



GOVERNMENT OF KENYA

MINISTRY OF NATURAL RESOURCES
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE NDEYINI AREA

DEGREE SHEET 45, S.E. QUARTER
(with coloured geological map)

by

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FOREWORD

The Ndeyini area straddles the Thika-Garissa road and represents a transition from the hill ranges of the eastern part of the Kitui district to the monotonous plain country that forms eastern Kenya. In the west of the Ndeyini area there are a few small hills that yield geological information on the rocks that underlie the country, but further east a blanket of superficial deposits hides any but the most recent geological features. In an attempt to "see through" this blanket some time was spent during the survey of the area in carrying out magnetic and gravity measurements. A notable anomaly was discovered in the eastern part of the area and, though unlikely to be of economic interest, illustrates the only way in which it will be possible to map sub-surface rocks in eastern Kenya at reasonable cost.

It appears that at present there are no minerals known in the area that are likely to be of economic interest. The provision and conservation of water is the most pressing problem and the author makes suggestions to that end.

Nairobi,
7th July 1961.

WILLIAM PULFREY,
Commissioner (Mines and Geology).

CONTENTS

	PAGE
Abstract	
I—Introduction	1
II—Previous Work	2
III—Physiography	2
IV—Summary of Geology	4
V—Details of Geology	5
1. Basement System	5
(1) Metamorphosed calcareous sediments	5
(2) Metamorphosed semi-pelitic sediments	6
(3) Metamorphosed psammitic sediments	7
(4) Pegmatites	9
(5) Metamorphosed igneous (?) rocks	10
(6) Metamorphism and Granitization	10
2. Possible ultrabasic intrusive of post-Basement System age	11
3. Minor intrusive rocks	11
4. Pleistocene to Recent superficial deposits	14
VI—Structure	17
VII—Mineral Deposits	22
VIII—Geophysical Survey	23
IX—References	27
Appendix I—Geology of the Mwitamisyi Valley	28
Appendix II—Radiometric Survey	32

ILLUSTRATIONS

Fig. 1—Physiographic sketch-map of the Ndeyini area	3
Fig. 2—Drawings of photomicrographs of aegirine-bearing intrusive rocks	12
Fig. 3—Drawings of photomicrographs of minor intrusive rocks	13
Fig. 4—Structural sketch-map of the Ndeyini area	18
Fig. 5—Composite structural stereogram for the Ndeyini area	19
Fig. 6—Minor slip-structures in the Ndeyini area	20
Fig. 7—Stereogram of joints in the Ndeyini area	21
Fig. 8—Geophysical traverse map for the Ndeyini area	24
Fig. 9—Sketch map of the Mwitamisyi valley, north of the Ndeyini area	29
Fig. 10—Gravity profile diagram	at end
Fig. 11—Magnetic profile diagram	at end

CONTENTS—(Contd.)

PLATES

Plate I—

Fig. *a*—Concordant segregation veins in paragranelite, Kangui ..

Fib. *b*—Biotite-rich inclusion in paragranelite, Nzewani

Plate II—

Fig. *a*—Contorted pelitic lenses in migmatitic gneiss, Kimuu

Fig. *b*—Slip-folded pelitic lens with quartzo-felspathic veining, Katumba

} at
centre

MAPS

Geological map of the Ndeyini area (degree sheet 45, S.E.) scale 1:125,000 at end

ABSTRACT

The report describes an area on the plains between Mwingi and Garissa in the south-east part of central Kenya, bounded by latitudes $0^{\circ} 30'$ and 1° S., and longitudes $38^{\circ} 30'$ and 39° E. The plains form part of the end-Tertiary bevel, overlain in the east by Pleistocene sediments whose western limit coincides approximately with $38^{\circ} 45'$ E. Inselbergs of gneiss rising above the plain are believed to be residuals of the sub-Miocene peneplain.

Owing to the flat terrain there is thick soil cover, supporting dense thorn-bush vegetation. Outcrops are therefore scarce and consist almost entirely of resistant leucocratic Basement System gneisses, although there are small exposures of softer semi-pelitic and calcareous gneisses in some of the stream channels. There is also a small number of intrusive dykes, which may be of Mesozoic or Tertiary age. Gravimeter and magnetometer surveys were made in the area in order to supplement the scanty geological information.

Notes describing briefly the geology of a small part of the area to the north are given in an appendix. In a second appendix are described the results, relevant to this area, of a country-wide radiometric survey.

GEOLOGY OF THE NDEYINI AREA

I—INTRODUCTION

The country described in this report is bounded by latitudes 0° 30' and 1° S. and by longitudes 38° 30' E. and 39° E., covering about 1,200 square miles, and corresponds with quarter degree sheet 45 S.E. (Kenya) (Directorate of Overseas Surveys sheet No. 138). About half of the area lies in the Kitui District of the Eastern Region, half in the Tana River District of the Coast Region, and the boundary between the Kitui Special Area and the Kitui Eastern Crown Lands cuts across the south-western corner of the area.

The area is sparsely populated by nomadic Kamba and Galla herdsmen, who graze their cattle throughout the area during rainy seasons, when the seasonal water-holes are full. During dry seasons, they withdraw to localities of more permanent water, the Kamba westwards into the Special Area and northwards to the Tana river, the Galla eastwards towards Garissa. There are small Kamba settlements near the western boundary round the Ukazzi hills, as far north as Kimuu and south as far as Methe. A little maize is grown in this region, but the rest of the area is too dry for cultivation.

Rain falls in the area usually from March to May, and more heavily from October to December. Rainfall data are scanty, but rain gauges at Ngomeni, just outside the area to the north-west, and at Sosoma in the south-west part of the area (where the rain gauge was destroyed in 1958), give some idea of the precipitation to be expected:—

Place	Year	Total rainy days	Total rainfall (inches)	Heaviest rain (inches)	Average (inches)
Ngomeni*	1956	29	21.24	3.70	17.22
	1957	42	20.61	4.90	17.79
	1958	28	14.28	4.35	17.28
	1959	37	22.98	2.95	—

Place	Period recorded	Total rainfall (inches)	Source
Sosoma	1-1-53 to 5-6-54	13	African Land Development Board Agricultural Department, Kitui
	19-4-56 to 15-1-57	17½	

*From East African Meteorological Department records.

Calculations of approximate rainfall averages for the Kitui Eastern Crown Lands have been made from data collected in and near them by the African Land Development Board (ALDEV, 1956, p. 60†). For the strip of Eastern Crown lands in the Ndeyini area, the rainfall average varies from about fifteen inches on the western boundary down to ten inches on the eastern boundary, which passes through Katumba.

The Thika-Garissa road runs approximately west to east across the middle of the area, and other parts are accessible to vehicles along tracks cut in recent years by the Game Department and ALDEV units; such tracks together with cattle and game tracks, enabled fairly thorough cover of the area to be made. It is necessary to use tracks for the most part, as the thorn-bush vegetation is thick, with dense undergrowth. Baobab trees were occasionally seen, and thorn acacias grow at water-holes and along better developed drainage lines. Slightly moister conditions on the slopes of Katumba and the Ukazzi hills permit, in addition, the growth of trees such as the candelabra *Euphorbia*, and *Sansevieria*.

The only maps available of the area at the time of the survey were the 1:500,000 scale Army map, Garissa sheet, 1940, and an ALDEV enlargement of this to a scale of 1:200,000 with the more recent tracks and boreholes marked approximately on it. Neither map is

†References are quoted on pp. 27 and 28.

particularly reliable. The map accompanying this report was compiled in part from aerial photographs, controlled by plane-table survey based on Army trigonometrical stations and by astro-fixes made in 1958 by the 89th Field Survey Group, and partly from compass and cyclometer traverses. The line of geodetically levelled bench-marks, at mile-posts along the main Garissa road (Survey of Kenya Geodetic Levelling Diagram, 1955, Line 57, and Diagrams 18, 24 and 27), greatly simplified the measurement of altitudes in the area, by making possible daily calibration of the aneroid. For convenience only five bench mark heights are shown on the map.

II—PREVIOUS WORK

Piggott crossed the north-west corner of the area on his way to Ngomeni, after his journey up the Tana river in 1889, and described (Piggott, 1890, p. 133) the difficulties he experienced in finding water. The map accompanying his account figures Kalumba (Katumba) mountain, and a settlement named Winzana (also shown on the 1:500,000-scale Army map), which was understood during the present survey to be on the Nthunguthu flood-plain about 12 miles in from the western boundary, and to be no longer inhabited. Neither locality was mentioned by Piggott in the text.

Hobley (1894, p. 117) also travelled to Ngomeni from the Tana, in 1891, but started further upstream than Piggott and may only just have crossed the extreme north-west corner of the present area. He described the terrain he traversed as trackless and waterless thorn-bush. He also commented briefly on the geology of Ngomeni rock ("folded and contorted micaceous gneiss"), about which he found a relatively high population density, because of the permanent water-supplies collected in pits dug at the base of the rock.

A map accompanying Gedge's account (1892) of Captain Dundas' expedition from the Tana river to Mount Kenya, gives two positions for Katumba (Piggott's and Hobley's, the latter more accurate), as well as figuring Winzana and Ugasi (Ukazzi), although the position of the latter is rather too far west. "Conical hills", shown in the south of the quarter degree square, probably represent the Kandelongwe syenite mass in the north-east corner of the Endau area (Baker, 1964).

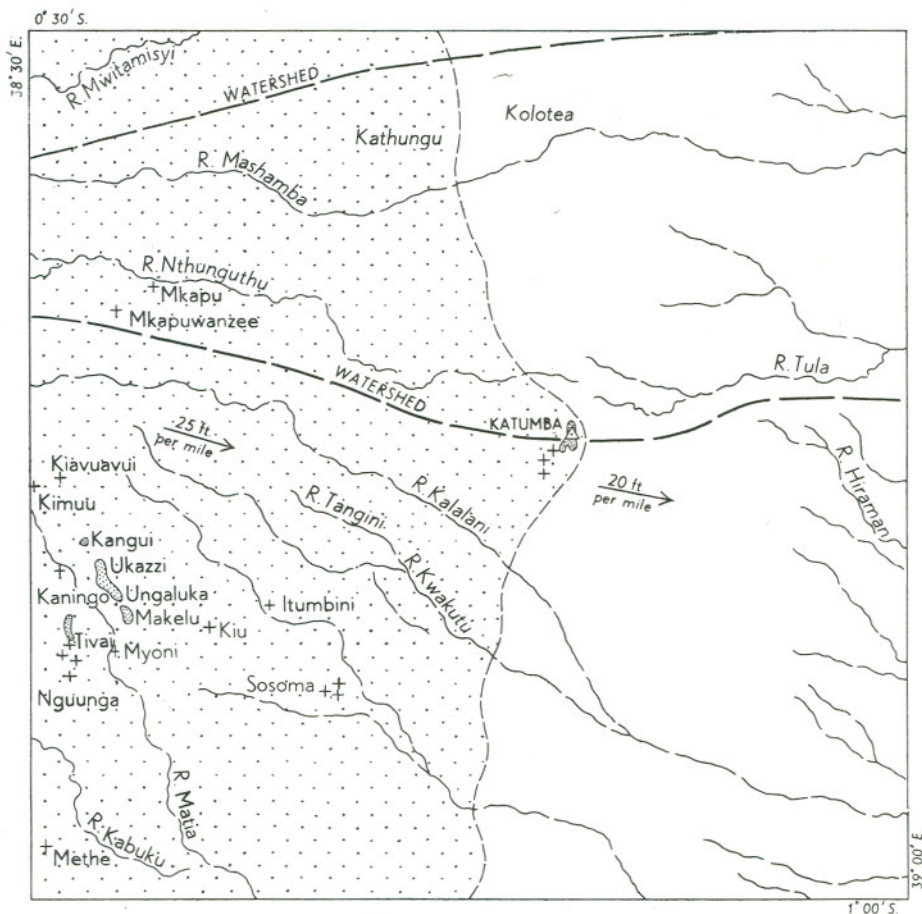
Dixey entered the area along the Garissa road, during his extensive investigations into the water-supply of the Northern Province. According to him (1944, appendix, p. 15), almost all the Garissa District is underlain by Tertiary sediments, including sandstones, marls, and gypsiferous clays, which thin out on to Basement System rocks, about 72 miles from Garissa on the Kitui road (i.e. at Katumba), where he thought both formations were bevelled by the end-Tertiary peneplain.

Munger (1950) discussed the water-supply problems of the Kitui District and described water conservation programmes of dam building, borehole drilling, and terracing.

III—PHYSIOGRAPHY

The area is almost completely flat, being part of the extensive plains of late or post-Tertiary age, which form much of eastern and north-eastern Kenya. Katumba and the Ukazzi and Tivai groups of hills rise to 600 feet above the plain and are considered to be eroded remnants of the sub-Miocene peneplain (cf. Baker, 1964, p. 2). Otherwise relief never exceeds 75 feet, minor heights being formed by small inselbergs and whalebacks of metamorphic rocks, and by ridges of surface limestone. In the western half of the area, where the gneisses are near the surface, being covered only by a thin mantle of superficial deposits, the ground slopes down in a direction slightly south of east, with a gradient of about 25 feet per mile. This is considered to approximate—in the Ndeyini area—to the present slope of the somewhat dissected end-Tertiary peneplain, which has bevelled the Basement System rocks in this part of Kenya. In the eastern half of the area, the slope of the ground is less, about 20 feet per mile, and further east the gradient decreases still further (see ground profile, Fig. 10 (at end) and cf. Rix 1964, p. 3). The decrease in slope is attributed to the presence of sediments deposited on the end-Tertiary peneplain, and overlain by superficial deposits. Dixey (1948, p. 9) regarded such sediments as being of pre-Pliocene age (because he thought they were bevelled by the peneplain), but it is now generally conceded that as the sediments rest on the bevel, they must be Upper Pliocene or Pleistocene in age (cf. Joubert, 1963, p. 3). It is considered that there was slight eastward tilting of the peneplain before sediment deposition, but the main phase of tilting which produced the present slope, probably occurred after the sediments were deposited (cf. Pulfrey, 1960, p. 10).

