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GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE NAROK AREA

DEGREE SHEET 50, NE. QUARTER
(with coloured geological map)

by

J. B. WRIGHT, M.A., B.Sc., F.G.S.
Geologist

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25-D.

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FOREWORD

The Narok area, which lies less than 80 miles from Nairobi, is little known to visitors other than hunters. This report is the third of a series covering recent mapping of the western side of the Rift Valley, and considerably extends the knowledge of the distribution of Tertiary and Quaternary volcanics and sediments of that region.

Precambrian metamorphic rocks outcrop over about a third of the Narok area, and Mr. Wright gives a detailed account of these rocks and their rather complicated structure. In his account of the later volcanic rocks he gives a time-scale, as accurate as present methods will allow, for the succession of volcanic events in the area, and compares this with similar sequences elsewhere in Kenya. In addition he gives a well-supported hypothesis for the existence and origin of early lakes in which sedimentary deposits accumulated.

Few mineral occurrences were found to be of economic importance. Water supplies over most of the area are good, and there are possibilities of development in cattle ranching (now carried on by itinerant Masai) and in agriculture.

Nairobi,
18th April 1967.

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

ABSTRACT

The report describes an area, approximately 1,225 square miles in extent, bounded by longitudes 35° 30′ E. and 36° 00′ E., and by latitudes 1° 00′ S. and 1° 30′ S., falling entirely within the Narok District of the Rift Valley Province.

The area has been partly bevelled by the sub-Miocene peneplain, which probably underlies the extensive Loita Plains. Remnants of a widespread end-Cretaceous surface may also be preserved on the summit of the Loita Hills.

Highly folded Precambrian rocks of the Kenya Basement System are mainly confined to the south-western corner of the area, into which they extend from the region immediately to the south; they are seen in extensive outcrops in the Loita Hills, representing a metamorphosed sedimentary succession characterized by prominent bands of massive quartzite.

A variable series of lavas ranging from Miocene to Pleistocene in age overlies the sub-Miocene peneplain. The volcanic rocks include melanephelinites and derived nephelinites, two varieties of phonolite, plateau and orthophyre-type trachytes, basalts and alkali basalts, and probably late olivine melanephelinite plugs. In addition tuffs and ashes were deposited throughout the latter half of the volcanic episode, and some of the ashes may have been deposited in a former extensive lake occupying the central and eastern parts of the area. A blanket of ashes represents the close of volcanic activity, and obscures much of the underlying geology, particularly over the Loita Plains.

The occurrence, distribution and petrography of the rocks is described, and metamorphic and structural syntheses have been attempted for the metamorphic rocks within the framework of available data. Rift faulting, which is believed to have commenced during the Miocene, has affected the volcanic rocks in the eastern part of the area.

Mineral occurrences and water supplies in the area are also described.

GEOLOGY OF THE NAROK AREA

I—INTRODUCTION

The Narok area is the north-east quarter of degree sheet 50, bounded by longitudes 35° 30′ and 36° 00′ East, and by latitudes 1° 00′ and 1° 30′ South. Narok, the administrative headquarters, is situated in the north-eastern part of the area, which falls entirely within the Narok District of the Rift Valley Province.

The indigenous population are nomadic Masai herdsmen. They graze their cattle over the whole area, watering them at the major rivers, at spring-fed streams in the Loita Hills, and also at wells which have been excavated near isolated rocky hills or along the larger seasonal stream courses. There are also a number of salt licks, especially along major river channels. Many of the tribesmen are of mixed Kikuyu and Masai descent, and some of them engage in cultivation. There are small plots at Narosura in the Loita Hills region to the south, at Maji Moto and Uaso Ngiro, and larger areas at Ol Olong'a and Seyabei. Maize, oranges, tomatoes and beans are successfully cultivated, particularly where the volcanic soil is irrigated.

The presence of tsetse fly in the south-west corner of the area, around Barkitabu, renders it unsuitable for habitation; since shooting is prohibited in it, big game abounds, particularly buffalo, rhino and lion. Game is also plentiful on the Loita Plains.

Climate and Vegetation

The presence of tsetse fly in the south-west corner of the area, around Barkitabu, but these periods are not sharply defined, and minor falls of rain may occur at any time. It is never excessively hot and dry, as most of the region is above 6,000 ft. elevation, and there are a number of permanent rivers and streams.

Rainfall data, taken from the records of the E.A. Meteorological Department, are tabulated below for three stations in the northern half of the Narok area, two of which are now closed:—

Station	Annual Total—Inches				Number of years recorded
	1951	1955	1959	Average	
Narok	—	—	28·89	27·60	45
Uaso Ngiro	—	18·00	—	19·30	6
Ngore Ngore	42·61	—	—	33·56	2

The north-east corner is densely forested, being part of the southern edge of the Mau uplands. Elsewhere, except on the open grasslands of the Loita Plains, the dominant vegetation is *leleshwa* scrub. Patches of open grassland also occur on tops of interfluves, particularly along the Narok and Seyabei river systems, and in the Loita Hills, where there are also scattered patches of forest. Thorn scrub and *sansevieria* grass are encountered locally in the larger valleys, particularly the Uaso Ngiro.

