37/710 however, rounded quartz is more abundant than oligoclase and is set within the microcline. Accessories are similar to those of the non-feldspathized biotite gneisses.

Estimated modes of biotite gneisses are as follows:—

					Percentages			
					37/645	37/766	37/710	37/717
Quartz	..	..	..	..	19	15	17	8
Orthoclase	..	..	..	..	12	7	—	5
Plagioclase	..	..	..	..	25	44	12	25
Microcline	..	..	..	..	28	18	60	50
Biotite	..	..	..	..	12	10	8	7
Muscovite	..	..	..	..	—	2	—	—
Magnetite	..	..	..	..	2	3	2	3
Epidote	..	..	..	..	1	—	—	2
Apatite	..	..	..	..	1	1	1	—

37/645 Toge River.

37/766 South-west of Kubi Dimtu.

37/710 Iresikunor River.

37/717 Matagone River.

(d) Biotite-garnet gneisses

Biotite-garnet gneisses outcrop in abundance along the Lagadima River and on the eastern bank of the Kubi Kalo River and small bands and lenses are found in other parts of the area. In addition they form part of the host rocks in the migmatite zone around Kubi Kalo and Garbasalo.

They are distinctive medium-grained grey rocks with many small garnets associated with biotite flakes, which impart a good foliation. Biotite is more abundant than in the biotite gneisses, and thin sections of 37/676 from south of Kubi Kalo and 37/743 from the north bank of the Uaso Ngiro show that the garnets are confined to the micaceous layers. The garnets, which may be slightly chloritized along cracks, do not deflect the biotite layers and show no signs of rotation. Oligoclase is the chief leucocratic mineral with subsidiary quartz, which is often rounded, but orthoclase is rare. There is a little myrmekite in 37/676 and accessories are magnetite, which is often enclosed in garnets, apatite and zircon.

An unusual variety is represented by specimen 37/682 from the Kubi Kalo River which contains only garnets and leucocratic minerals. It is a fine-grained grey rock with numerous small garnets but lacks foliation. The slide shows many small rounded garnets embayed by oligoclase, which is more abundant than quartz. Magnetite is a frequent accessory and zircon is also present.

Volumetric modes of the above rocks were estimated as follows: —

							<i>Percentages</i>		
							37/676	37/743	37/682
Garnet	..	..	..	..	..	..	18	16	30
Biotite	..	..	..	..	..	..	16	20	—
Quartz	..	..	..	..	..	..	20	15	20
Orthoclase	..	..	..	..	..	..	—	10	—
Plagioclase	..	..	..	..	..	..	43	35	45
Magnetite	..	..	..	..	..	..	2	2	4
Apatite	..	..	..	..	..	..	—	1	—
Zircon	..	..	..	..	..	..	1	1	1

37/676 Biotite-garnet gneiss, south of Kubi Kalo.

37/743 Biotite-garnet gneiss, north bank of the Uaso Ngiro.

37/682 Garnet gneiss, Kubi Kalo River.

(3) METAMORPHOSED PSAMMITIC SEDIMENTS

The rocks in this group are believed to have been derived from arenaceous sediments, the quartzites representing pure sandstones and the quartz-felspar gneisses arkoses. Mica reaches only accessory proportions so quartz-felspar-biotite gneisses are not distinguished from the quartz-felspar gneisses.

(a) Quartz-felspar gneisses

This group outcrops only in thin bands, usually surrounded by biotite gneisses, of which they appear to be a psammitic variety. The rocks are pale coloured, fine or medium in grain, and have a poor foliation because of the paucity of flaky minerals. When present foliation is as often marked by iron ores as by micas, which latter rarely exceed 2 per cent of the rock.

Specimen 37/652 from north of the Matagone River is a white rock with a sugary appearance, and contains some thin layers of mica. No mica occurs in the thin section, which is composed of almost equal proportions of quartz and oligoclase with less abundant microcline; magnetite and zircon are accessory. A pink variety is represented by 37/647 from the Oluko River, which has a foliation given by layers of different minerals. Under the microscope the colour is seen to be due to sericitization of oligoclase along its twin planes. There is some incipient microclinization of the oligoclase but microcline itself is less abundant. Quartz occurs only as small grains enclosed in felspar and there are a few partly chloritized biotite flakes. Magnetite, epidote and zircon are accessory.

More feldspathized types of quartz-felspar gneisses are 37/626 from the Galana Gof and 37/642 from north of Benane. In the latter microcline is nearly as abundant as oligoclase and in the former it equals the plagioclase, which it partly replaces. Small, rounded quartz grains, which are enclosed in felspar, are subsidiary. In both specimens there are a few muscovite flakes and in 37/626 accessory magnetite forms large crystals set in layers: other accessories are apatite and zircon.

Estimated volumetric compositions are as follows:—

					<i>Percentages</i>			
					37/652	37/647	37/626	37/642
Quartz	..	..	..	..	35	25	20	18
Microcline	..	..	..	..	27	17	38	35
Plagioclase	..	..	..	..	36	55	38	42
Mica	..	..	..	..	—	2	2	3
Accessories	..	..	..	..	2	1	2	2

37/652 North of the Matagone River.

37/647 Oluko River.

37/626 Galana Gof.

37/642 North of Benane.

(b) *Quartzites*

Quartzites outcrop only in narrow bands, which are often lensoid, on the northern bank of the Uaso Ngiri and the eastern bank of the Kubi Kalo River. They are frequently dark in colour due to impurities, but 37/683 from east of Kubi Kalo has iron staining only at the margins of clear quartz grains. In thin section quartz forms an interlocking mosaic of fresh grains, but limonitic ores are deposited between the crystals and along cracks. Specimens 37/693 from north-west of Garbasalo and 37/695 from east of Kubi Kalo are both dark because of impurities which are seen under the microscope to consist largely of hæmatite. In addition 37/695 contains some grains of altered felspar which appears to be oligoclase with replacive microcline, while epidote and zircon are accessory.