Drainage lines in the area are broad and shallow alluvium-filled valleys, with intermittent narrow winding and branching channels, which carry water only when there is rain, cut into the alluvium. The drainage direction swings from generally south-east in the southern part of the area, to generally eastwards in the north (Fig. 1), though in the north-west corner the R. Mwitamisiy flows north-eastwards and then north towards the R. Tana soon after crossing the northern boundary of the area. All the valleys are tributaries of the R. Tana, which they eventually join far outside the area to the east.



-  Hills rising to about 600 ft. above the plains, their summits being close to the level of Sub-Miocene peneplain
-  Inselbergs between about 50 and 200 ft. above surrounding plains
-  Slightly dissected End-Tertiary peneplain, with thin superficial deposits
-  Approximate western limit of Pleistocene (?) sediments on End-Tertiary peneplain.

0 5 10 15 MILES

Fig. 1—Physiographic sketch-map of the Ndeyini area.

Baker (1964, p. 10) has noted that the alluvial deposits in this region conceal valleys of more youthful cross-section than would be expected of drainage on a mature peneplain surface, for they reach thicknesses of between 60 and 80 feet (Baker, *op. cit.*, p. 2, and this report p. 23). He considered that gentle easterly tilting and climatic changes were responsible for the initial incision and subsequent aggradation which have given rise to the present form of the valleys. From west to east across the present area there is a marked change from relatively well-defined to extremely ill-defined and shallow valleys with wide alluvial flats. This is thought to be due to the lowering of valley gradients on passing from the slightly tilted peneplain surface on metamorphic rocks, to the more gently inclined surface of softer sediments resting on it.

The alluvial fill in the valleys draining the peneplain in this general region probably accumulated under earlier more temperate and humid climatic conditions. Since then the climate has become progressively drier, and seasonal heavy storms are now the characteristic form of precipitation. Flood waters from the storms have cut into the alluvial deposits in most places to form the steep-sided, and often quite deep channels seen today. North of the Kathungu-Kolotea watershed in the present area, where there has been slightly more dissection than elsewhere, because this is where the Tana dissection starts, the Mwitamisyi is a well-developed sand-river. South of this watershed, however, where the country is flatter, the channels are usually less well-defined, due to poorer canalization and more rapid spread of flood-waters, with consequent tapering of the channels. There are also unchanneled alluvial flats of old river valleys, as in the south-west and south-east corners of the area. In some places south of the watershed, however, the channels are also broad and sandy over short distances, notably along the Nthunguthu-Tula river. Such features are perhaps due to locally steeper gradients and to rainfall being more frequent and heavier in some places than others, resulting in locally more powerful streams. These would rapidly lose impetus and spread out, dropping their load of sand and silt where the gradient decreases again, when the storms nourishing them ceased and there was no rain down-stream to replenish them.

Dixey (1944, p. 4), noted that many of the natural pans in the North-Eastern Region are remains of vanished river systems, and frequently have the form of cut-off loops of old stream courses. Two crescent-shaped water-holes in the present area—one $3\frac{1}{2}$ miles north-east of Ndeyini Pool, the other about 1 mile north of the astro-fixed point in the south-east corner—may well have originated in this way. Dixey also observed that sub-surface layers of secondary lime, iron, and silica enrichment which are common in the North-Eastern Region, are evidence of climatic desiccation.

IV—SUMMARY OF GEOLOGY

The rocks of the area can be divided into four groups:—

- (1) Metamorphic rocks of the Basement System
- (2) An altered ultrabasic intrusive
- (3) Alkaline minor intrusives
- (4) Pleistocene to Recent superficial deposits.

It has been established by workers in adjacent areas of good exposure to the west, that the Basement System rocks of the Kitui District are a folded and granitized series of originally psammitic, semi-pelitic, and pelitic sediments, with calcareous bands. A well-defined foliation has been developed parallel to the original bedding, with an approximately north-south regional strike. In the present area, the exposed Basement rocks consist of isolated outcrops chiefly of psammitic quartzo-felspathic granulites, passing in the north-west to semi-pelitic biotite, biotite-hornblende, and hornblende gneisses.

In the Mwitamisyi valley in the area further north there are hornblende migmatites, charnockitic rocks, gabbros and lamprophyres.

A small outcrop of ferruginous rocks 5 miles north-north-west of Sosoma may be part of a highly altered ultrabasic intrusive of post-Basement System age.

Alkaline minor intrusive rocks in or near the area comprise dykes of quartz micro-syenite and camptonite, and fragments of these and other types containing aegirine. All are presumably connected with the syenite intrusions in the Endau area further south (Baker, 1964).

Three small and widely separated grit outcrops of probable Pleistocene age were found in the area, and pebble sheets occur mainly in scattered patches, but are widespread in the south-west. The deposits are correlated with similar sediments described by Baker from the Endau area (1964, p. 9).

Calcareous crustal deposits are common, but mainly developed in the south-western part of the area. Many fragments of siliceous rocks were found, some of them silicified breccias, some probably silcrete, the latter possibly of concretionary origin within the superficial limestones. Cellular lateritic ironstone also occurs in small exposures. Red sandy soils cover most of the area, giving way along drainage lines to alluvial deposits, and there are patches of black-cotton soil in the north-west corner.

V—DETAILS OF GEOLOGY

1. Basement System

The Basement System rocks of the area together with some associated rocks, which are included here for convenience, are subdivided for description as follows:—

- (1) Metamorphosed calcareous sediments—calc-silicate granulites
- (2) Metamorphosed semi-pelitic sediments
 - (a) Banded biotite, hornblende, and biotite-hornblende gneisses
 - (b) Biotite gneisses
 - (c) Garnetiferous quartz-felspar-biotite gneisses
- (3) Metamorphosed psammitic sediments
 - (a) Biotite and hornblende-bearing quartz-felspar paragneisses
 - (b) Muscovite quartzites
- (4) Pegmatites
- (5) Metamorphosed igneous (?) rocks—amphibolites

Exposures are too scattered and infrequent to enable a stratigraphic succession of these rocks to be elucidated with any degree of certainty.

(1) METAMORPHOSED CALCAREOUS SEDIMENTS

Calc-silicate Granulites

These rocks occur in areas to the west as bands and lenses of varying size, associated with crystalline limestones, semi-pelitic gneisses, and amphibolites. They are regarded as the metamorphosed products of originally impure limestones. In the present area, only three occurrences worthy of note were found.

The largest occurrence is in a pit, 2 miles west of Kathungu on the Garissa road, where a thin layer of red sandy soil and pebbles overlies secondary limestone, which forms the walls of the pit and contains calcified remnants of coarse quartz-felspathic gneiss. At the bottom of the pit large blocks of green and pink calc-silicate granulite were found. The surrounding gneiss (specimen 45/411b*) exhibits in thin section an irregular mosaic of quartz, oligoclase, microcline, and biotite; oligoclase is the dominant felspar, altered in part to sericite, and replaced by calcite in patches. Specimens 45/411a and 45/411 probably typify the granulites themselves. The former is a fairly uniform aggregate of pale yellow epidote, green pleochroic diopside (cf. Sanders, 1954, p. 9; and Saggerson, 1957, p. 10), plagioclase, light pinkish brown garnet, quartz, and scapolite. The plagioclase is labradorite and not andesine such as has been previously described from such rocks in Kenya (Sanders, 1954, p. 11; Saggerson, 1957, p. 10). Specimen 45/411 is a similar granular aggregate, with some bands rich in garnet and some in diopside, a feature common in such rocks (Sanders, 1954, p. 11).

*Numbers prefixed by 45/ refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

A volumetric mode* for specimen 45/411a is given below:—

					%
Quartz	..	..	..	..	6
Diopside	..	..	..	..	28
Garnet	..	..	..	..	12
Plagioclase	..	..	..	..	18
Scapolite	..	..	..	..	4
Epidote	..	..	..	..	32

The second occurrence is a nine-inch lenticular inclusion of epidote granulite in banded hornblende gneiss, found in the Mwitamisi valley about six miles from the western boundary of the area. The gneiss (specimen 45/658), in which microcline is the dominant feldspar, has an irregular granoblastic texture with some hornblende showing incipient poikiloblastic growth, and with scattered granular sphene. This passes to a felt of sericite (specimen 45/663) with plagioclase relics and chloritized hornblende, which contains grains of pale yellow epidote, becoming more concentrated towards the inclusion. The inclusion (specimen 45/661) consists of an irregular mass of crudely orientated bright yellow-green pleochroic epidotes, with a little slightly to much altered plagioclase, chlorite patchily pleochroic from green to pale brown and rare grains of sphene, quartz, and amphibole pleochroic from dark green to brown.

The third occurrence of calc-silicate rocks was found as large blocks of silicified quartz-epidote breccia (see p. 16), in the Kisioni valley, about half a mile north of the Garissa road just upstream from an exposure of red, hornblende-bearing surface limestone and pegmatite, with amphibolite fragments nearby.

(2) METAMORPHOSED SEMI-PELITIC SEDIMENTS

(a) Banded Biotite, Hornblende, and Biotite-hornblende Gneisses

Strongly banded, flaggy and friable biotite gneisses were found in two small exposures in the Nthunguthu valley, near the western boundary of the area, and in the Mwitamisi valley, where they alternate with less friable biotite-hornblende gneisses, relatively resistant hornblende gneisses, and occasional harder more leucocratic quartz-feldspathic bands. The more pelitic members of these gneisses are characterized by frequent alternations of bands rich in biotite and/or hornblende with white quartzo-feldspathic pegmatites. Such pegmatites also occur in the leucocratic bands, but are less common. At Kimuu, on the western boundary of the area, there are migmatitic biotite-hornblende gneisses with intensely contorted streaky banding (Plate II, Fig. a).

Because they are so friable, it is difficult to make satisfactory thin sections of these rocks, but texturally they probably do not differ much from the more psammitic rocks described below. Two approximate modes are appended.

				45/339	45/658
				%	%
Quartz	..	..	..	28	38
Microcline	..	..	..	12	32
Oligoclase	..	..	..	50	13
Biotite	..	..	..	8	—
Hornblende	..	..	..	2	15
Iron ore	..	..	..	—	2

45/339. Migmatitic biotite-hornblende gneiss, Kimuu.

45/658. Hornblende gneiss, R. Mwitamisi.

The hornblende gneiss from the Mwitamisi valley is described on p. 30.

*All modal measurements were made with a Swift automatic point counter.

(b) *Biotite Gneisses*

Biotite gneisses were found in four isolated exposures, at Methe and Nguunga, near the western boundary of the area, at Nguluni, in the Nthunguthu valley, and at Temboka, north of Kathungu on the Garissa road. They probably represent bands and lenses of more pelitic rocks in the psammitic granulites (cf. Saggerson, 1957, p. 13) described below. They are well-foliated rocks, with biotite tending to concentrate into darker bands. The foliation is usually quite regular across the outcrops, but at Nguunga it is irregular, with strike variations of up to 90° over a few feet. Irregular segregations of pegmatite and quartz, containing iron ore, also occur on Nguunga. Texturally and mineralogically these rocks closely resemble the leucocratic quartz-felspar-biotite paragranelites (described later), into which they grade, differing from them chiefly in the greater amount of aligned biotite, and sometimes a preponderance of microcline over plagioclase. Three approximate modes are given below.

	45/333	45/514	45/709
	%	%	%
Quartz	20	12	35
Microcline	55	36	43
Oligoclase	20	41	13
Biotite	3	8	7
Iron ores	2	3	2

45/333. Biotite gneiss, Nguunga.

45/514. Biotite gneiss, Temboka.

45/709. Biotite gneiss, Methe.

(c) *Garnetiferous Quartz-felspar-biotite Gneisses*

Garnetiferous gneisses occur as a relatively thin development in the Mwitamisyi valley, about four miles from the western boundary of the area. Small deep red garnets are sparsely visible in the leucocratic gneiss, but are sometimes concentrated. There is considerable development of pegmatite, and local small pockets of biotite enrichment, in which the flakes are up to half an inch across, occur in the gneiss. A silvery mica also occurs, apparently along certain fracture planes. A thin section (45/657) indicates that plagioclase is the dominant felspar, and that the larger garnets (up to 2 mm.) contain quartz inclusions.

(3) METAMORPHOSED PSAMMITIC SEDIMENTS

(a) *Quartzo-felspathic Paragranelites*

Quartzo-felspathic granulites are by far the most common rocks seen in the area because of their resistance to weathering, as would be expected in a region of poor exposure such as this. They are yellow-, pink-, and buff-weathering, usually well-jointed, prone to exfoliation and carious weathering, the outcrops being usually rounded. Apart from the five main groups of hills, Ukazzi, Myoni, Tivai, Sosoma, and Katumba, outcrops take the form of small inselbergs never more than thirty feet high, low whalebacks, and exposed surfaces at ground level.