Exposures of solid rock are scarce. In the north-east corner thick forest and broad scrub-covered interfluves obscure most of the geology, and the Loita Plains are devoid of exposure except where quartzite inselbergs protrude above them. The Loita Hills often have grass-covered summits, while the slopes and valley floors are well wooded and frequently mantled with rock debris.

Communications

Four main earth roads, to Kijabe, Mau, Kilgoris and Loliondo, pass through the area, and there are numerous minor roads used by Government services and local traders. Some of the cattle tracks and major footpaths are motorable, and the Loita Plains can be motored over almost anywhere. Moderate rain renders many of the tracks impassable to all but four-wheel-drive vehicles, and even these may be held up for several hours at drifts, particularly on roads leading to Nairobi and Narosura. Only roads and motorable tracks used during the geological survey are plotted on the map accompanying this report. An airstrip is located six miles south-west of Narok, which township is 104 miles by road from Nairobi.

Method of Mapping and Maps Used

Geological field work in the area was carried out between February and August 1959. The geology was recorded on air photographs in the field, and transferred to 1 : 50,000 scale preliminary plots, which were reduced photographically and redrawn for reproduction at the final scale of 1 : 125,000.

Form lines on the geological map were delineated using air photographs, controlled with survey spot-heights and aneroid and Indian clinometer readings. The aneroid was found to be unreliable in some parts of the area, especially the deeply dissected Loita Hills, where high winds are usual and atmospheric pressure is sometimes lower in valleys than on ridges.

II—PREVIOUS GEOLOGICAL WORK

Very little previous geological work has been done in this area. Sir Albert Kitson (1934, p. 59),* at the completion of a geological reconnaissance of the Kavirondo District, motored through the north of the Narok area from Ngoro Ngoro through Ol Olong'a and Uaso Ngiro to Narok, thence to Nairobi. He commented briefly on the tuffs and ashes he saw exposed along this route, and noted the quartzite outcrops in the Uaso Ngiro valley about four miles south-east of Ol Olong'a.

An unsuccessful search for piezoelectric quartz was made in the south of the Narok District during the war years (Mines and Geol. Dept. Ann. Rep., 1942, p. 5, and 1945, p. 23).

The Report of the Development Committee for 1946 (Vol. 2, p. 67) states that railway ballast and building stone are available within easy reach of Narok, although sand in quantity can be found only in the south of the district.

In 1957, E.P.L. No. 124 was granted to Ansurfox Mining Co. Ltd. for diamond and metalliferous ore prospecting in part of the Narok District. The company searched unsuccessfully along the base of the Loita Hills between Maji Moto and Barkitabu, and generally west from there into the Mara River area, and also visited the lime pans near Ol Donyo Rasha.

III—PHYSIOGRAPHY

For descriptive purposes the physiography of the area can be divided into three units (Fig. 1):—

1. A dissected eastern strip.
2. The Loita Plains.
3. The Loita Hills.

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* References are quoted on p 48.