A garnetiferous variety is represented by 37/752 from the north bank of the Uaso Ngiri, which is somewhat dark in colour and has iron staining along cracks and grain boundaries. Small garnets are arranged along discontinuous bands. The thin section is dominantly composed of quartz grains with strings of elongated lobate garnets and some altered biotite. The garnets often contain inclusions and the iron ores associated with them were identified as hæmatite. Rutile needles and zircon are accessory.

(4) MIGMATITES

The rocks of the region to the west of the Kubi Kalo River were mapped as migmatites with semi-pelitic host rocks since they contain many bands of hornblende, biotite-hornblende and biotite-garnet gneisses. Granitoid gneisses also form an important part of the succession but boundaries between the various types are complicated, with many variations along the strike, so the components of the migmatites were not differentiated.

Two specimens of hornblende gneisses which show degrees of migmatization are 37/686 and 37/672 from west and south of Kubi Kalo respectively. They are similar to normal hornblende gneisses, except that microcline replaces orthoclase, partly in the former and completely in the latter.

Specimen 37/689 from south-west of Garbasalo is a migmatite with bands of acidic material cutting a biotite-garnet gneiss host. It is a fine-grained, well-banded rock in which, under the microscope, biotite and garnet are seen to be associated with oligoclase altered orthoclase and quartz, whereas the leucocratic layers are represented by microcline set in oligoclase and quartz, both largely recrystallized. There are some flakes of muscovite in both components of the rock while magnetite and zircon are accessory.

A migmatite outside the main outcrop is represented by 37/633, from the Galana Gof, which consists of feldspathic nodules in biotite-hornblende gneiss. It is a pink, fine-grained rock with random streaks of quartz and ferromagnesian minerals. The slide is composed of microcline crystals set in altered feldspar, with a few small, rounded crystals of quartz. There are some grains of magnetite and chloritized biotite, while chlorite also fills cracks in the altered feldspar, and apatite is accessory.

(5) ANATECTIC OR PALINGENETIC ROCKS

The great majority of the rocks of this group are granitoid gneisses which are well developed in the west of the area, particularly in the migmatite zone. Other representatives are the pegmatites, and the giant white quartz veins which are associated with them.

(a) *Granitoid gneisses*

In the west these rocks form narrow ridges, standing above the surrounding country, where other rocks are often obscured by thick soil cover. Within the migmatites the granitoid gneisses are often responsible for ridges, even though this region is more broken and rugged than other parts of the area. They range from medium to coarse in grain size and are usually buff in colour, but may be pink when their feldspar is altered. Foliation is usually faint, being often marked by quartzose bands, and it may locally be emphasized by mafic minerals, especially magnetite.

In thin section the granitoid gneisses are characterized by microcline, which in some is only beginning to replace oligoclase, but in others has almost completed the process. Examples of the first type are specimens 37/603 from Garba Tula rocks and 37/613 from the ridge between the Lagadima and Iresikunor rivers. In 37/668 from the Lagadima River and 37/762 from west of Kubi Dimtu the two feldspars are approximately equal in volume, but in 37/610 and 37/703, from survey point G.T.30 and the Lagadima River respectively, microcline predominates. Rounded or lobate grains of quartz are subordinate to either of the feldspars and there are some flakes of biotite, while 37/603 contains a little hornblende. Magnetite is a common accessory and can give foliation; it is especially abundant in 37/613. Other accessories are epidote, apatite and zircon.

(b) *Pegmatites*

The pegmatites are ubiquitous but are most abundant in areas of migmatization and granitization. They usually form lenticular or irregular segregations in granitoid gneisses, but this type is rare in other hosts. Others are conformable to the foliation planes, but the great majority are cross-cutting dyke-like bodies. They are generally between six inches and two feet wide and do not persist over any great distance; micas and other ferromagnesian minerals are extremely rare. Petrologically they can be divided into two varieties on the character of the feldspar, their most abundant constituent. The commoner type is composed almost entirely of pink microcline with some streaks of clear quartz, and examples are 37/655 from south of the Matagone River and 37/761 from north of Kubi Dimtu. In the former microcline is seen under the microscope to be much more abundant than quartz, which it partly replaces, and one grain of sericitized oligoclase is preserved where shielded by quartz. The latter slide is composed almost entirely of microcline, which locally has cores of oligoclase and encloses small rounded grains of quartz and flakes of muscovite. A little magnetite and zircon are the only accessories.

The other type of pegmatite, which also intrudes the host rocks, has oligoclase as its chief feldspar, and is white in colour and tends to be coarser in grain than the microcline pegmatites. There is usually a higher proportion of quartz than in the microcline pegmatites and the quartz fragments are more angular in shape. In specimen 37/662 from the Lagadima River both biotite and muscovite are present but magnetite is lacking, whereas 37/679 from south of Kubi Kalo contains only muscovite and magnetite. Zircon, found in both specimens, is the only other accessory.

(c) *Giant white quartz veins*

A large vein of white quartz outcropping on the ridge east of the Kubi Kalo River runs at right angles to the strike of the foliation, forming a low ridge. It is 4,000 feet long by 500 feet wide and is sheathed by an oligoclase pegmatite only a few inches wide. The vein is formed of massive quartz and in thin section the quartz grains are seen to be dotted with accessory magnetite, epidote and zircon, all of which are rare and small in size.

(6) METAMORPHOSED INTRUSIVE ROCKS

The only metamorphic rocks which are thought to be derived from igneous rocks are the amphibolites and plagioclase amphibolites. Some of them may possibly have been transformed from calcareous sediments as is the case with amphibolites already described under the section on calc-silicate gneisses. The amphibolites are regarded as being local variants of the plagioclase amphibolites. The change from one to the other often occurs along the strike of one horizon, and can sometimes be seen in a single small exposure.

(a) *Plagioclase amphibolites*

These rocks outcrop in narrow bands which, while not persisting for long distances, are found in all parts of the Basement System. They are dark in colour and range in grain size from fine to medium. A pepper-and-salt texture is often displayed, with a foliation given by mineral orientation, but some have a stronger foliation produced by mineral layering.

In typical specimens, such as 37/665 from the Lagadima River and 37/753 from the north bank of the Uaso Ngiro, pleochroic hornblende, which is brown or green in colour, is slightly more abundant than feldspar. Relics of diopside are preserved within hornblende in 37/753 but most specimens do not contain it. The feldspar is usually andesine, but sometimes it is sodic labradorite. Magnetite and apatite are the usual accessories while epidote and sphene are less frequent.