Foliation is typically difficult to determine in such leucocratic rocks, owing to the scarcity of aligned ferromagnesian minerals. In many places, however, but notably in the Ukazzi hills, concordant pegmatitic auto-segregation veins (cf. Sanders, 1954, p. 27) enable the foliation direction to be more clearly seen. The veins are usually composed of quartz alone, but iron ore, often locally concentrated, and hornblende are also commonly developed. Their width is not usually more than an inch or two but may be as much as three feet, e.g. near Kangui (Plate I, Fig. (a)). In addition, bands rich in biotite and/or hornblende sometimes occur parallel to the foliation, and can be interpreted as metamorphosed lenses of pelitic material in the original psammitic sediments. They provide further evidence that the foliation is developed parallel to original bedding.

Similar paragranelites have been described from many other places in Kenya. They consist mainly of heteroblastic aggregates of quartz, usually fresh microcline or microcline-perthite, and oligoclase, often somewhat sericitized and occasionally myrmekitic. They also

contain a little perthite and perhaps orthoclase, and flakes of green-brown biotite are usually more or less aligned along the foliation direction, though sometimes green-brown hornblende occurs in place of biotite. The rocks invariably contain grains of iron ore, which is probably titaniferous.

Replacive margins between the feldspars and quartz are ubiquitous. In similar rocks from adjacent areas to the west, microcline replaces plagioclase, evidence for this being seen in the albitization rims of plagioclase adjacent to microcline (Sanders, 1954, p. 19; and Saggerson, 1957, p. 21). Quartz occurs typically as rounded grains, usually smaller than the feldspars. It is often strongly corroded, and not infrequently deeply embayed and is embayed by feldspar. Instances of one feldspar enclosing another, or of ferromagnesian minerals enclosed by other minerals, are relatively rare, but feldspar is often seen completely enclosing small rounded grains or truncated embayments of quartz, described by other workers as "pools" or "droplets". Accessory minerals include sphene, apatite, and minute zircons.

Quartz-feldspar-biotite varieties are much the commoner type of paragranelite but the hills of Kangui and Tivai, and the whaleback of Syumbungu, appear to be parts of a band of quartz-feldspar-hornblende paragranelites, distinct from the biotite-bearing rocks in the vicinity, which form the Ukazzi and Myoni hills. They are slightly more compact and even-grained than the latter, and carry hornblende and sometimes garnet (45/335, Kangui) to the exclusion of biotite. Modal analysis shows also that quartz and microcline predominate greatly over plagioclase in samples taken from this postulated hornblende granulite band, while in the nearby biotite granulites, the proportions of the three minerals are about equal. Some modal analyses of the hornblendic rocks, and of the biotite granulites of the adjacent Ukazzi and Myoni hills are given below. The volumetric compositions of the rocks within each group are strikingly similar.

QUARTZ-FELSPAR-HORNBLLENDE PARAGRANULITES OF THE KANGUI-TIVAI GROUP OF HILLS

	45/329	45/335	45/337	45/541	45/628	Mean
	%	%	%	%	%	%
Quartz ..	44	51	41	39	41	43
Microcline ..	33	32	34	46	42	38
Plagioclase ..	18	13	22	13	11	15
Hornblende ..	4	3	Tr.	Tr.	5	2
Iron ores ..	1	1	3	2	1	2

45/329. Tivai.

45/335. Kangui (also carries a little garnet).

45/337. Half a mile west of Kangui.

45/541. Kangui.

45/628. Syumbungu.

QUARTZ-FELSPAR-BIOTITE PARAGRANULITES OF THE UKAZZI-MYONI GROUP OF HILLS

	45/340	45/344	45/347	45/347b	45/348	45/598	Mean
	%	%	%	%	%	%	%
Quartz ..	31	28	33	29	29	33	31
Microcline ..	35	35	33	34	36	32	34
Plagioclase ..	30	35	33	33	32	30	32
Biotite ..	3	2	1	4	3	4	3
Iron ores ..	1	Tr.	Tr.	Tr.	Tr.	1	Tr.

45/340. Myoni.

45/344. Half a mile south of Ukazzi.

45/347. Ukazzi.

45/347b. Ukazzi (also carries a little hornblende).

45/348. One mile north of Ukazzi.

45/598. Nzewani.

Other exposures of hornblende granulite occur in the Mwitamisyi river, on the western boundary of the area, and Katumba appears to be formed of similar rocks, (specimen 45/422), though the evidence on this point is not conclusive, owing to insufficient sampling.

Finally, it is interesting to note that the biotite granulites of Sosoma and Itumbini are structurally aligned, and that samples from them have similar modal compositions:—

QUARTZ-FELSPAR-BIOTITE PARAGRANULITES OF SOSOMA AND ITUMBINI

	45/350	45/357	45/363
	%	%	%
Quartz ..	33	34	34
Microcline ..	28	27	30
Plagioclase ..	36	34	35
Biotite ..	2	4	1
Iron ores ..	1	1	—

45/350. Sosoma.

45/357. Itumbini.

45/363. Sosoma.

(b) *Muscovite Quartzites*

Quartzites were found at only two places in the area, as large blocks about a mile north-east of Methe in the south-west corner of the area, and as small fragments at Kolotea water-hole, near the northern boundary of the area. About a mile south-south-west of the south-west corner of the area, a small ridge called Kangando is formed of muscovite quartzites dipping west-north-west at 30°.

In addition, occasional fragments of unusually fine-grained and slightly felspathic quartzites were found lying on the ground in the area, all resembling layered sandstones, specimen 45/352 from Sosoma in particular. Thin sections, however, show that they are metamorphic in origin, with interlocking granular textures and felspar grains sometimes growing round quartz. Specimens 45/478 and 45/499 (from near Ndeyini and Giraffe Pools respectively) contain sphene, and all are rich in iron ore, particularly specimen 45/478, which also carries yellow garnets and epidote. Specimen 45/518, from the Kalalani valley, 4 miles south-east of the Garissa road, contains pink garnets.

(4) PEGMATITES

Joint planes in the quartz-felspathic granulites are frequently filled with pegmatites, of presumably later origin than the auto-segregation veins already described (p. 7). They are parallel-sided and straight, with sharp but unchilled margins, and are almost always of simple quartz-felspathic composition, the perthitic felspar often predominating over quartz. Their maximum development is reached on Ukazzi hill, where a group of them, each about twelve feet thick, cuts across the north-west face, approximately perpendicular to the foliation dip. These are exceptional, both in their size and in that they carry biotite. Quartz-felspathic pegmatites also occur as segregations and sinuous veins, apparently following neither foliation nor joint directions. Sanders (1954, p. 26) and Saggerson (1957, p. 24) described pegmatites under the heading of Anatectic or Palingenetic rocks, implying that they represent extremes of metasomatic soaking. The straight, parallel-sided pegmatites appear to have filled joint fractures and were presumably locally derived since their composition approximates to that of the host-rocks. They are aligned in fracture systems, because the fractures provided spaces in which the fluids involved in pegmatite formation could crystallize. The irregular, cross-cutting segregations and sinuous veins, with no apparent regional orientation, are presumably of similar origin to the more regular veins, (i.e. emplaced by growth more or less *in situ*), although there are no obvious channels which the pegmatite-forming fluids might have exploited.

(5) METAMORPHOSED IGNEOUS (?) ROCKS

Amphibolites

West-north-west of Kaningo, there is a pit by the Garissa road, the sides of which are formed chiefly of surface limestone, but expose an assortment of hornblende rocks in places. Specimen 45/551 from this locality is an even-grained hornblende gneiss with a good deal of quartz, and a well developed orientation is displayed by the dark green and brown hornblende, which in some grains can be seen passing patchily into pale tremolite. There is also colourless diopside in rare small grains associated with amphibole. Specimen 45/548 is an amphibolite much richer in hornblende, without tremolite, and sericite has taken the place of plagioclase and quartz presumably as a result of retrograde metamorphism; small prisms and grains of brown rutile as well as appreciable amounts of apatite are scattered in profusion throughout the rock, and there are some elongate flakes of brown biotite. Specimen 45/549 is also rich in hornblende, but there is much iron ore, with an appreciable amount of apatite as the only other constituent. These rocks are all dark grey or black in colour and apparently form part of a formation striking more or less north-south.

A bright green rock (specimen 45/552) with a surface sheen, composed entirely of pale green pleochroic actinolite needles with rare tremolite, appears to form a band perpendicular to the amphibolites just described, but it is not possible to be certain on this point, as the field relationships are obscure. Although no talc was visible in the thin section, the rock could perhaps be compared with the actinolitic schists carrying subordinate talc, which were described by Sanders (1954, p. 11) as being associated with amphibolites in the Kitui area.

(6) METAMORPHISM AND GRANITIZATION

The Basement System rocks of Kenya are regarded as comprising regionally folded and metamorphosed Precambrian sediments, mainly argillaceous and arenaceous, with local lenses of calcareous rocks, and basic extrusive rocks and perhaps pene-contemporaneous intrusive rocks. The chief characteristic of the later stages of the metamorphism appears to have been an intensive alkali metasomatism, with soda preceding potash, owing to greater mobility of the smaller Na^+ ion. In this way were formed, from predominantly arenaceous sediments, the quartzo-felspathic paragneisses, with their small amounts of disseminated titaniferous magnetite; and from the more argillaceous sediments, biotite and biotite-hornblende gneisses. The later potassic stages of metasomatism appear to have been resisted by the calcareous rocks, which were transformed into calc-silicate granulites and amphibolites with few potassium minerals. By virtue of the similar ionic properties of Ca^{++} and Na^+ , the sodium ion should have easy access into calcareous environments, while the larger K^+ ion, introduced during a later wave of metasomatism, would probably be excluded from a relatively stable Na/Ca assemblage.

Although it is generally agreed that mobility was not achieved on a large scale in these rocks, there are signs that mobility may have occurred locally, for example at Nzewani, about two miles south of Myoni, where a lens of original pelitic sediment appears to have been squeezed and contorted into an irregular mass of biotite-rich rock, veined by quartzo-felspathic material (Plate I, Fig. (b)). The host-rock is a quartz-felspar-biotite paragneiss, in which almost all vestige of foliation has disappeared, and the general appearance of the rocks at this locality seems to approach that of agmatite, as described and figured by Sanders (1954, Plate III, Fig. 4) from the Kitui area. The small whaleback at Kimuu is composed of intensely contorted and migmatized gneisses (Plate II, Fig. (a)), and on Katumba there has also been contortion and fracturing of pelitic lenses (*see* p. 20 and Plate II, Fig. (b)) with invasion by quartzo-felspathic material. The rocks at these localities were undoubtedly plastic at one time, but probably not molten.

It is possible, however, that differential fusion and recrystallization of low-melting constituents was a relatively widespread phenomenon responsible for the numerous essentially quartzo-felspathic concordant auto-segregation veins (p. 7), which may well be of eutectic composition (*cf.* Sanders, 1954, p. 37). Many of these segregation veins, however, are composed almost entirely of massive quartz, and it is possible that the explanation given

by Sanders (1954, p. 37), for the origin of large quartzite formations, may here have application on a smaller scale: differential fusion is considered to have removed the lower-melting feldspar constituents from the metasomatized granitic rocks, leaving a practically pure quartz rock. It is possible that feldspar so removed would become available in the formation of later cross-cutting, predominantly feldspathic pegmatite veins* (p. 9).

The metamorphic grade of these rocks is that of the sillimanite zone of regional metamorphism (Sanders, 1954, p. 35, and Saggerson, 1957, p. 31). No sillimanite was found in the area, but probably only because no metamorphosed alumina-rich argillaceous rocks are exposed; almandine garnet, however, which is frequently associated with sillimanite, was found in a number of samples.

2. Possible Ultra-basic Intrusive of Post-Baseament System Age

An unusual ferruginous facies developed in calcrete about five miles north-north-west of Sosoma, is tentatively considered to represent part of a small ultrabasic intrusive mass.

Specimen 45/402, a hard brown siliceous rock, is composed of much dark brown iron oxide, with abundant patches and ramifying veinlets of mosaic, finely flamboyant, and even crypto-crystalline quartz, and irregular grains and small veins of opaque oxide. Associated with the siliceous veining are ragged crystals of a pale brown uniaxial mica having undulose cleavage and extinction. Specimen 45/402a can be seen in hand-specimen to be calcareous, and in thin section it displays a reticulate pattern, with pale brown iron oxide and calcite dominant, in which are smaller and more local reticulate patches of darker brown oxide with rounded quartz grains and some calcite. The whole is shot through with streaks and small veins of opaque oxide and there are larger veins of calcite and mosaic and flamboyant quartz. Specimen 45/494 is a fragment of similar rock found at Pangali, and has a pale brown cryptocrystalline base probably of silica, with irregular veins and patches of mainly flamboyant quartz, and much unorientated and ragged pale brown biaxial mica with undulose cleavage and extinction. The micaceous minerals in these rocks strongly resemble the serpentine minerals chrysotile and antigorite and could well be pseudomorphs of them, while in the more calcareous specimen 45/402a just described, some of the patches of darker iron oxide with quartz and calcite are strongly suggestive of olivine pseudomorphs. For these reasons it is tentatively suggested that the brown rocks exposed north of Sosoma may be the highly weathered surface manifestations of a serpentine body of unknown but probably small size, similar to the serpentine rocks found by Crowther (1957, p. 14) at Kamuthengi in the adjacent Mwingi area. The fragment found at Pangali was almost certainly transported there by human agency, and may derive from the outcrop north of Sosoma.