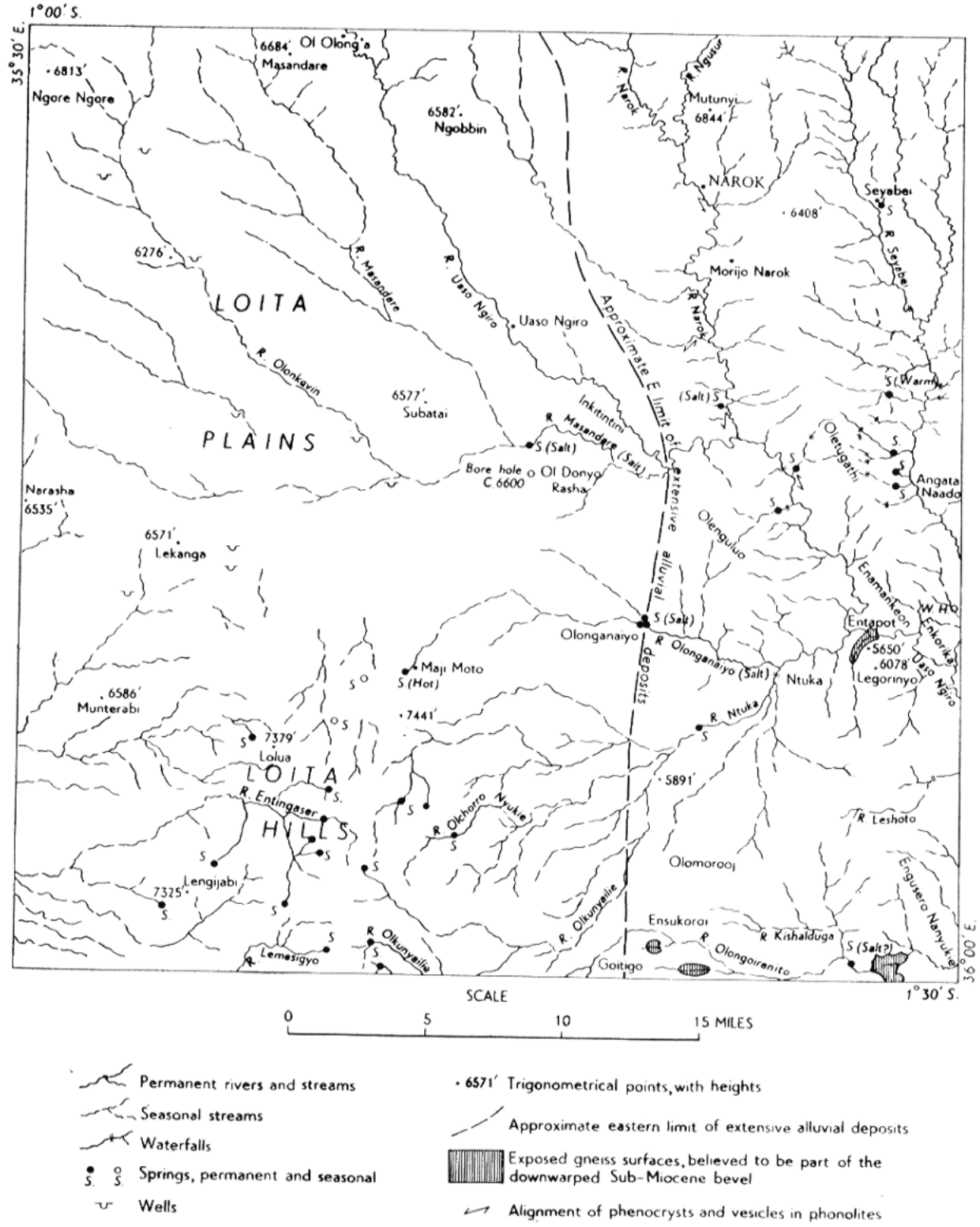


Fig. 1—Physiographic map of the Narok area

1. A belt of dissected country, about ten miles wide, extends along the eastern margin of the area. In the north it forms part of the forested Mau highlands, where broad north-south ridges carved in volcanic ashes are separated by the deep winding valleys of the Narok and Seyabei river systems. South of the Narok-Seyabei road the interfluves of the Seyabei system are relatively flat, and the valleys of the river and its tributaries are deeply incised due to resistant alkali basalt lavas capping a thick series of soft volcanic ashes. By contrast the Narok river flows in a relatively shallow winding valley with gentle slopes of volcanic ash alternating with abrupt features formed in harder tuffs and phonolites; this valley becomes steeper near the confluence with the Uaso Ngiro, and below it the river flows through a spectacular gorge.

Ashes, tuffs and alkali basalts form a sharply stepped topography around Entapot and Enamankeon where the deeply incised Olonganaiyo-Ntuka system joins the Uaso Ngiro. West of the Uaso Ngiro river the plateau and hill country extending from Ntuka through Olenguluo to Inkitintini is almost entirely formed of phonolites.

At Entapot the Uaso Ngiro swings due east for about four miles and crosses the highly dissected Naitiami fault scarp ridge. The ridge itself and the hilly country to the west are formed of melanephelinite lavas, with a quartzite inlier at the northern end. Plate I is a panoramic view of the country round Entapot. Here the fault scarp is flanked by narrow plateau strips of trachyte lava which slope down towards a second and younger Naitiami fault scarp on Engusero Nanyukie, part of the discontinuous Lengitoto Plateau (Baker, 1958, p. 6). This plateau is also formed of trachyte overlain by ashes, red soils and alluvial fan deposits of the seasonal streams draining the high ground to the west, and from it the ground slopes steeply into the Uaso Ngiro valley floored by soft volcanic ashes.

2. The flat, grass-covered expanses of the Loita Plains cover the north-western quarter of the area. The plains are formed of volcanic ashes and are probably underlain by the sub-Miocene peneplain cut in Basement System rocks. Inselbergs of quartzite rise above the plains to between 6,500 and 6,600 ft. In the north, near the southern edge of the Mau uplands, the ground rises and becomes more undulating.