Garnet-plagioclase amphibolites are rare even where there is a good development of garnet in the surrounding gneisses. Specimen 37/629, collected from the river south of the road between Garba Tula and Benane, is a fine-grained dark rock with hornblende more abundant than plagioclase and a few small garnets. A faint foliation is imparted by mineral orientation. Under the microscope the hornblende is seen to be brown with only slight pleochroism. Garnets are rare and small. The plagioclase, which is often untwinned, was determined as andesine, while magnetite, epidote and apatite are accessory.

(b) *Amphibolites*

Amphibolites with only relatively minor amounts of feldspar appear more frequently on the north bank of the Uaso Ngiro than elsewhere, and 37/750 comes from that locality. It is a dark, fine-grained rock, with a foliation imparted by mineral orientation. The plagioclase was determined as andesine. The predominant green hornblende is accompanied by bright green pleonaste spinel and encloses some grains of diopside, while apatite is accessory.

Estimated volumetric modes of the metamorphosed igneous rocks are as follows:—

					<i>Percentages</i>			
					37/665	37/753	37/629	37/750
Hornblende	..	..	..	..	55	48	50	60
Diopside	..	..	..	..	—	10	—	12
Garnet	..	..	..	..	—	—	5	—
Plagioclase	..	..	..	..	43	36	40	17
Magnetite	..	..	..	..	1	3	3	—
Epidote	..	..	..	..	—	—	1	—
Apatite	..	..	..	..	1	1	1	1
Sphene	..	..	..	..	—	2	—	—
Spinel ..	..	..	..	..	—	—	—	10

37/665 Plagioclase amphibolite, Lagadima River.

37/753 Plagioclase amphibolite, north bank of the Uaso Ngiro.

37/629 Garnet-plagioclase amphibolite, south of the Garba Tula-Benane road.

37/750 Amphibolite, north bank of the Uaso Ngiro.

2. Jurassic Sandstones

Sandstones outcropping at Kubi Dakhara and the small hill north of it are thought to be of Jurassic age although they themselves are unfossiliferous. Jurassic limestones associated with identical sandstones containing probable Oxfordian fossils have been discovered in the Matasade Hills some 40 miles to the west-north-west (Dodson, Report No. 93).

The hills rise 200 feet above the Merti Beds in the surrounding plain, forming steep scarps which on aerial photographs give the impression of being lavas similar to those capping the Merti Plateau. The outcrops are surrounded by thick deposits of red, sandy soil which is of a darker colour than that of soils derived from the Basement System and is believed to have been produced by the weathering of the sandstones. The sandstones are highly indurated, in contrast to the surrounding grits belonging to the Merti Beds, and a gentle NW-SE anticline, which can be distinguished on Kubi Dakhara, carries the sandstones below the grits. The sandstones in the small hill north of Kubi Dakhara dip gently towards the north-east, but on the south-western side of the hill there is a wide area of dark red, sandy soil which may mark the south-western limb of another anticline. The most westerly hill of the Kubi Dakhara group appears to be faulted on its western boundary, which is in line with a fault breccia farther south. This latter fault breccia occurs among grits but appears to be derived from sandstones rather than grits, so there may be more sandstones covered by grits at that locality.

The sandstones are fine-grained, indurated rocks, the colour of which depends on the quantity of limonite present; when it is small they are pale yellow but when it increases they become maroon. The yellow variety occurs only as lenses within the dominant maroon sandstones.

Typical examples are specimens 37/770 from Kubi Dakhara and 37/774 from the hill to the north. The former is maroon and the latter yellow with faint bedding planes. In thin section both are seen to be composed of rounded quartz grains with subsidiary, more angular feldspars set in a siliceous matrix containing many small quartz fragments. Most of the feldspar fragments are altered but some oligoclase can be recognized. Ilmenite is common to both specimens but there is also a little haematite in 37/770, in which limonite along the grain boundaries is much more abundant.

On account of their induration and folding the sandstones are thought to be older than the Merti Beds, which are believed to be Upper Pliocene or Lower Pleistocene in age, because they rest on the end-Tertiary peneplain of mid-Pliocene age. As there is evidence of faulting west of the outcrops it seems probable that the sandstones owe their surface position to up-faulting. The presence of sandstone fragments in the fault breccia suggests that there may be sandstones concealed by the grits of the Merti Beds in other parts of the area.

Similar sandstones were found north of the Merti Plateau at Dogogicha in the Bar-chuma-Kom area (Dodson, Report No. 93) but these are more varied in lithology than the Kubi Dakhara outcrop, containing calcareous sandstone horizons and shale partings. At the Matasade Hills in the north-west of the same area Dodson also found fossiliferous limestones which yielded the following species:—

? *Somalirhynchia* sp.

? *Daghanirhynchia* sp.

Although the fossils were poorly preserved, Dr. H. M. Muir-Wood of the British Museum (Natural History) suggested that they resembled Oxfordian species from north-eastern Kenya and Somalia, and so the Matasade limestones are believed to be of Upper Jurassic age, possibly Oxfordian. The proximity of these fossiliferous outcrops suggests that the Kubi Dakhara and Dogogicha sandstones are also Jurassic in age, but are probably slightly older than the limestones because of their more westerly occurrence and general east-north-easterly dip.

The sandstones are similar lithologically to the Mansa Guda formation of north-eastern Kenya (Thompson and Dodson, 1960, pp. 15-18), which is overlain by Toarcian limestones and so is placed in the Trias. They also resemble the Mariakani and Mazeras sandstones of the Coast Province, which are probably Triassic in age but may range up into the Lower Jurassic (Caswell, 1953, p. 17, Sanders, 1959, pp. 28-35). In the absence of definite evidence the Kubi Dakhara and Dogogicha sandstones are thought to be younger than these other outcrops because their nearest datable horizon is the Oxfordian limestone of the Matasade Hills. The lithology of sandstones is a doubtful factor to use in correlation over the distances involved, especially as the littoral conditions under which they were deposited would probably be later towards the west during the incursion of the Jurassic Sea from the east. The more variable Dogogicha exposures were probably deposited slightly farther from the coast than the Kubi Dakhara sandstones. A further westward advance of the sea produced the conditions required for the formation of the Matasade limestones, but the water could not have been deep because of the presence of oolites and the fragmental condition of the fossils. That the sea did not persist for long in this area is shown by the sandstones capping the limestones, which points to a return of littoral conditions on the retreat of the sea.