3. Minor Intrusive Rocks

(1) QUARTZ MICROSYENITES

Many loose fragments of purplish quartz microsyenite were found scattered over the area, but parts of only four dykes were seen exposed *in situ*; one in the Kisioni valley about two miles north of Sosoma, two close together on the Sosoma-Kandelongwe track, about one mile east-south-east of Sosoma, and the fourth near the Sosoma-Engamba track, just south of the area boundary. The Kisioni dyke is the best exposed: it is six feet wide, with a 165° trend, and is associated with sandy secondary limestone. Joints are developed at 165°, 70°, and 25°. The rock is feldsparphyric, with phenocrysts up to 2 mm. long aligned sub-parallel to the trend of the dyke. In thin section (specimen 45/355) it is seen to be composed almost entirely of turbid feldspar with traces of Carlsbad and sometimes multiple twinning, probably anorthoclase, forming stout subhedral microphenocrysts and elongate sub-parallel groundmass prisms averaging around 1 mm. in length. A narrow vein of secondary quartz is also visible in the thin section.

*Dr. W. Pulfrey has suggested that the removal of quartz-feldspathic components could equally well have occurred by differential hydrothermal solution without any melting.

The two dykes on the Sosoma-Kandelongwe track are exposed only in disconnected patches over a small area. One specimen (45/412a) is strongly porphyritic, with phenocrysts up to 5 mm. long, some of fresh sanidine (?), some of sericitized anorthoclase* with small multiple-twinned relics. Both varieties of feldspar have turbid outer rims. The groundmass consists chiefly of small stout interlocking altered alkali feldspar prisms, with a little quartz and granular iron ore. Short veins of opaque iron oxide cut the large phenocrysts, and an irregular grain of sphene, associated with iron ore, can be seen in the slide. The second of these two dykes (specimen 45/412) is also strongly porphyritic, but with smaller and more turbid phenocrysts and a little more quartz in the groundmass. The chief difference is in the iron ore, however, which is markedly acicular, and probably pseudomorphoses aegirine (cf. Baker, 1964, p. 6). A similar though only sparsely porphyritic rock occurs as numerous green and purplish fragments (specimens 45/535, 537), clearly marking the site of another dyke, a few hundred yards west of the Sosoma-Engamba track, just south of the area boundary. In some of the loose microsyenite fragments in the area (e.g. specimen 45/359 from near Sosoma), there are small grains of what appears to be colourless epidote associated with the larger grains of iron ore, and in others, such as specimen 45/371b from Sosoma, interstitial quartz patches are more numerous than in the specimens described above and up to $\frac{1}{2}$ mm. across.

Aegirine-bearing rocks of the types just described occupy a place between quartz microsyenites proper and tinguaies, both of which have been described by Baker (1964, p. 7) from the Endau area and by Rix (1964, p. 14) from the Enyali-Ndiandaza area, south of the present area.

(2) OTHER AEGIRINE-BEARING ROCKS

These were nowhere found *in situ*, but are so distinctive as to merit description. There are two types, aegirine-bearing quartz microsyenites, different from those just described, and aegirine-bearing porphyries. The former were nearly all found at Sosoma and Myoni, but almost exclusively as artefact flakes (see p. 17). They are bluish grey rocks with light grey weathering surfaces, sparsely speckled with feldspar and aegirine phenocrysts. The feldspar phenocrysts, possibly originally anorthoclase, are strongly zeolitized, with turbid margins (e.g. specimen 45/370, Fig. 2 (a)). The granular quartzo-feldspathic groundmass contains numerous needles of fresh aegirine, only rarely pseudomorphosed by iron ore.

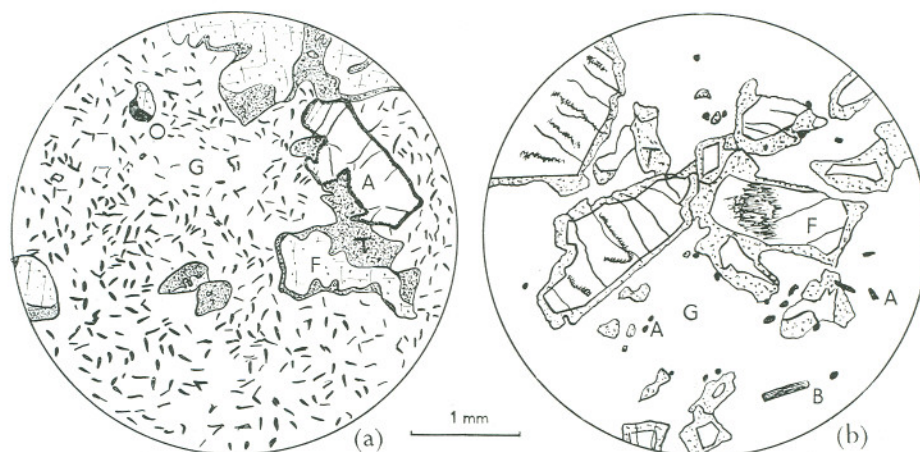


Fig. 2—Drawings of photomicrographs of aegirine-bearing intrusive rocks from the Ndeyini area.

- (a) Specimen 45/370, Sosoma, Ordinary light, $\times 15$. F=zeolitized feldspar; T=turbid feldspar; A=aegirine; O=iron ore; G=groundmass of turbid finely granular feldspar, with needles of aegirine partly pseudomorphosed by iron ore (black dashes) and some quartz grains.
- (b) Specimen 45/371, Sosoma, Ordinary light, $\times 15$. F=relatively clear orthoclase; T=reaction rims of turbid feldspar; A=larger aegirine grains, pseudomorphosed by iron ore; B=rare biotite; G=groundmass of finely granular feldspar and aegirine.

*The feldspars in the minor intrusive rocks found in the Ndeyini area are probably all members of the sanidine-anorthoclase cryptoperthite series of Tuttle (1952) and Mackenzie and Smith (1956).

The aegirine-bearing porphyries, mostly found at Sosoma, are greenish grey rocks with brown weathering surfaces, liberally speckled with dark felspar phenocrysts, which in thin section are seen to be relatively clear sanidine having turbid and ore-speckled rims. The quartz-free groundmass is composed of granular and relatively fresh sanidine (?), with some irregular comb-textured vein-like aggregates of turbid elongate anorthoclase (?). It carries appreciable amounts of granular aegirine and iron ore, rare biotite flakes (specimen 45/371, Fig. 2 (b)), and sometimes well-scattered rutile granules (specimen 45/375a).

(3) LAMPROPHYRES

In the Mwitamisi valley, about three miles from the western margin of the area, a poorly exposed camptonite dyke, two feet wide and trending at 120° , cuts the Basement System rocks. It is a black fine-grained rock with a brown weathering skin. In thin section (specimen 45/654, Fig. 3 (a)) it is seen to be porphyritic: the phenocrysts, up to 4 mm. long, are of fresh, euhedral, slightly purplish augite. The groundmass is extremely fine-grained, and consists of altered acicular barkevikite, alkali feldspar, augite, iron ore grains, possibly a little nepheline, and small patches of brownish yellow serpentine, probably pseudomorphing small olivine phenocrysts. Sanders (1954, p. 34) describes similar lamprophyres, crowded with such brownish yellow olivine pseudomorphs.

In the Nthunguthu valley, north of Twamagau, in the area to the west (Mwingi area) is a dyke of greenish fine-grained camptonite, twenty feet in width and trending at 140° . This rock (specimen 45/539) is non-porphyritic, but has many irregular amygdaloids of fibrous green chlorite; it is chiefly composed of altered alkali feldspar laths, acicular barkevikite, a little granular colourless pyroxene, and iron ore grains. There are also patches of later crystallized calcite and epidote.

Similar lamprophyre dykes have been described from other Kitui District areas (Sanders, 1954, p. 33; Baker, 1964, p. 7; Rix, 1964, p. 14). They are probably all related to the syenite intrusions exposed in the Endau area (Baker, 1964) and the Enyali area (Rix, 1964), and considered tentatively by Baker (1964, p. 4) to be of late Mesozoic or Tertiary age.

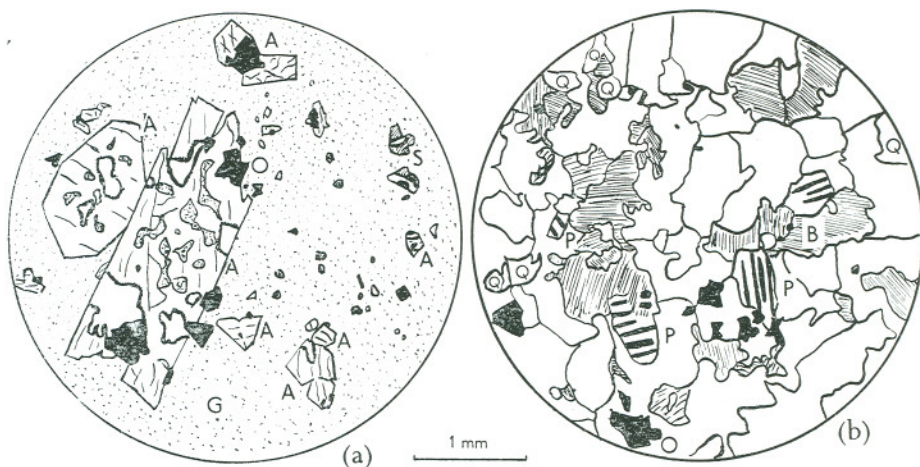


Fig. 3—Drawings of photomicrographs of (a) camptonite, and (b) mafic syenite (?) of possible hybrid origin from the Ndeyini area.

(a) Specimen 45/654, Mwitamisi valley. Ordinary light, $\times 15$. A = augite; S = serpentine (?), possibly pseudomorphous after olivine; G = fine-grained groundmass (stippled) with small serpentine (?) patches, iron ore, pyroxene, and altered barkevikite granules; O = iron ore; stippled patches in augite are irregular inclusions of groundmass material.

(b) Specimen 45/506, Giraffe Pool. Crossed nicols, $\times 15$. P = sodic plagioclase; q = quartz; O = iron ore; B = biotite and hornblende with secondary chlorite and calcite; orthoclase, blank.

PLATE I



Fig. (a). Well-developed concordant pegmatitic segregation veins in quartzo-felspathic paragonulite, near Kangui.



Fig. (b). Intensely contorted and veined biotite-rich inclusion in quartzo-felspathic paragonulite, Nzewani. Hammer handle lies along the faint foliation strike.

PLATE II



Fig. (a). Contorted pelitic lenses in migmatitic gneisses, Kimuu.

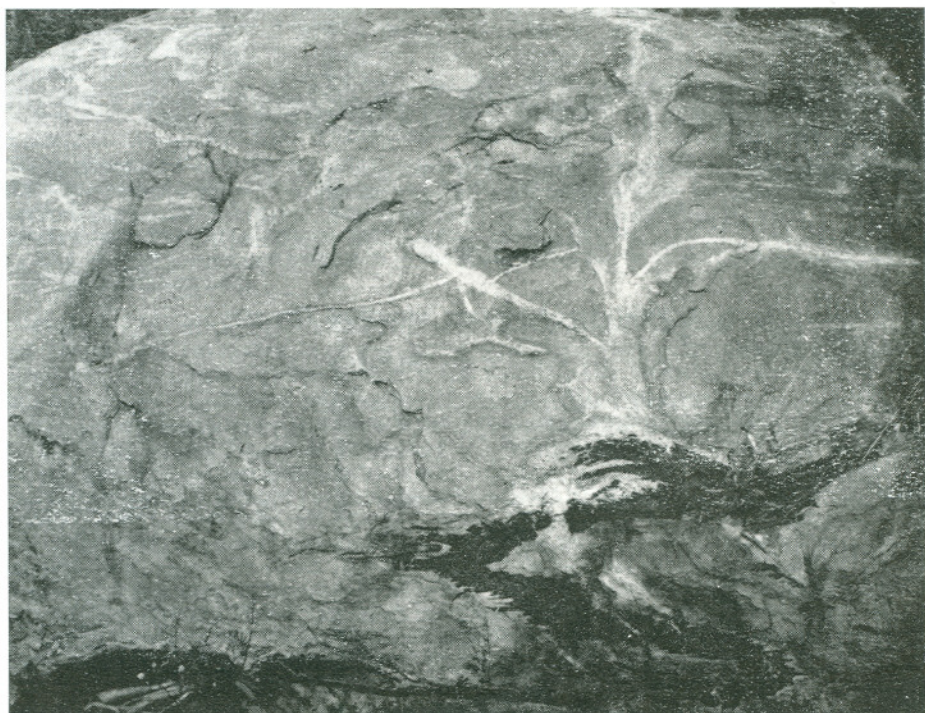


Fig. (b). Slip-folded pelitic lens with quartzo-felspathic veining, Katumba.

(4) OTHER ERUPTIVE ROCKS

A small rounded boulder of an interesting biotite-rich rock, found near Giraffe Pool¹ on a Galla grave-mound, is probably derived from an intrusion having affinities with the syenites mentioned above. It is characterized (specimen 45/506, Fig. 3 (b)) by the raggedness and irregular textures of its constituent minerals. Orthoclase and fresh sodic plagioclase, the former predominating, compose over half the rock. The remainder consists of strongly pleochroic dark brown to almost colourless biotite, frequently intergrown with hornblende, and often with secondary chlorite and calcite. Quartz, iron ore, and much accessory apatite are also present. The rock is a mafic quartz syenite, possibly a hybrid variety, judging from its textures.