3. Upper Pliocene Sediments

These rocks are best exposed on the flanks of the Merti Plateau, where they have been preserved from erosion by the capping of olivine basalt, but they also outcrop in the eastern half of the Garba Tula area. Their exposure is poor on the featureless plains, since they are easily eroded on account of their friable nature and are covered by thick soils derived from them. The grits are however exposed along rivers, notably the Galana Gof and Madodubdera. Exposures in the areas shown on the map as grits on the eastern plains are largely covered by grey, sandy soil which contain fragments of grit. The parts mapped as grey sandy soil on the other hand have no grit fragments, but it is considered that they overlie the grits because the soil is identical to that formed from the grits. At the eastern end of the Merti Plateau the grits are 400 feet thick, but their base is not seen, and the figure for the eastern outcrop must approach this, when the projection of the end-Tertiary peneplain is taken as their base.

A borehole (C.96) drilled at El Dera during the 1939-1945 war confirms this figure, for the following section was recorded:—

	<i>Feet</i>
Surface sand	0- 3
Reddish grey grits and clays (Merti Beds)	3-240
Greenish beds containing volcanic debris	240-408

The lower deposits were not seen at the surface, so were probably overlapped by the Merti Beds.

The grits are uniform, coarse-grained rocks, off-white in colour, but sometimes, especially on the Merti Plateau, they are red due to staining by iron ores. Pebbles, which range up to four inches in diameter, are mostly quartz with subsidiary felspar and occasional mafic minerals. The deposits are poorly sorted and no fossils were found during the survey, but this is hardly surprising in view of their texture.

A typical example is 37/636 from the Galana Gof, which is a medium-grained rock with rounded grains of quartz and felspar set in a fine, marly matrix. In thin section quartz grains are more abundant than those of felspar, which are often altered, but oligoclase and microcline are recognizable. There are smaller quantities of hornblende, biotite and magnetite set in a matrix which is too fine for its composition to be determined. Specimens 37/725 from the Galana Gof and 37/735 from the Madodubdera River show redeposited calcite rimming the larger grains and filling cracks in them, but magnetite abuts directly against the matrix. Both of these rocks are darkish, well-cemented rocks, but 29/7 from the south side of the Merti Plateau, which has similar microscopic characteristics, is a typical white, friable grit.

There are some finer bands within the grits, which are similar in character to the matrix of the coarser types but with only a few small fragments of quartz and felspar. A thick lens of kaolin, found in the southern scarp of the Merti Plateau immediately underlying the olivine basalt, forms part of the original sequence and is not a re-worked deposit. This deposit, specimen 37/776, is a fine, white rock with rare quartz grains. Under the microscope the matrix is extremely fine and nearly isotropic so that little can be recognized. There is a small amount of felspar and magnetite in addition to quartz.

In view of the lack of fossils the age of the grits can be deduced only from erosion surfaces. The Basement System surface represented by residuals in the western part of the Merti Plateau is taken by Williams (1966, p. 6) to be the sub-Miocene peneplain, but there are none of these residuals in the eastern part of the plateau described in the present report. The eastwards projection of the sub-Miocene bevel would pass through the upper part of the Merti Beds, so they must be younger than Miocene. The base of the Merti Beds and grits, however, appears to rest slightly below the end-Tertiary peneplain, as projected eastwards from the levels of the ridges in the Basement System farther west.

When the end-Tertiary erosion cycle was approaching its completion, deposition, if any, would form fine sediments, but the grits are coarse and poorly sorted, indicating rapid erosion and deposition. It appears likely therefore that the grits were deposited after maturation of the end-Tertiary peneplain, when renewed uplift had initiated rapid erosion of the Basement System farther west. The conditions of deposition were probably torrential fluvial, under which conditions the larger pebbles could be rounded quickly whereas the smaller fragments would remain angular. Accordingly the source of the sediments can be postulated to have been not far distant from their present outcrop. As the end-Tertiary peneplain matured during the middle of the Pliocene it appears to be most probable that the grits are of Upper Pliocene age.

4. Tertiary Volcanic Rocks

The only volcanic rocks in the area are the lava flows on the Merti Plateau. They consist of a lower olivine basalt, forming the capping of the Merti Beds, and an upper basanite, which outcrops locally on top of the olivine basalt. The lower flow is thought to have been extruded immediately after the deposition of the Merti Beds was completed, since it preserves the flat, upper surface of the sediments, so is probably also Upper Pliocene in age. The upper flow on the other hand could be related to the Pleistocene Nyambeni vulcanicity on account of its composition and the relatively unweathered state of its outcrops. Rix (Report No. 92) found similar basanites capping olivine basalt plateaux in the Kauro-Merille area and correlated them with similar flows in the Nyambeni Range. In the present area however, it is thought preferable to link them with the olivine basalt, so that the two flows are referred to one volcanic episode in the Upper Pliocene.

The olivine basalt is about 20 feet thick at the edge of the plateau, where it forms a steep scarp standing above the slope formed by the friable Merti Beds, but probably thickens to 50 feet in the middle where its outcrops consist of boulders set in red sandy soil. The lava is a finely porphyritic, dark blue-grey rock, which weathers to grey or reddish brown. Small vesicles are common but seldom filled by calcite or zeolites. Both olivine and black pyroxene microphenocrysts are set in a fine-grained groundmass. Specimen 29/8 from the south side of the plateau is typical, and in thin section the olivine microphenocrysts are seen to be largely replaced by iddingsite. Small granules of olivine in the groundmass have often been completely altered to iddingsite. The main mafic constituent of the groundmass is titanite, which is accompanied by laths of plagioclase in the andesine-labradorite range. Opaque iron ores are seen in reflected light to be ilmenite.

A more olivine-rich variety is represented by 37/775 from the tongue of lava projecting into the north-western corner of the Garba Tula area; in it the olivine phenocrysts are larger and fresher than the microphenocrysts in other specimens. The lava from the small hill north of the Merti Plateau, specimen 29/12, is similar to the main outcrop petrologically, but is somewhat coarser in grain.

The upper basanite flow, of which 29/13 from the south side of the Merti Plateau is a typical example, is a dark grey, fine-grained rock. Its outcrops have a knobby appearance and the rock rings when hammered. The outcrops stand out above the level olivine basalt because of their irregular shape and show as darker patches on aerial photographs. Each outcrop appears to be the remains of a small eruptive centre, but cones or flows cannot be distinguished. There appears to be no evidence for the former presence of basanite over the whole plateau. There are more small amygdaloids of zeolites in the basanite than in the olivine basalts, but it is petrologically similar except for the presence of small interstitial crystals of nepheline.

5. Dykes

The great majority of the dykes are olivine dolerites which are thought to be related to the olivine basalt of the Merti Plateau. There is however, one lamprophyre, which outcrops on the ridge east of the Kubi Kalo River. It is about four feet wide and 1,500 feet in length, trending west-north-westerly.

Specimen 37/685 from this dyke is a fine-grained, dark rock with small phenocrysts of feldspar and titanite; its colour is somewhat lighter than that of the olivine dolerites. In thin section the titanite phenocrysts are seen to be fresh, but some of the calcic oligoclase phenocrysts are sericitized, and the smaller, less common olivines, which are enclosed by the titanite, are often chloritized. The groundmass is largely composed of oligoclase laths, often sericitized and developing secondary calcite, but also

contains numerous elongated prisms of barkevikite, which are more abundant than titanite granules. Magnetite is a common accessory and there are many small apatite crystals. Although the phenocrysts seem to be in equilibrium with the groundmass the rock is regarded as a camptonitic lamprophyre.

Williams (1966, p. 32) suggested that lamprophyre dykes in the Chanler's Falls area are related to metamorphosed igneous rocks which were intruded into the Basement System gneisses after they had suffered some degree of metamorphism. In the Chanler's Falls area, where the lamprophyres have a north-easterly trend, they are dominantly composed of amphibole, with pyroxene and biotite, and are cut by quartz-felspathic stringers. The lamprophyre dyke in the Garba Tula area may be related to those described by Williams but corresponds more closely to unmetamorphosed dykes described by Sanders (1954, p. 34) from the Kitui area, placing them in the Tertiary. Lamprophyres are often thought to be genetically connected with major intrusions but Turner and Verhoogen (1960, p. 255) point out that they frequently occur in olivine-basalt volcanic associations. Following Bowen, they postulate that lamprophyres can be derived from an olivine-basalt magma by differentiation, adding that there are several probable modes of origin.

Small dykes of olivine dolerite are found in most of the Basement System outcrop, but are most common along the upper part of the Lagadima River. They range up to two feet in width but may persist over a length of up to one mile. The majority display a north-westerly trend, but some run from north-east to south-west.

The olivine dolerites are dark, fine-grained rocks, with some small phenocrysts of felspar and rarer ones of pyroxene. They are often highly weathered along many joints, which makes collecting a good specimen difficult, but two fresh examples are 37/667 and 37/677 from the rivers Lagadima and Kubi Kalo respectively. In thin section the felspar phenocrysts are seen to be labradorite, largely sericitized in 37/677, which also contains some small phenocrysts of fresh titanite, whereas 37/667 has some of olivine. The groundmass is composed of labradorite laths and titanite granules which are sometimes chloritized, while subsidiary olivine is often replaced by iddingsite. Magnetite is a common accessory, and calcite often replaces the felspar. Chlorite partly replaces pyroxene in altered specimens such as 37/604 from south-west of Garba Tula.

6. Pleistocene Lake Beds

Along the Galana Gof north-west of Benane white clays are exposed, which are in many places capped by kunkar limestone, indicating that they are partly calcareous. Their outcrop is terminated to the west by a ridge of granitoid gneiss which passes through Benane. The river now flows through a narrow channel cut in the granitoid gneiss and it is believed the clays were deposited in a lake formed when the river was partially dammed in the Pleistocene. Renewed down-cutting later breached the ridge, which still restricts the flow to some extent since permanent water is found along the clay outcrop. A typical specimen of the clay is 37/632, which displays fine stratification and contains a few small grains of quartz and calcite set in a cryptocrystalline matrix with some redeposited calcite. A coarser variety, from which 37/627 was collected, is greenish in colour and contains some grains of quartz and iron ores. In the thin section small angular fragments of quartz, felspar, biotite and hornblende with a small quantity of magnetite are seen to be set in a fine matrix.

7. Superficial Deposits

The three main soil types in the Garba Tula area are red sandy soils, grey sandy soils, and alluvium. The red sandy soils are developed over most of the rocks of the Basement System, being thickest on the end-Tertiary peneplain, while darker chocolate-coloured soils sometimes cover amphibolitic rocks. The grey sandy soils are derived from the Upper Pliocene sediments and are rather similar to black cotton soils with an admixture of sandy material. The alluvium is best developed along the Uaso Ng'iro, where it forms a wide belt, especially on the south bank.

Several other types of soil are also found, the most important being black cotton soil, which formed in areas of poor drainage in place of both the red and grey sandy soils. Kunkar limestone is well developed along the Galana Gof River system, where it overlies amphibolitic gneisses and Pleistocene lake beds. Surrounding the Jurassic sandstones of Kubi Dakhara is a mantle of sandy soil of a darker red colour than that on the Basement System rocks. It is believed to have been derived from the sandstones and may conceal additional occurrences of sandstones. On the Merti Plateau reddish brown soils have formed from the olivine basalt.