Numerous fragments of phonolites that probably originated far to the west were found in the area, mainly at Sosoma. There appear to be two varieties, fragments of the first variety being grey with fracture surfaces of recent appearance, and containing elongate phenocrysts of feldspar. In thin section (specimen 45/322a), the Carlsbad-twinned sanidine (?) phenocrysts are seen to be mainly clear and fresh, but with marginal zones rich in iron ore dust and irregular in outline. Rare microphenocrysts of pale green pyroxene occur (one of them partly surrounded by a feldspar phenocryst), and the slide shows two large irregular biotite crystals, pleochroic from pale yellow to deep foxy red, which may possibly result from some soda enrichment. One of these surrounds a resorbed olivine crystal, is intergrown at one end with an irregular kataphorite crystal and encloses a cluster of apatite crystals at the other. The second biotite crystal encloses apatite crystals and is also intergrown at one end with irregular kataphorite, an irregular olivine remnant being enclosed by both minerals. The groundmass of the rock consists of acicular alkali feldspar probably similar to the phenocrysts, with poikilitic patches of nepheline, cossyrite, kataphorite and aegirine. Aegirine is also often concentrated about numerous rounded amygdaloidal patches of analcite, which probably also forms the isotropic base to the groundmass.

The second variety (specimen 45/324) is also grey in colour, but has a brown weathering rind, and is slightly coarser in grain. There is a 7 mm. phenocryst of zeolitized anorthoclase in one slide and a smaller fresh clear one of sanidine appearance showing signs of attack by groundmass material. The groundmass ferromagnesian minerals are the same as in the first variety, but are less in amount and have intersertal rather than poikilitic habit towards the alkali feldspar laths. Zeolites, chiefly analcite, are plentiful in the groundmass, although no distinct amygdales were seen; nepheline was not positively identified but is no doubt present. Apatite is present and forms rare microphenocrysts, and there are occasional amygdales of dark amorphous substance. This rock bears similarities to the Yatta Plateau phonolites described by Dodson (1953, p. 17) and Saggerson (1957, p. 28).

Rare fragments of vesicular glassy trachyte were also collected in which needles of alkali feldspar in small irregular stellate clusters are the only recognizable mineral (specimen 45/368, Sosoma). A piece of tuff found at Sosoma (specimen 45/323a) is chiefly composed of grey-brown glass with fragments of sanidine (?) crystals, and occasional rounded inclusions of altered trachyte.

4. Pleistocene to Recent Superficial Deposits

(1) PLEISTOCENE SEDIMENTS

At three places in the area small exposures of arkosic grits were found. They are bedded but poorly sorted, cemented with calcite, and were all found near present drainage lines. The largest outcrop occurs just south of the Mashamba valley, a mile north of Boloini water-hole; another was found 3½ miles south-east of the Garissa road, in the Kalalani valley; and the third rests on gneisses, about half a mile north of Mandongoi, on the Ngomeni-Tata river track. Similar grits occur to the south, in the Endau area (Baker, 1964, p. 9), and are regarded as Pleistocene, being probably thin extensions of the main sedimentary series deposited on the peneplain further east.

Unconsolidated sheets composed mainly of rounded brown quartz pebbles (with altered cleavage fragments of feldspar as the second most common constituent) are quite common, particularly in the south-west corner of the area, where they form a continuation of widespread conglomerates described by Baker from the Endau area, and considered by

him to be of Pleistocene age (Baker, *op. cit.*, p. 9). The pebble sheets are probably in part residual deposits, settled *in situ* by erosion of the sand and silt matrix from pebbly facies of the grits, but may be in part of fluvial origin rather than directly derived from older sediments. Most of the exotic float fragments of minor intrusive and other rocks were found in these pebble deposits. There is a good exposure of pebbles resting directly on altered gneisses about $2\frac{1}{2}$ miles north-east of Ukazzi, and another of pebbles banked against gneisses about $2\frac{1}{2}$ miles north-east of Kapingo in the north-west corner of the area—pebbly ferricrete is also well developed here.

Although the sediments exposed in the Ndeyini area are probably of Pleistocene age, it is possible that in the east of the area they are underlain by Upper Pliocene deposits, laid down before the main phase of tilting and uplift occurred (p. 2). At least some of the pebble sheets in the east of the area may be derived in part from such earlier sediments, which also include a considerable proportion of grit and pebbles (Dixey, 1948, p. 11). Dodson has described conglomerates and grits, the Massissini Series, which he considered to be of Tertiary age, from the North Kitui area, to the north-west, regarding pebble sheets derived from them as Pleistocene (Dodson, 1955, p. 20). The series can probably be correlated with the postulated upper Pliocene sediments in the Endau and Ndeyini areas. Later work in areas further north has strengthened this view (Wright, Korah Wells area).

(2) CALCAREOUS CRUSTAL DEPOSITS

Calcareous superficial deposits are fairly widespread, mainly in the south-west part of the area. They are usually irregular sheets forming low mounds, but there are two northerly-trending ridges formed of them: one of these occurs where the Tangini river crosses the Garissa road, and the other is situated south of the Mwitamisi river, in the north-west corner of the area. The ridges are presumably derived from underlying metamorphosed calcareous bands, but the more irregular sheets, particularly those in the east, probably developed in superficial sediments.

Surface limestone sheets owe their formation to leaching during rainy seasons, followed by upward capillary migration and deposition during intervening dry periods. Secondary limestones can be seen forming locally at the present day, from calc-silicate rocks, semipelitic gneisses, amphibolites, and microsyenites, where these rocks are exposed. The limestones vary from pale pink and grey in colour to muddy black, and are usually nodular, rubbly, and gritty, but sometimes develop locally pure and cream-coloured facies, or a fine undulose lamination. The most interesting variety, however, is pisolitic, and is quite common. The pisolites vary in size from 2 to 10 mm. across, and are formed (specimen 45/354) of relatively pure calcite, with well-defined reddish rims, while silty material and angular detrital grains, including quartz, fresh microcline and plagioclase, sphene, hornblende and altered biotite, are concentrated in the spaces between them. They presumably owe their origin to gradual concentration of calcite during later stages of development of the rocks. The best exposures of such limestones were seen in the Tula valley north of Ndeyini, where there are sections up to 20 feet high.

Wherever they are found together, the superficial limestone deposits are overlain by the pebble sheets. The best example of this can be seen in the Hoti valley about a mile west of Pangali, where roadside diggings expose a few feet of gritty limestone overlain by an unconsolidated layer of rounded pebbles, mainly quartz. Another good exposure of this type of association occurs about a mile south-south-east of Pangali, where there is a steep east-west-trending bank (El Togocho) about 40 or 50 feet high and formed of gritty and pebbly calcrete with a thin layer of quartz pebbles on the top. The relatively steep and high southern bank of the valley near the old Army camp at Walesa on the Pangali-Yanzeu track, is formed of similar rocks, capped by pebbles and sand. Occurrences of pebbles thinly overlying calcrete deposits are not confined to the eastern part of the area, but they are certainly better developed and commoner there. More recent work in areas where gritty arkosic Upper Pliocene and Pleistocene sediments are relatively well exposed has shown that the association of calcrete with residual thin pebble layers is common (Wright, Korah Wells area). A calcrete layer almost invariably forms the top few feet of the sediments and is of diagenetic origin, so that overlying residual pebbles are not necessarily much younger than the limestone on which they rest.

(3) FERRUGINOUS SUPERFICIAL DEPOSITS

Cellular lateritic ironstones (ferricrete), often gritty, are quite common in the area, and are found as flat sheets of reddish brown rocks, in exposures up to three feet thick, usually exposed at water-holes, and in small patches near stream courses. They frequently contain large quartz pebbles and feldspar fragments. They are also found at the base of quartzofeldspathic gneiss outcrops, where the rocks are poor in ferro-magnesian minerals, but contain disseminated iron ore (magnetite). These ironstones are undoubtedly formed, like the limestones, by leaching during rainy seasons, and subsequent capillary rise of iron-bearing solutions during dry seasons. At Ndeyini Pool, a calcareous gritty ironstone has been broken down and incorporated as fragments in a later pink calcrete deposit.

Ferruginous pellets and the small exposures of massive ferricrete occur mainly on watersheds in the western part of the area, which is regarded as part of the dissected end-Tertiary peneplain (p. 2). Such deposits are typical of the end-Tertiary surface in Kenya (cf. Joubert 1963, p. 3), and of other erosion surfaces in similar environments.

(4) SILICEOUS SUPERFICIAL DEPOSITS

Near the Kisioni river, about six miles south-east of Sosoma, occur many blocks of conchoidally-fracturing siliceous rocks, possibly *silicified breccias*. Specimens 45/449 and 45/451 are greenish and purplish in colour respectively, with pink angular fragments embedded in them. Thin sections show them to consist of angular grains, of all sizes up to 1.5 mm., of quartz and feldspar, in a fine-grained siliceous matrix cut by small irregular veins of comb-textured quartz. There are also patches of calcite, and shreds of chlorite and pale mica. The edges of the calcite and the larger clastic grains are fretted. Occasional small boulders of similar rocks, yellow in colour (e.g. specimen 45/701), were found in the region round Boloini water-hole. These rock fragments resemble a silicified fault-breccia found by Baker (verbal communication) in the Endau area, in which were embedded blocks of quartzofeldspathic granulite up to a foot across. Mason and Gibson (1957, p. 23), found similar rocks in the Kalossia-Tiati area developed along a clearly defined fault-line. Again, in the Kisioni valley, about half a mile north of the Garissa road, are large blocks of bright green silicified breccia, with veins and patches of calcite and pink quartz-feldspathic material. They carry little feldspar, much clastic quartz, and considerable amounts of granular epidote, both in irregular patches and interstitially in the uneven-grained siliceous matrix (specimens 45/418, 418a)*.

In contrast to the presumed silicified breccias are conchoidally fracturing, fine-grained *silcretes* which are typically uniformly white, grey, pink or purplish, and are found in large numbers as loose fragments in the area. The only occurrence found *in situ* is on the north side of the Garissa road, at the Kwakutu valley crossing, where it is surrounded by superficial limestone. The rock (specimen 45/404), is greenish grey in colour, consisting mainly of a fine siliceous mosaic with rather rare clastic fragments of quartz, feldspar and occasional carbonate. Fretted edges are developed round the clastic grains as in the breccias. The mode of occurrence of the rock indicates a concretionary origin within the calcrete by which it is surrounded. Mountain (1945, p. xxxi), describing the peneplain silcretes of the Eastern Province, South Africa, recorded that there is no evidence of silcrete replacing or being associated with limestone. Debenham (1952, p. 13), on the other hand, remarked in his descriptions of the Kalahari desert, that leaching and subsequent deposition of lime and silica have produced superficial deposits consisting of an upper calcrete layer and a lower silcrete layer, the one grading into the other.

Owing to lack of exposure in the Ndeyini area, it is not possible to draw a hard and fast line between rocks described as silicified breccias, and those termed silcretes, for they have so many features in common. As an example of these difficulties, Fairburn (1963, p. 24)

*Dr. W. Pulfrey has pointed out that from their appearance these rocks could as well be breccias formed by siliceous cementation of angular detrital fragments.

found in the North Machakos-Thika area a siliceous breccia-like rock which, however, he was able to identify as a silcrete formed when gneiss debris was sealed beneath Tertiary lava. A few chips of opaline silica were also found, mainly at Myoni (e.g. specimen 45/611) among the numerous artefact chips occurring there.

(5) ALLUVIAL DEPOSITS

River deposits in the area include pale-coloured sand flooring the better-developed drainage channels, and alluvium containing varying amounts of sand, silt, and clay. Where the drainage is relatively good, as along the Mwitamsiyi valley and in the Matia near Ukazzi, the alluvium is reddish in colour. In areas of poorer drainage, as along the Nthunguthu/Tula, the alluvium is brown, finer-grained, and forms shrinkage cracks on drying. In many places along the drainage channels virtual stagnation occurs during wet seasons, and here the alluvium is similar, but grey in colour, and shrinkage is more pronounced on drying. (Black-cotton soil is presumably the end product of this process, resulting from complete stagnation).

Seasonal pans and water-holes on the red sandy soil terrain which covers most of the area, usually have a red or brown floor of clayey material which prevents the water seeping away. On the flat areas of grey plains soils in the east (*see below*), however, the water-holes are floored by grey clays.

(6) SOILS

Small patches of *black-cotton soil*, without bush cover, occur in the north-west corner of the area in places where the drainage is poor. They contain nodular calcareous concretions of kunkar limestone (p. 15).

Broad expanses of grey and black *silty plains soils*, similar to the grey alluvium described above, cover much of the ground near the eastern margin of the southern part of the area, and are wide-spread further east. Such soils are typically developed in flat areas of poor drainage, and were probably established here and more extensively further east as a result of sediments deposited on the tilted peneplain, lowering the gradients of rivers flowing east across the area. Sand, usually white but occasionally with a pink tinge, is sometimes associated with the grey soils, which also contain nodular kunkar concretions.

The rest of the area is covered with red, quartzose, sandy, *low humic soils*, supporting the thick thorn-bush vegetation. In river-courses where there is run-off from rocks and hills, as Ukazzi and Sosoma, the sands are white, owing to the rubbing away of the surface colouring films of iron oxide on grains during transport. In areas of poor drainage, however, where grey soils predominate (*see above*) the pale colour of the sands is probably due to inhibition of oxide formation—stagnant water is a relatively strong natural reducing agent.