Narrow river terraces standing about 20 feet above the alluvial plain are present on the north bank of the Uaso Ngiri immediately below the Merti Plateau. They are formed of red sandy soil similar to that developed on Basement System rocks but containing numerous rounded quartz pebbles. As their level is below that of the end-Tertiary peneplain and they are banked against the Merti Beds, they are probably of Pleistocene age, and indicate that the river flowed at a slightly higher level during the Pleistocene. Later there was renewed downcutting, probably the same as that which caused the breaching of the granitoid gneiss ridge then damming the Galana Gof at Benane, to the level of the alluvial plain. When the river had again matured the present-day alluvium was deposited, but the upper part of the river has incised its channel into this later alluvium, showing that there must have been a further slight uplift.

VI—METAMORPHISM AND GRANITIZATION

The metamorphism of the Basement System in the Garba Tula area would appear to fall within the garnet zone as proposed by Barrow (1893). Almandine garnet is well developed only in the biotite-garnet gneisses, but this is probably due to variations in original composition along the strike rather than to varying grades of metamorphism. The higher zonal minerals are not developed, although some of the rock types would appear to be of suitable composition, if the requisite conditions of pressure and temperature had occurred. By applying the classification of Turner and Verhoogen (1960, pp. 531-560) the relationship of other rock types, such as limestones, semi-pelitic and psammitic gneisses and plagioclase amphibolites, to the garnetiferous rocks can be determined.

Typical mineral assemblages of the limestones are:—

Diopside-epidote-calcite
calcite-diopside-phlogopite

both of which are typical of the staurolite-almandine sub-facies of the almandine-amphibolite facies, corresponding to the upper part of the Barrovian garnet zone.

In the semi-pelitic gneisses common assemblages found are:—

quartz-almandine-muscovite-plagioclase-biotite-(epidote)
quartz-muscovite-biotite-microcline-plagioclase

while the assemblage of the psammitic gneisses is similar, being:—

quartz-microcline-plagioclase-biotite-(muscovite-epidote)

but the proportions of the minerals differ. Some of the microcline may have been introduced during later metasomatism.

The plagioclase amphibolites show the following assemblages:—

hornblende-plagioclase-almandine-epidote
hornblende-plagioclase-epidote
hornblende-plagioclase-(diopside)

Thus the assemblages in all the rock types fit the staurolite-almandine sub-facies of the almandine-amphibolite facies.

Granitization is thought to be the result of potash metasomatism since microcline replaces quartz and sodic plagioclase in many of the above rocks. In the west of the area the process has been carried further with the appearance of migmatites and granitoid gneisses. The latter may well have been formed by a granitic magma, generated locally by the fusion of pre-existing rocks, because there is no trace of sedimentary fabric, although they have a faint foliation.

VII—STRUCTURE

The interpretation of the structure of the Garba Tula area is rendered difficult by the discontinuous nature of the exposures, but they are sufficient to enable a general account of the folding to be given. Except for a small anticline in the Jurassic sandstones of Kubi Dakhara, major folds were recognized only in the Basement System as shown in Fig. 4.

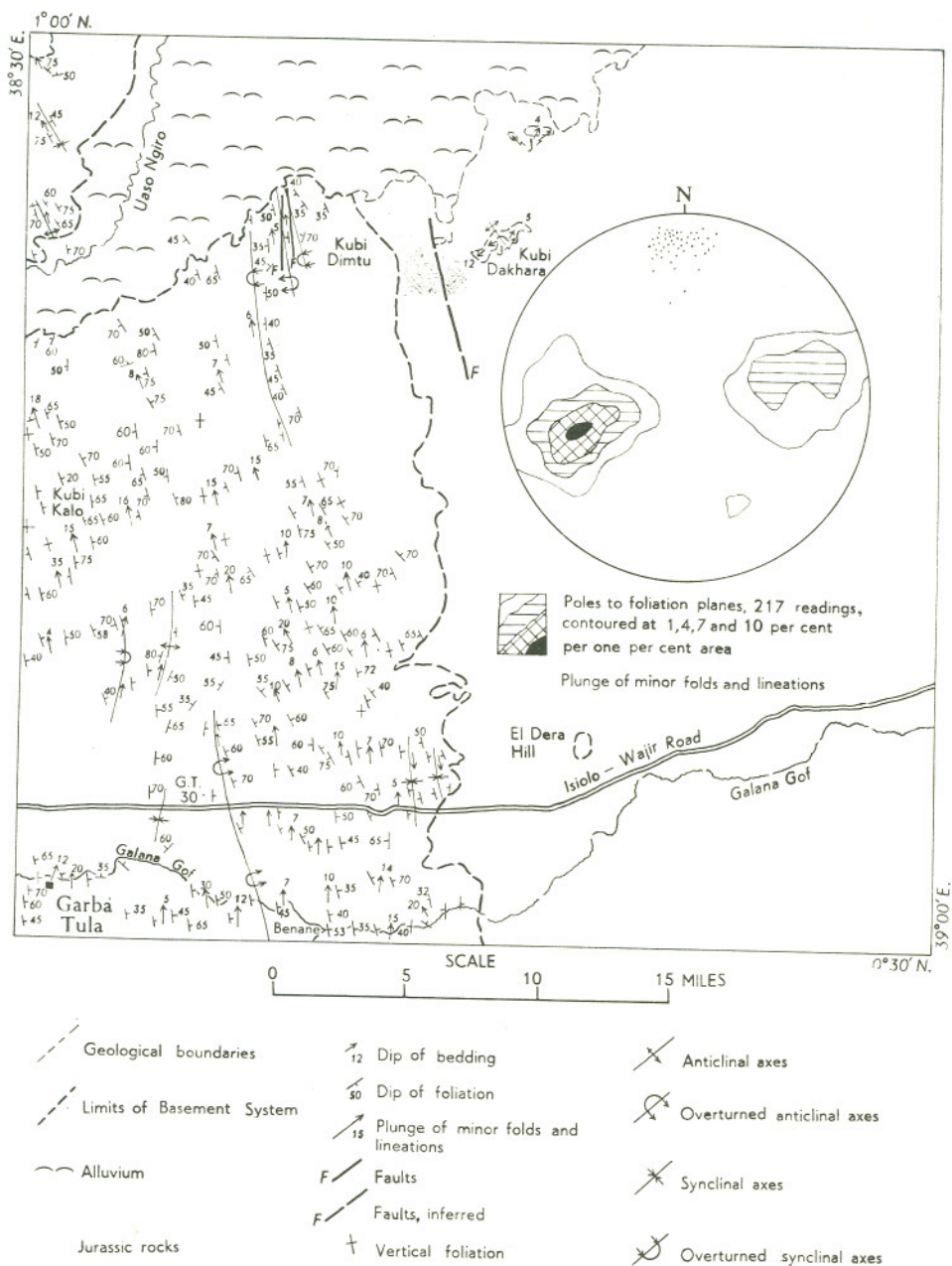


Fig. 4—Structural map of the Garba Tula area

Among the Basement System rocks foliation is best developed in the semi-pelitic types containing a good proportion of mica. Although the limestones did not develop foliation, banding due to variations in colour and grain size gives them planar surfaces, which are probably original bedding planes. As the foliation in the gneisses parallels these planar surfaces and the boundaries of formations, it is thought to follow bedding and is not seen to cut across it, even at fold closures. The foliation generally strikes north-north-westerly, but there are some local variations. Dips are generally high, with easterly dips somewhat more abundant than westerly.

Minor folds are common in all parts of the Basement System but are somewhat more abundant in the eastern parts of the outcrop. A stereogram showing poles to foliation planes and plunges of minor folds and lineations is inset in Fig. 4. It shows monoclinic symmetry, with folds usually plunging to the north-north-west. Their style is open, as shown by the two maxima of poles to foliation planes. As shown in Fig. 5,

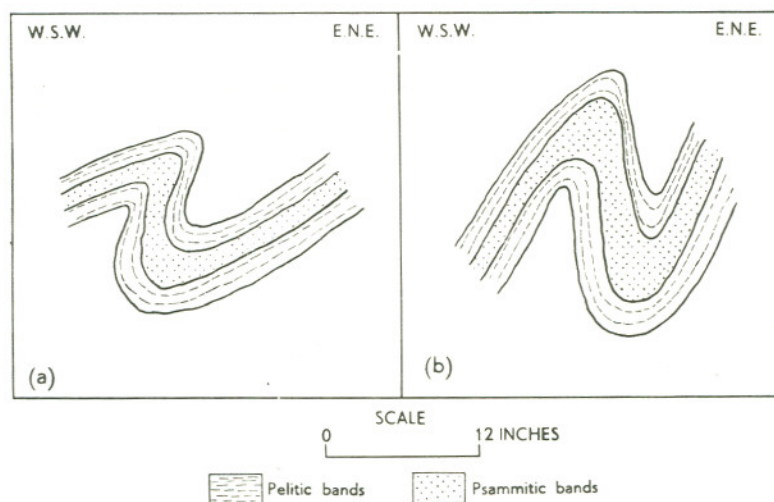


Fig. 5—Sections of minor folds north of the Kobato River

the observed style of the minor folds agrees with this conclusion, the folds in Fig. 5 (a) being of more common occurrence than the sharper ones of Fig. 5 (b). True isoclinal folds were rarely seen.

The most frequent type of lineation is marked by striations on foliation planes, but when mica is a common constituent its orientation also gives a lineation.

Oblique joints, which are symmetrically intersected by the lineation, are common in unfolded rocks but *ac* joints often take their place where the rocks are folded.

Major Folds

The style of folding recognized in the minor structures is repeated in the major structures, but these are difficult to trace over any distance due to poor exposures. As a result few major folds are shown on the structural map, those indicated mostly having a north-north-westerly trend.

Stratigraphically the entire Basement System outcrop appears to form a broad syncline, with the calcareous sequence forming the core and the more granitized rocks the envelope. As the only exposures east of the calcareous sequence are the granitoid gneisses of El Dera Hill, which is surrounded by Upper Pliocene sediments, and small

ridges near the Garba Tula-Merti road, this cannot be conclusively proved. The limestones of Kubi Dimtu however, appear to form the eastern limb of a nearly isoclinal syncline with some smaller anticlines, but the western limb has either been sheared out or is not exposed west of Kubi Dimtu. In the Lagadima River a thinner limestone band, which forms part of the western limb, is exposed. Biotite gneiss forms the envelope of the syncline but a thin band of plagioclase amphibolite separates the biotite gneisses of the core from the limestone. The dip is westerly or north-westerly at angles ranging between 30 and 70 degrees.

Immediately north of the Isiolo-Wajir road thin limestones in the eastern part of the Basement System are synclinal, and close to the north with a southerly plunge. Biotite gneisses form both the envelopes and the cores. These folds and that of Kubi Dimtu are believed to form the core of the large syncline already mentioned, which is postulated on account of the stratigraphy. Between the two localities folds cannot be distinguished since there are no closures, although several bands of limestone, which are discontinuous in places, dip towards the east.

In the western gneisses the most important fold is at point G.T. 30, to the north of which an overturned anticlinal closure can be seen in granitoid gneisses. The fold is nearly isoclinal in style, with steep, easterly dips, and its closure is to the north due to its northerly plunge. The core is composed of hornblende gneisses and the envelope of biotite gneisses. This fold can be traced southwards to the Galana Gof by the continuation of the granitoid gneiss outcrops, but both the core and envelope rocks have passed laterally to biotite-hornblende gneisses. Another fold in granitoid gneiss immediately to the west is of unknown extent because of poor exposure. The rock of the ridge at the junction of the Isiolo-Wajir and Garba Tula-Merti roads dips to the east at 70 degrees, but another low ridge of granitoid gneiss to the south-south-east dips north-westerly at 60 degrees, thus forming an open syncline which closes to the south.

Two more smaller folds, the trends of which swing from north-north-easterly in the south to north-north-westerly at their northern ends, have developed in the Lagadima River north of G.T. 30. The more easterly is again defined by granitoid gneisses, with a core of hornblende gneiss and an envelope of biotite gneiss. The fold is an open anticline, with steeper dips on its western limb, and plunges northwards, although the actual nose is obscured by soil cover. The western fold, which is formed by a band of plagioclase amphibolite surrounded by biotite-garnet gneisses, is an overturned syncline, with the axial plane dipping eastwards at 50 degrees. It closes towards the south where biotite-garnet gneisses of the envelope have passed laterally to biotite gneisses, but the fold can be recognized by the presence on both limbs of a band of biotite-hornblende gneiss.