(7) ARTEFACT FLAKES

Numerous artefact flakes were found in the area, the great majority of them concentrated in a small area a few hundred yards south-west of Myoni dam. There is a smaller concentration at Sosoma, and others were collected in small numbers from various localities throughout the area. The flakes are made of a variety of materials, the most common being quartz, opaline silica, silcrete, and greenish aegirine-bearing quartz microsyenite. One collected is made of quartz-felspathic gneiss. A small number of the flakes was shown to Dr. L. S. B. Leakey of the Coryndon Museum, who identified those made of quartz (specimen 45/371c) as belonging to the Stillbay culture of Upper Palaeolithic age. The other flakes, representing the majority of samples collected, he found to be of no diagnostic value.

VI—STRUCTURE

Foliation of the Basement System rocks in Kenya has been established by others as parallel to the original bedding. The general structural grain of the rocks over much of the country is approximately north-south.

but there is a subsidiary statistical axis (β') with gentle northerly plunge, whose direction is defined by the strike of vertical and steeply dipping beds in a number of exposures. The second axis is close to the dominant axial direction in the Basement System gneisses of Kenya. In an area of poor exposure such as this it is impossible to assess whether these two statistical directions are the result of more than usually pronounced lateral variation in the regional fold-axis, or to cross-folding, but it is felt that the former is the more likely alternative.

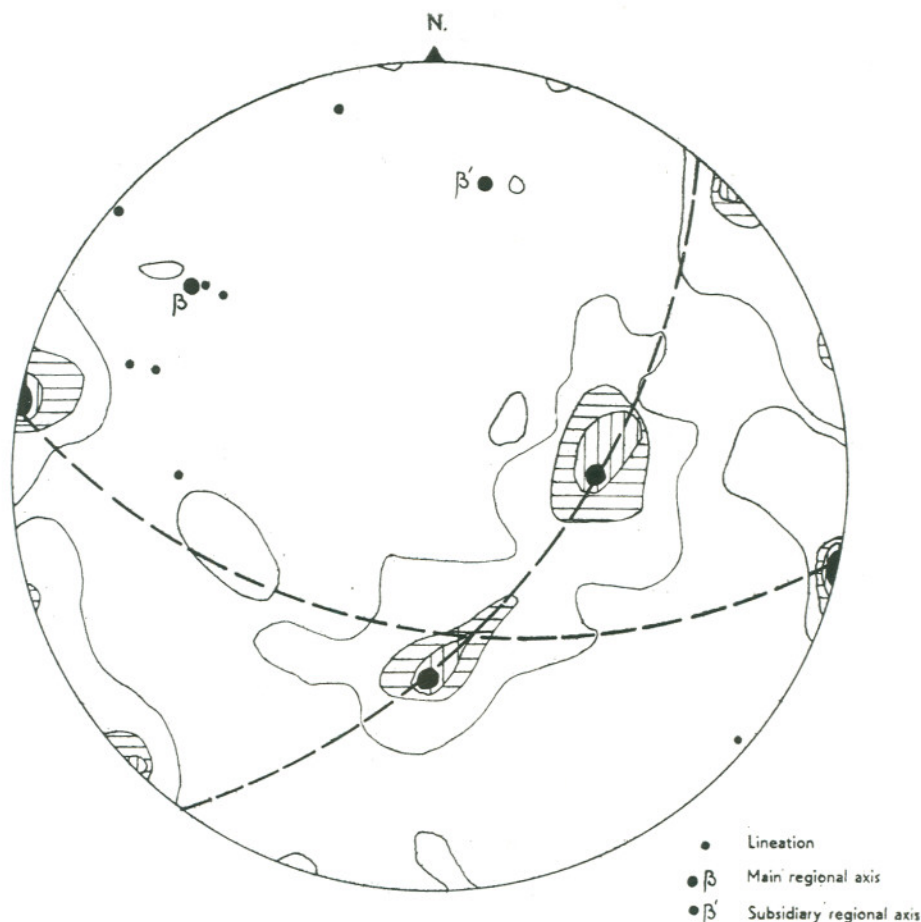


Fig. 5—Composite stereogram of poles to foliations, and lineations, to illustrate structures in the Ndeyini area. Schmidt net projection on lower hemisphere, contours at 2, 6, 8 and 10 per cent per one per cent area.

The axial trend varies mainly between these limits in the Ndeyini area, as indicated by the trends of lineations and vertically dipping rocks, but sometimes strays beyond them. The most extreme divergences are seen at Mkapu, where vertical foliation strikes at 65° , and at Ukazzi, where a lineation plunging due west was seen. The curving trend of the vertical rocks forming the southern end of the Tivai ridge could be due to a curving fold-axis of moderate plunge; but abrupt changes in the strike of steeply dipping foliation, as at Kangui, suggest that locally there are steeply plunging fold-axes, for a horizontal axial swing would have to be very sharp to produce such a feature.

The occurrence of minor movements along the foliation strike of the quartzo-felspathic paragneisses, as a result of lateral slip along bedding planes during folding, is shown by small local crumples, incipient boudinage, and fracturing of concordant segregation veins and pelitic bands, exposed in strike sections perpendicular to the foliation dip (Fig. 6). A

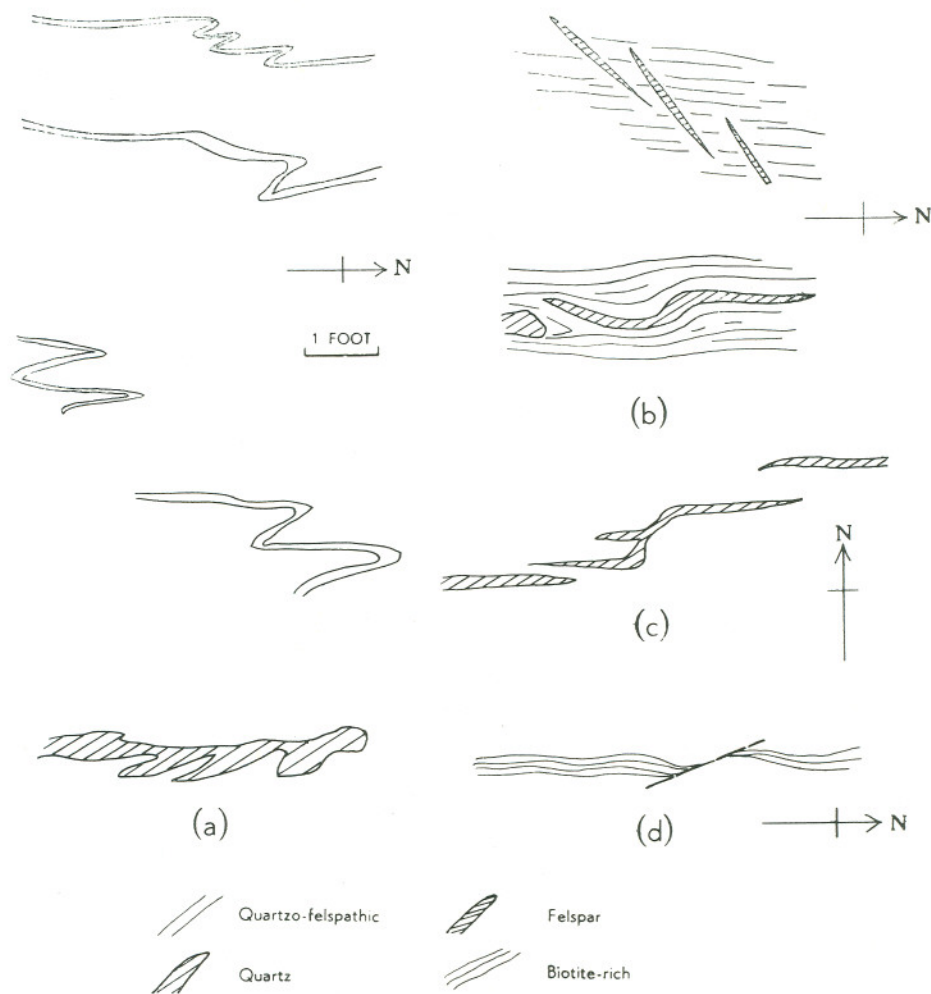


Fig. 6—Minor slip-structures in concordant veins and bands exposed on surfaces perpendicular to the foliation dip of gneisses.

- (a) Southern part of Myoni, strike 180° , dip 45° to 60° west.
- (b) One mile south of Myoni, strike 190° , dip 40° west.
- (c) One mile north of Ukazzi, strike 80° , dip 70° north.
- (d) Itum'ini, strike 175° , dip 70° west.

fine example of stretching and fracture is displayed near the trigonometrical beacon on Katumba, where there is parallel to the foliation an irregular line of large hornblendic inclusions which probably represent an original lens of pelitic sediment torn apart during the folding. The largest of the inclusions carries a sizable lentoid quartzo-felspathic segregation (p. 10). A short distance to the south there is another pelitic band (Plate II, Fig. (b)) which has been slip-folded in the foliation plane (virtually horizontal at this locality) and also invaded by quartzo-felspathic material (p. 10), but here the movement was along the dip direction, for the fold-axes are parallel to the strike. Other contortional features were observed on Kimuu (p. 10) and to a lesser degree on Nguunga (p. 7).

Jointing is common in the harder and more frequently exposed quartzo-felspathic paragneulites and is almost always vertical or steeply inclined. There is an approximately north-west—south-east regional trend, best seen at Ukazzi and Sosoma. Less important, approximately east-west and north-south patterns also occur, and there are strong north-east—south-west joints developed locally round Myoni, which show up well on air photographs as a pseudo-strike. Poles to the joint-planes measured have been plotted on a stereogram



Fig. 7—Stereogram of joint-planes in the Ndeyini area; 92 measurements, contours at 5, 10, 20, 30 and 35 per cent per one per cent area.

(Fig. 7), which summarizes the major trends. The dominant joint direction is parallel to the main statistical fold-axis in the area (Fig. 5), and therefore the main joints appear to form a *bc* set. It is unusual to have *bc* joints dominant and *ac* joints so poorly represented, and the coincidence of the statistical maxima in the two figures may be fortuitous. It is worth noting that there are occasional signs of movement along the *bc* joint direction, for example at Kaningo and Kimuu, and at Kimuu indications of movement along the east-west joint set were also seen.

Although the rocks in the area must have been heavily faulted in common with those further west, the position of only one fault is shown, and that tentatively, its position being inferred from geophysical data.

VII—MINERAL DEPOSITS

1. Barytes

A single small block of barytes was found at Kathungu water-hole, near the Garissa road. The nearest known source of barytes is the Vitengeni lead mine near Kilifi (Thomson, 1956, p. 54); it is probable, despite the distance involved, that the fragment found was brought by human agency.

2. Felspar

Many of the pegmatites cutting the gneisses are composed of nearly pure felspar (p. 9), but they are too small and scattered to be of economic value.

3. Garnet

Garnet was found in some rocks in the north of the area (p. 5), but is much too sparsely disseminated to make attempts at extraction worthwhile.

4. Ironstone

If found in sufficient quantities close to the road, ironstone deposits could be used for road-metal (murrum). The small exposures seen at water-holes (p. 16) are probably parts of relatively large sheets, hidden under surrounding sands and soils. The ironstone is too impure to be considered as iron ore.

5. Limestone

Only impure secondary surface limestones are exposed in the area. They appear to have been worked for road-metal at three pits along the Garissa road—near the western margin of the area, in the middle, about three miles west of the Sosoma turn-off, and further east, in the Hoti valley. The limestones could perhaps be calcined as a source of low quality lime.

6. Pebbles

There are two pits in pebble deposits along the Garissa road, one $2\frac{1}{2}$ miles east of Ukazzi, the other in the Hoti valley. It is not known what the pebbles were used for, unless possibly as a source of silica, for they are mainly of quartz (p. 14).

7. Radioactive minerals

A "Redbox" ratemeter was used throughout the survey, but at no time gave readings above background intensity level.

8. Sand

Small supplies of chiefly quartzose sand could be obtained from the Mwitamisyi river and in parts of the Nthunguthu-Tula drainage, where the channels broaden out.

10. Water-Supply

Three boreholes were drilled by an ALDEV team in the Nthunguthu valley, about eight miles west-north-west of Katumba, during 1952-3, but they were not successful. The sparse details of the operations are given below:—

WATER

No.	Locality	Water Struck	Rest-Level	Total Depth	Remarks
15	$\frac{1}{4}$ m. from S. edge of flood plain.	—	—	10'	Abandoned on striking hard quartz gravel.
16	$\frac{1}{2}$ m. W. of 15, on flood plain S. bank of river.	—	—	21'	
17	Alongside 16 ..	55'	49'	71'	Drill stem lost, hole abandoned. Water sealed by layer of clay at 59', decomposed rock at 66'.

The "hard quartz gravel" struck in borehole No. 15, may be more of the grits described on page 14, but it could also be quartzite or quartzo-felspathic gneiss. The log for borehole No. 17 indicates that considerable amounts of alluvial deposits have accumulated in what must have been originally quite a deep channel (p. 4). If this is true of other drainage channels with broad alluvial plains, more intensive borehole operations along such channels in these arid regions might meet with some success, although it is unlikely that the size of the perched water bodies encountered would be sufficient to yield large perennial supplies. Furthermore, as Munger (1950, p. 580) points out, boreholes, though materially better, are psychologically less suitable for the majority of the local inhabitants than dug wells and dams, which can in any case be more cheaply built and maintained with local labour.