North of the Uaso Ng'iro exposures are confined to isolated hills, but a small anticline can be seen affecting granitoid gneisses near the western boundary; both the core and the envelope are plagioclase amphibolites. Farther north and east biotite-garnet gneisses are folded in a syncline, along the axis of which a thin band of granitoid gneiss is emplaced.

A gentle north-westerly trending anticline affects the Jurassic sandstones of Kubi Dakhara, and appears to be of sufficient amplitude to carry them below the surrounding Upper Pliocene sediments.

Faults

Few faults were proven because of the discontinuous nature of the exposures, but many more may be concealed under the thick soil cover. Two north-north-westerly trending faults cut the limestones of Kubi Dimtu, downthrowing the block between them. The downthrow as shown by the displacement of formations is slight, but a considerable amount of brown fault breccia is developed, probably because the limestone is more susceptible to solution than other rock types.

Fault breccia is also developed south of Kubi Dakhara, where only Upper Pliocene sediments outcrop, but the sediments appear too unconsolidated to yield a compact breccia. As the breccia appears to have been derived from the Jurassic sandstone, it is probable that there are sandstones concealed by the grits at this point. When produced in a north-north-westerly direction the line of the breccia passes just to the west of the small outcrop of Jurassic sandstones on the Garba Tula-Merti road. It is therefore believed that the fault continues along this line. The present position of the sandstones at a higher level than the Upper Pliocene grits would appear to be due to their superior resistance to erosion. Williams (1966, p. 47) thought the north-north-westerly trending faults in the area to the west to be Precambrian in age because they are followed by metamorphosed dykes. If this is also the case in the present area the movement affecting the Jurassic rocks must be due to renewal of activity along a much older line of weakness.

Another outcrop of fault breccia north of the Galana Gof east of Benane, also has a north-north-westerly trend, but is surrounded by soil so nothing can be said about the direction and size of displacement of the fault.

VIII—ECONOMIC GEOLOGY

1. Minerals

Only a few minerals of potential economic importance were found during the survey. The remoteness of the area from main centres of population makes most of these minerals of no value at present due to high transport costs.

Limestone

Limestones are well developed in the eastern part of the Basement System outcrop but most of the horizons are thin. There is a thick band at Kubi Dimtu but it contains diopside and dolomite in addition to calcite, so would appear to be unsuitable for cement manufacture. A fold closure just north of the Isiolo-Wajir road about half way across the area forms a thick outcrop, which appears to be of purer composition. It is readily accessible, because a track running northwards from the main road passes it. It would however, have to be of exceptionally good quality to be worth working in view of the large reserves of limestones which are already worked in other parts of Kenya.

Garnet

This mineral is widespread in the biotite-garnet gneisses, but is always found as small crystals which contain many inclusions of quartz.

Graphite

Small quantities of graphite occur in the quartzites, but the small percentage of the mineral and the hardness of the matrix makes economic extraction unlikely.

Magnetite

This mineral is locally abundant in some of the quartz-felspar and granitoid gneisses but no concentrations of economic importance were seen.

Olivine

The lavas of the Merti Plateau contain a good proportion of olivine, but much of it is altered. It often weathers out to form small concentrations in watercourses.

Kaolin

A bed of kaolin outcrops in the upper part of the Merti Plateau in the north-western corner of the Garba Tula area, but it is rather impure and its relative inaccessibility is likely to make it uneconomic to work.

2. Water Supplies

Although the Uaso Ngiro flows through the northern part of the area the great majority of the population and their animals are dependent on shallow wells dug in sand rivers.

The Uaso Ngiro

Flow figures for the Uaso Ngiro were recorded at Archer's Post and Habaswein (upstream and downstream respectively from the present area) in 1958 and are shown by Williams (1966, p. 51). No intermediate stations have been used for recordings, but the figures quoted by Williams indicate that there is an appreciable loss of water in this stretch. The level in the lower reaches is maintained by controlling the use of water in the headwaters to ensure that the minimum flow at Archer's Post is $42\frac{1}{2}$ cusecs. Much of the loss is caused by evaporation, and the Water Development Department of Kenya Government have investigated the possibilities of a pipe-line between Kittermaster's Camp in the Chanler's Falls area and Habaswein. Although this would probably increase the supply at Habaswein it could cause even more frequent drying up of the river at Merti than at present, with resultant hardship to the local population.

In view of the large number of stock using water from the Uaso Ngiro, causing overgrazing and erosion, it has been suggested that close control of the numbers of stock and rational grazing methods should be employed (Howard Humphries, 1958, pp. 34-36).

Other Permanent Water

Along the course of the Galana Gof, near Benane, permanent water is found on the outcrop of the Pleistocene lake beds. This appears to be preserved by the ridge of granitoid gneiss bounding the lake beds to the east, which still causes a certain amount of damming of the flow. The lake beds themselves probably also retain water for longer periods than the Basement System gneisses and the sandy soils.

Wells

Two permanent wells on the banks of the Galana Gof at Garba Tula provide water for stock and much of the human population. They are built of concrete, lined with corrugated iron, giving a more stable supply than wells dug in sand. Even at these wells however, the danger of pollution by animals remains high, although permanent watering troughs have been constructed.

In other parts of the area wells are dug by the tribesmen in sandy river beds at points where water is retained by clay beds or natural rock bars. Some of these wells reach a depth of 20 feet, and water containers are passed up by hand along a human chain. The water is then emptied into troughs, hollowed out of tree-trunks, for the waiting stock. It would appear that the life of the tribesmen would be alleviated by the construction of permanent vertical wells, similar to those at Garba Tula, since then they would not have to dig the wells afresh after the rivers had flowed, and water could be raised in buckets on ropes. Where natural barriers are scarce artificial ones should be built across the rivers to give additional reservoirs, but open pans are not recommended since evaporation losses would be high.

Boreholes

The borehole (C. 96) drilled at El Dera during the 1939-1945 war and now abandoned, yielded 720 gallons per hour at a depth of 355 feet. It should be reopened to improve water supplies in the eastern part of the area, or if this is impracticable the site is obviously suitable for future drilling.

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