Two dams have been built under the supervision of the Kitui District Agricultural Department, at Ukazzi and Myoni, constructed at the base of steep, almost bare rock faces, to collect the run-off which formerly merely supplied minor seasonal streams and seasonal wells dug in the surrounding sands (small wells were also seen about one mile north-west of Kangui, but they appear to be impermanent sources of water). The dams provide a perennial water-supply, except possibly in years of particularly low rainfall. Dug wells at the Sosoma inselbergs hold water for three to four months after rain. Apart from these, Pangali wells, which are about twenty feet deep and dug in sand, are the only other source of water approaching permanence from Ukazzi eastwards to the Tana river. There is no properly developed drainage channel visible at the site of the wells, either on the ground or on air photographs; the nearby Hoti valley, as drawn on the map, gives only a general idea of the local drainage trend. Pangali is situated close to the junction between an area of superficial sandy and calcareous deposits on the west, and an expanse of grey and black soils on the east (p. 17). The water-bearing sands probably fill a local basin floored by impervious or semi-pervious clayey rocks (cf. borehole No. 17, page 22, where the water was found to be sealed by clay in depth). In good years the water in the wells is permanent, but when the rains fail, as in 1958, the wells dry out in the hot season.

In his report on the hydrographic survey of the North-Eastern Region, Dixey (1944, appendix VI, p. 19) suggested that to improve water-supplies, properly dug wells should be constructed at Pangali, and that Ndeyini Pool should be deepened. The latter is one of the largest seasonal water-holes in the area, and is conveniently near the Garissa road, but there are other large water-holes which could with advantage also be deepened, notably the group including Giraffe Pool in the north-east corner of the area, and Kathungu, on the Garissa road near the Sosoma turn-off. It is of course necessary to replace the original clay soil floors of the pans after excavation, to prevent the water draining away into the underlying sands. B. H. Baker (verbal communication) has pointed out that the seasonal wells at Sosoma, filled during rainy seasons by run-off from the rocks, could be vastly improved merely by excavating them further. The construction of cement "garlands", low retaining and guiding walls, round the rocks would much increase the quantity of water collected, both at Sosoma and at Ukazzi—as it has done at Ngomeni, in the adjacent Mwingi area. Although particularly applicable at Sosoma, which is already a well-known watering place for cattle, this practice could readily be extended to other low, bare, steep-sided inselbergs, whose run-off during the rains is at present collected in inadequate pits and shallow depressions, e.g. Itumbini. Comparatively little outlay of labour and materials, therefore, would appreciably increase the amount of water available in the area during dry seasons and thus alleviate the biennial congestion at such places as Ukazzi and Ngomeni, as well as ease the task of the women, who must often carry water over great distances in the drier months.

VIII—GEOPHYSICAL SURVEY

The instruments used for the survey were a Worden portable gravimeter and a Hilger and Watts vertical magnetic force variometer. Thick bush cover made a network survey impracticable, so traverses were made along all but one of the motorable tracks in the area, stations being selected at approximately one-mile intervals or less, sometimes at two-mile intervals. The traverses covered are indicated in Fig. 8.

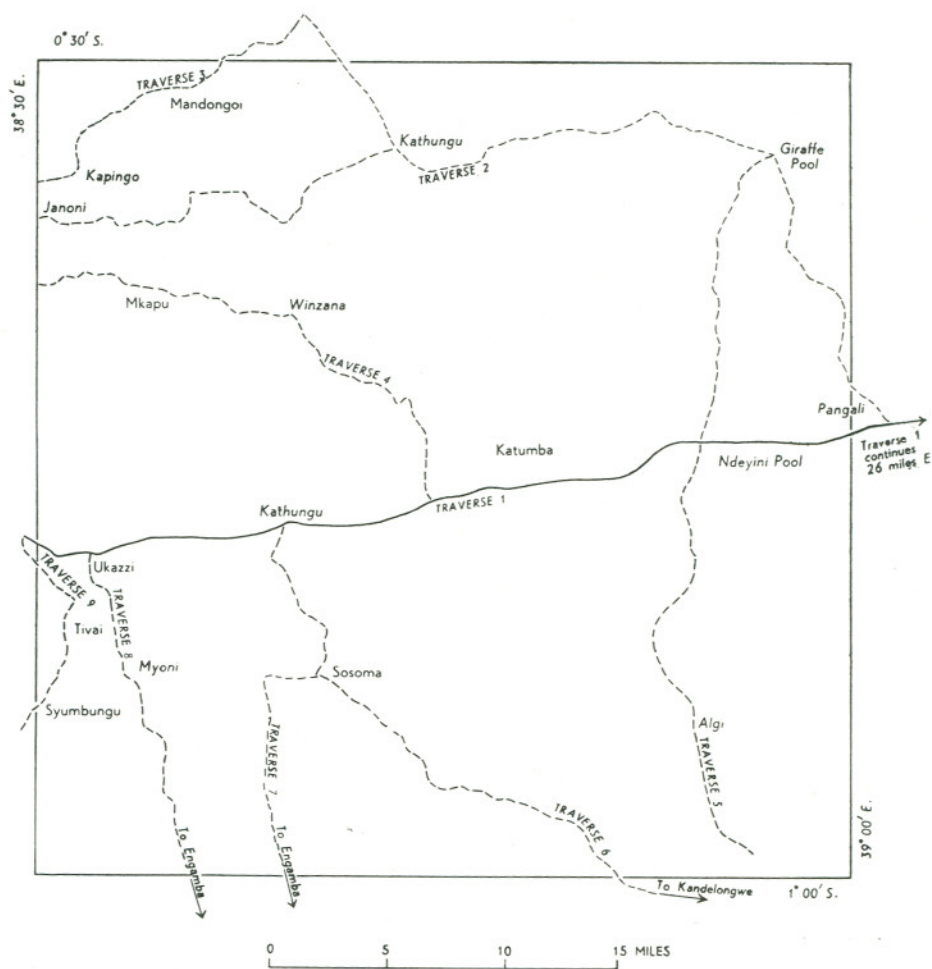


Fig. 8—Geophysical traverses in the Ndeyini area.

1. Gravity Measurements

Heights in the area are accurately known only along the Garissa road, at geodetically levelled bench-marks near all the mile-posts. The bench-marks are difficult to find, however, so that along the road measurements were made near the mile posts themselves, and the altitudes of main road stations may therefore be taken as known to the nearest foot, their positions to within a few feet. Along other traverses, however, the altitude values, obtained by means of an aneroid, though in a few places possibly reliable to within five feet (owing to numerous repeated readings), may in many others be up to 50 feet or more in error—and this despite calibration of the aneroid every day, by diurnal variation curves and readings at the mile-posts of known altitude.* Furthermore, although the positions of many stations are known to within a few feet, many others were in featureless bush, selected at mile or two-mile intervals according to a vehicle speedometer. For these stations the positional uncertainty may be as much as two hundred yards. Fortunately, however, this is not a source of error at present, but would become important should the survey be repeated. In the circumstances, the gravity profiles can be expected to provide only general anomaly patterns.

*At the level of Ukazzi, used as datum, and given as 1,930 ft. above M.S.L., a difference of ± 10 ft. in altitude determination would affect the corrected gravity reading by ± 0.6 milligal.

Readings were repeated morning and evening at convenient stations, to allow corrections for overnight and diurnal drift to be made. The diurnal drift was usually positive and was assumed linear, a valid approximation for such a general survey. The overnight drift also was usually positive, and for each day was added to the accumulated drift of the previous days, thus increasing the daily correction to be made as the survey proceeded. All readings were corrected with reference to Ukazzi, chosen for convenience as the area datum.

After converting the drift-corrected gravimeter readings to milligals, with the given scale factor of 0.08748 mgl. per division, topographic corrections were applied, using elevation correction factors of 0.0598 and, for one traverse only, 0.737, calculated according to the formula:—

$$h(0.09406 - 0.0127\rho)\text{mgl.}$$

using density values: $\rho = 2.7$ (gneiss) and $\rho = 1.6$ (sand), respectively. Terrain corrections (almost negligible here) were made for the rare stations sited near larger hills, using a 1:83,333 scale zone-chart and tables in Jakosky (1950, p. 406). Latitude corrections were also applied, determined for each station with a 1:83,333 scale minute interval chart and a correction graph based on the formula:—

$$g = 978.0373 (1 \times 0.0052891 \sin^2 \varphi - 0.0000059 \sin^2 \varphi),$$

where φ is the latitude.

Traverse profiles were then plotted from the final corrected Bouguer anomaly values (Fig. 10, at end).

The most reliable anomaly curve is that having least correlation with topography, being therefore neither an imitation nor a reflection of it. To this end, established procedure is to calculate anomaly values using different elevation correction factors, corresponding to different densities of possible sub-surface rocks, until the best profile is found. In the present area, however, altitude values differ only slightly from station to station, and hence the products of their multiplication by the two factors vary little relative to one another. To illustrate this, two profiles have been drawn for Traverse 1, using factors corresponding to gneiss and sand as the sub-surface material. The curves are almost identical in shape, so that an optimum profile would be difficult to recognize, and for a general survey such as this, where only major anomalies are sought, it is pointless to draw two or more curves, one being sufficient to show the overall general anomaly pattern.

2. Magnetic Measurements

The medium strength auxiliary magnet was used with the instrument throughout the survey; this was unnecessary, because the instrument could have been re-set for the area, but unimportant since the range of anomaly was adequately covered. Since in this survey also only major anomalies were sought, variations in temperature and the ambient field could be considered as having a negligible effect on the readings. It was therefore necessary only to convert the readings to gamma values using the given scale factor of 30.8 gamma per scale division, and to add to them the values calculated for different positions of the auxiliary magnet, according to the formula:—

$$\text{Magnet value} = \frac{F \cdot 10^5}{d^3} \text{ gamma,}$$

where F is the auxiliary magnet correction factor, given for the instrument used as 747.5 gauss (1 gauss = 10^5 gamma), and d is the distance of the auxiliary magnet from the variometer system, maintained at between 32.00 and 37.00 cm. during the survey.

Magnetic anomaly profiles (Fig. 11 at end) were plotted for each traverse, using Ukazzi as the most convenient magnetic datum, to which all measured values are referred.

3. Discussion of Geophysical Profiles

(a) Gravity Profiles

The general trend of the gravity profiles (Fig. 10, at end) is usually a gentle rise to eastwards, which is probably the result of some systematic error in the measurement or the application of corrections, but cannot affect the detection of important anomalies. Small fluctuations in the gravity profiles must in many instances be due to the uncertainty of altitude determination and it is therefore profitless to discuss them. They do not materially affect the form of major anomalies.

The most striking anomaly found during the survey is a positive one of nearly thirty milligals relative intensity, extending some twenty miles eastward from about five miles inside the eastern boundary of the area, along the Garissa road (Traverse 1). The anomaly must be due to a large mass of relatively high density, probably having a roughly north-north-west to south-south-east elongation, for the profile of Traverse 2 rises gently eastwards, and then levels off, where the traverse swings south-south-east towards Pangali, at anomaly values approximating closely to those on the western slope of the peak shown in the profile of Traverse 1; and the profile of Traverse 5, with a south-south-westerly trend, falls away gradually from values of similar magnitude. It is the area in the region of this anomaly which would perhaps repay further investigations.

Further east along Traverse 1, there is a sharp monoclinical rise in the profile, where it crosses the gypsum deposits being worked by Diaclem Ltd. in the Tule valley. It coincides with a rise in the terrain profile, but as correction has been made for this, the anomaly may have some significance (cf. the magnetic results for Traverse 1, below).

Near the southern end of Traverse 5, on July 10th, 1958, between about 10 and 11 a.m., there was an earth tremor, which disturbed the instrument and made measurement impossible. The time of this tremor was confirmed by the seismic observatory at Entebbe. Although no shock was felt by any person in the area, the extremely sensitive gravimeter easily registered the disturbance.

(b) Magnetic profiles

The only marked trends in any of the magnetic profiles are to be seen in those of Traverses 5 and 7, which approach respectively the hills of Kandelongwe and Engamba (in the area to the south), both formed of syenite, a rock capable of producing large magnetic anomalies (cf. Rix, 1964, p. 20). The reason why the gravimeter registered little change on approach to these masses, is that their densities are similar to those of Basement System gneisses.

Almost all the fluctuations in the magnetic profiles can be regarded as due either to variation in composition of sub-surface rocks with respect to magnetic constituents, or to their depth of burial or, of course, to both. Owing to the general nature of the survey, it is impossible even to attempt to account satisfactorily for many of the magnetic anomalies, even large ones, seen in the profiles.

There is as a rule little correlation between the gravity and magnetic profiles, but there is some agreement at the large gravity anomaly described above, east of Pangali along Traverse 1: here there is a marked high in the magnetic profile which descends gradually eastwards from Ukazzi. This high corresponds with the upper eastern slope of the gravity peak, and a relative low occurs where there is a shoulder on the gravity slope. Thereafter, while the gravity profile continues to fall away, the magnetic profile swings upwards again, forming a second high. The magnetic anomaly is not great, and therefore the mass responsible for the strong gravity anomaly is unlikely to consist of very strongly magnetic material.

The profiles of Traverse 6 are the only others showing any degree of correlation between magnetic and gravity anomalies, both curves showing peaks in approximately the same localities.

At the Tula gypsum deposits on Traverse 1, there is an appreciable low in the magnetic profile, corresponding exactly with the sharp rise in the gravity curve. The magnetic low may be due to the sands and clays in which the gypsum occurs (Pulfrey, 1942) being augmented by Tula river alluvial deposits, forming a thicker blanket to sub-surface magnetic influences. Other marked magnetic lows, which are probably due to the blanketing effect of considerable thicknesses of superficial deposits, occur in the profiles of Traverses 4 and 5. The intense magnetic low near Tivai, Traverse 9, however is tentatively interpreted as due to a fault separating the biotite gneisses of Nguunga from the quartz-felspar-hornblende paragneisses of Tivai.

There is a relatively large broad peak between Kathungu and Giraffe Pool on Traverse 2, probably because in this vicinity Basement System gneisses are slightly nearer to the surface than elsewhere—they may also be slightly enriched in magnetic constituents. There is, however, no large mass with higher than usual density below the surface here, for the gravity profile gives no indication of anomalies. It is perhaps worth noting that the magnetic peak is roughly on a strike continuation of Katumba to which, however, the instruments gave no response on Traverse 1, which passes close to it.

Acknowledgement

Grateful acknowledgements are due to Dr. D. Masson-Smith, of the Geophysical Section of the Directorate of Overseas Geological Survey, for his assistance in the evaluation of the geophysical measurements, which enabled a summary of simple gravimetric and magnetometric procedure and calculation to be drawn up (Rix & Wright, 1958).

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APPENDIX I

The area to the north of the Ndeyini area was entered a few times during the survey, and a certain amount of geological information collected, particularly in the small portion shown in Fig. 9.

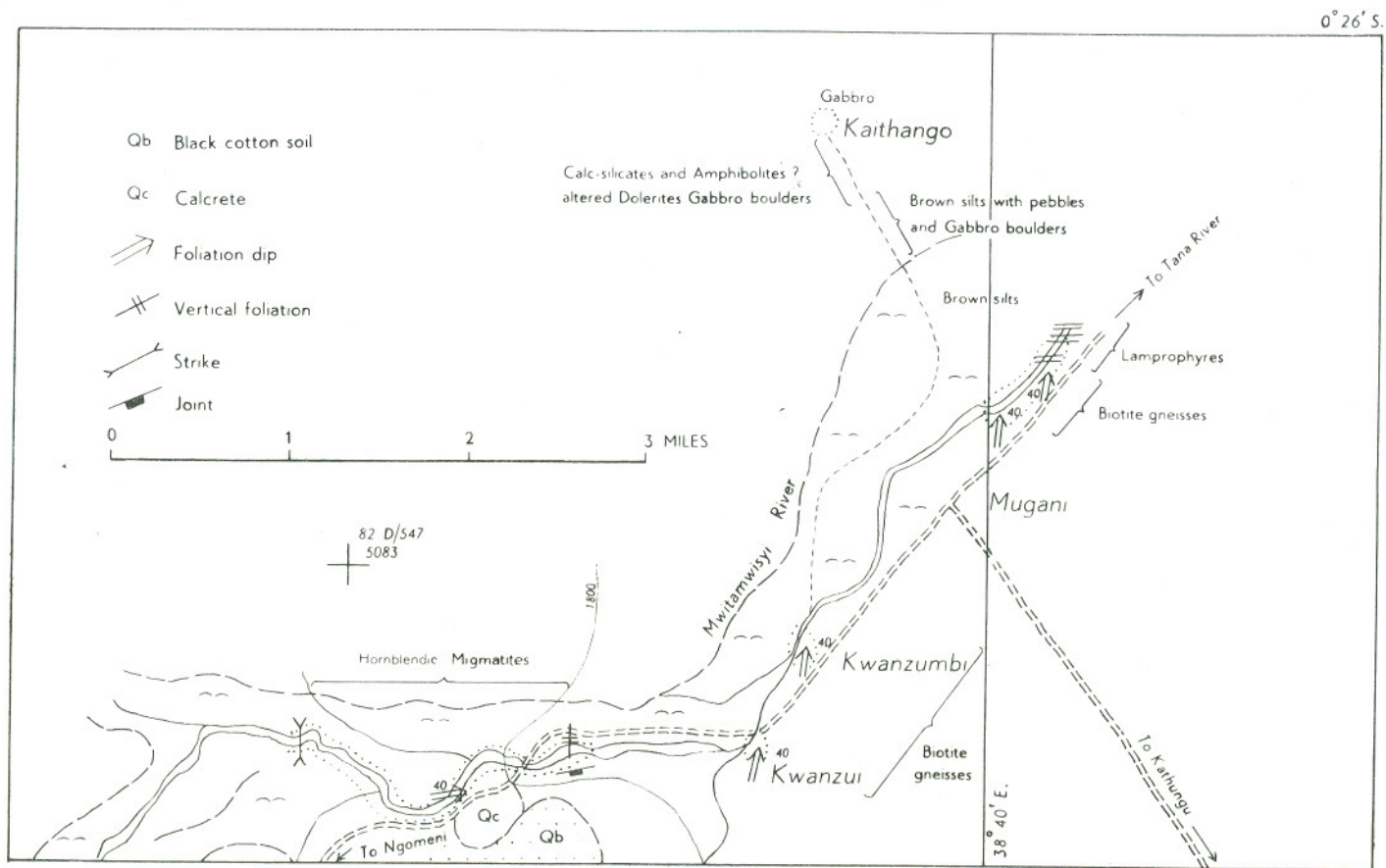


Fig. 9—Sketch-map of a small part of the area north of degree sheet 45 S.E.

Basement System rocks exposed along the Mwitamisyi valley include *biotite gneisses*, which form the whalebacks of Kwanzui and Kwanzumbi and are exposed north of Mugani. At the north-eastern end of the section there are pegmatitic and amphibolitic intercalations. *Hornblendic migmatites* are discontinuously exposed over a two mile stretch in the valley, just north of the Ndeyini area boundary. Some are streakily banded rocks, occasionally laminated in appearance, formed of granular aggregates of quartz and plagioclase, with elongated sub-parallel grains of hornblende (specimens 45/688, 45/689). Others are irregular mixtures of feldspathic and quartzo-feldspathic material with aggregates of granular hornblende and ragged biotite (specimens 45/691, 45/692), and large porphyroblastic faintly twinned plagioclase feldspars (specimen 45/690). The hornblende in these rocks is pleochroic from yellow to blue-green, similar to that described in hornblendic migmatites from the Kitui area (Sanders, 1954, p. 21)*. Hornblendic migmatites were also found near the exposures of charnockitic rocks, seen further north and described below.

Intrusives of probably late Basement System age are represented by a gabbro at Kaithango, altered marginally to a variety of metamorphic calc-silicate and amphibolite rocks, and forming the summit of the hill, where it outcrops as large rounded boulders over a roughly circular area about fifty yards across. In specimen 45/684 fresh olivine forms small cores to well developed coronas which are joined together in irregular chain-like aggregates. Hypersthene forms the inner part of the corona as radially aligned sub-parallel stumpy prisms, with scattered irregular grains of green spinel and thin veins of brown serpentine. The hypersthene is mantled by pyroxene in symplektitic intergrowth with the green spinel or by pale brown amphibole, often without spinel. Large grains of finely multiple-twinned labradorite, showing signs of strain, form the matrix of the coronal aggregates and sometimes occur within them. The boundaries of the feldspars are corroded against the coronas, which indicates that the plagioclase has figured in the formation of reaction rims round the olivines. Boundaries between adjacent feldspar grains also appear somewhat corroded, but not to the same extent as those between feldspar and corona minerals. Irregular grains of the brown amphibole, either singly or in aggregates, frequently occur among the feldspar crystals, which are also crowded with minute sub-parallel rods of a colourless high-relief mineral, whose identity is not known. Specimen 45/670, taken from a loose block near the hill, has larger and more irregular aggregates of pink granular hypersthene, surrounding relatively large fresh olivines and passing outwards in turn to pale blue-green actinolite and some clinopyroxene more coarsely intergrown with green spinel, or to pale brown amphibole, which grades into the actinolite, but is itself free of spinel. Labradorite, more strained than in the previous sample, but lacking the rod-like inclusions, is in correspondingly subordinate amount, and has even more marked reaction boundaries with the coronal hypersthene-actinolite aggregates and is more frequently enclosed within them.

During the later survey of the area to the north, D. J. Jennings collected a rounded pebble of basic rock (45/765) from the vicinity of Giraffe Pool, which is very similar to these Kaithango rocks, although not necessarily derived from them. Coronas are less common, and have larger olivine cores (up to 4 mm.), there is more hypersthene in granular aggregates, the dactylic spinel intergrowth is finer, and the hornblende is a relatively dark brown and often surrounds cores of opaque iron oxide. The hypersthene sometimes carries small plate-like inclusions of a pink mineral, possibly iron oxide.

Two fragments of fresh olivine dolerite (specimens 45/472, 635) found in the Ndeyini area, may have been derived from dykes associated with the Kaithango gabbro, but only altered minor intrusive rocks that possibly were originally dolerites, were found near it *in situ*. They are chiefly composed now (specimens 45/674, 675) of altered feldspar, chloritic material, iron ore grains, and profuse calcite veining.

The gabbro of Kaithango hill closely resembles the plagioclase-bearing dunites of Kamuthengi in the Mwingi area (Crowther, 1957, p. 13 and Fig. 3).

*References mentioned in the appendices are quoted in the general references section on pp. 27 and 28.

Minor Intrusive rocks are represented by four camptonite dykes, close together, exposed in the river section north of Mugani. They will be described in the order of their occurrence downstream:—

Dyke 1: 280° trend, 85° northerly dip, about three yards wide; a speckled spheroidally weathering rock, with secondary limestone developed on it. Specimen 45/642 has phenocrysts of barkevikite (patchily altered to calcite) and a pale purplish clinopyroxene, among numerous turbid, stumpy feldspar prisms associated with granular pyroxene and barkevikite, apatite needles, magnetite, chlorite, and calcite.

Dyke 2: 100 yards downstream from dyke 1, with similar trend and appearance, about one yard wide. The chilled marginal rock (specimen 45/647) has small barkevikite phenocrysts in a fine-grained groundmass, containing granular barkevikite and iron ore, amygdaloids of zeolites with chlorite and calcite, and large iron-ore grains. The rock is cut by feldspathic veinlets carrying biotite and barkevikite, and probably derived from reaction with the surrounding gneiss. Feldspars in the adjacent contact gneiss are pink and very turbid—large apatite crystals are seen developed in one (specimen 45/645)—and there are many irregular patches of secondary calcite with granular iron ore and fibrous pleochroic brown material, apparently replacing the original quartz.

Dyke 3: Adjacent to dyke 2, with similar trend and appearance, about one yard wide. No thin section was made.

Dyke 4: Adjacent to dyke 3, with similar trend, about three yards wide, sparsely porphyritic. In specimen 45/650, rare phenocrysts of barkevikite, patchily altered to calcite, and of chloritized pyroxene, are set in a groundmass of zeolitized feldspar, altered barkevikite needles, iron ore, often quite large apatite crystals, chlorite, and calcite.

These dykes must be part of the late-Mesozoic or Tertiary minor intrusive phase associated with the plutonic syenites of areas to the south. Jointing parallel to them is very marked in the surrounding gneisses.

Charnockitic rocks. From the northern boundary of the Ndeyini area, the Ngomeni-Tana river track follows the Mwitamisi valley beyond Mugani for about another eight miles, in a general north-easterly direction, crossing it twice. Then the channel swings northwards as a steep-sided relatively wide meandering sand-river, which the track crosses several times, finally leaving it after another two miles, near the low ridge of Kumbalanawa. After another six or seven miles along the track, still on a northerly heading, are the hills of Kalimangilu, where there is said to be saline water.

About five miles along the track from Mugani was found a coarse pyroxene rock (specimen 45/652), formed of large schillerized clinopyroxene crystals, with small pink hypersthene grains in them. It is possible, that although some distance from the nearest exposed charnockitic rocks, this rock may be connected with a similar suite nearby. Near Kalimangilu there are exposures of hornblende migmatites and rounded gabbro boulders. Specimen 45/668, taken from the latter, contains irregular olivine grains, altered along cracks to brown serpentinous material and iron oxide, somewhat elongated and irregular grains of schillerized clinopyroxene, and small amounts of orthopyroxene (often near and probably derived from olivine). Much granular brown hornblende and irregular masses of iron ore are associated with these ferromagnesian minerals. Plagioclase is not common. It is intermediate in composition and often poorly twinned and strained, and occurs as irregular grains, frequently together with pale green amphibole, which is sometimes also seen with the olivine and hypersthene and also grades laterally in places to brown hornblende. The rock is similar, though poorer in plagioclase, to charnockitic gabbros described by Schoeman (1951, p. 30) from the Embu-Meru area, which are also found in association with amphibolites (Schoeman, 1951, p. 18), as are the charnockite rocks described by Sanders (1954, p. 29) from the Kitui area.

APPENDIX II

In 1959 a car-borne scintillometer traverse was made by D. Hobden, Government Prospector, along the Garissa road, as part of a Kenya-wide radiometric survey. In the western half of the Ndeyini area, fluctuating low to moderate radiation intensities were recorded along the road, where the gneisses are close to the surface. Just east of Katumba, recorded intensities fell to uniformly low values, at about the place where the road must cross the feather edge of sediments deposited on the dissected end-Tertiary peneplain (*see* Fig. 1). Further along the road, between about five and ten miles east of Pangali, moderate intensities were again recorded. This is particularly interesting because along approximately the same stretch of road, there is a major positive anomaly on the gravity profile (Fig. 10) and a fair-sized positive anomaly on the magnetic profile (Fig. 11). There is thus a further indication that a large mass of probably crystalline rock lies close to the surface in that region.