3. The Loita Hills, formed of a variety of quartzites, rise some 1,000 ft. above the plains in the south-west corner of the area, and extend south and south-west into adjacent areas. They have been deeply dissected, for the most part along less resistant bands in the succession, so that the topography expresses the structural grain of the rocks. The grain in this part of the country trends generally NNW.-SSE., swinging round in the south-east around Olkunyailie and Oloirien to WNW.-ESE.

Drainage

Over most of the area the drainage direction is south-easterly, from the Mau highlands into the Rift Valley. The watershed separating this trend from the south-westerly drainage of areas further west follows roughly the western boundary, from Ngore Ngore south as far as Narasha. Here it is displaced some ten miles eastwards, where it coincides with the axis of the radial drainage pattern on the Loita Hills. Narasha is the most westerly of a line of hills which acts as a minor barrier, splaying out and turning back the radial Loita drainage as well as locally deflecting to due east the dominant south-easterly drainage.

The main river is the Uaso Ngiro. It rises in the Mau highlands some 40 miles north of Narok and meanders along a narrow channel cut in an alluvial valley through the rolling scrub-covered country in the north of the area and across the Loita Plains. An abrupt change in gradient occurs where it is joined by the Masandare; here the alluvium ceases and the river flows in a deepening gorge, narrow and winding, with sheer walls

over 200 ft. high in places. Where the Uaso Ngiro emerges from the gorge near Legorinyo there is another change; the river flows across soft volcanic ashes into which it has cut to a depth of up to 50 ft., leaving a now discontinuous boulder terrace along its banks. After leaving this area the river flows through a graben valley, and then along the west side of the Rift Valley, finally emptying into Lake Natron.

The Uaso Ngiro originally flowed on the down-warped sub-Miocene surface and survived the Tertiary and Pleistocene vulcanicity which probably caused its diversion a number of times. Eruption of the phonolites now forming the Mau highlands probably obliterated the original upper reaches, while the simultaneous activity round Olenguluo roughed out the course of the river as now seen, as well as providing the surface on which the tributary Olonganaiyo system was established.

Following eruption of the plateau trachytes, much of the drainage in the northern and eastern parts must have been obliterated during mainly sub-aerial deposition of tuffs and poorly consolidated ashes, over which the drainage in these parts now flows. The ashes in the Uaso Ngiro valley round Entapot show numerous signs of deposition under water, as do the ashes in the Seyabei valley. It is likely that in the early part of the Pleistocene period this region was covered by the south-west corner of a lake which was depositing pyroclastic material derived from outside the area to the east. If this is so the lake can only have been formed by damming of the Uaso Ngiro river and the southerly trending Mau drainage further east (the site of the present Seyabei river) by a barrier of plateau trachytes, which seem to have been erupted only as far north as Enkorika. Outlets from such a lake (or lakes) would have been the present Uaso Ngiro and Seyabei channels, later rejuvenated by fault movements to incise their present courses. Movement along the Enkorika fault was probably one of the first rejuvenating episodes. It downfaulted the trachytes forming the suggested southern boundary of the lake near Enkorika (Fig. 3), to provide the SSE.-trending valley in which the Uaso Ngiro now leaves the area. Soon afterwards the southerly drainage was probably dammed again across what is now the Seyabei valley, by downfaulted and northerly tilted alkali basalts.

Outside the area the Uaso Ngiro flows in a graben valley, with the Enkorika fault scarp as its western wall. It may have been dammed again at least once and possibly twice, to form small lakes and deposit more sediments, some of which were banked against the trachyte plateau in the present area. Bodies of standing water may also have come into being from time to time before the eruption of the plateau trachytes.

The Olongoirenito river, in the south-east corner of the area, is probably as old as the Uaso Ngiro, although it is mainly a dry channel now, with a few weak slightly saline springs. In the Magadi area to the south-east it joins the Lengitoto river, a large tributary of the Uaso Ngiro. The pattern of the Olongoirenito system must have been established much as it is today on the surface of the melanephelinite lavas, the earliest volcanics in the area, and it was probably dammed by the plateau trachytes banked against the Naitiami scarp to form a small lake. The lake was emptied when the second Naitiami fault movement rejuvenated its outlet, and the Olongoirenito channel has cut a gorge through the trachytes south of Engusero Nanyukie. The main Rift faulting is too distant to affect the river in this region, so it has not cut into the Engusero Nanyukie platform more than a few feet. By contrast the Leshota, another important river further north, has cut deeply both into the melanephelinites and the trachyte platform, because of the proximity of the Enkorika fault.

Other important permanent river systems are the Narok and Seyabei, left bank tributaries to the Uaso Ngiro, which also rise in the Mau highlands. They drain the north-eastern corner of the area, and their valleys are also deeply entrenched, particularly in the north. It is probable that they were initiated on the thick tuffs and ashes in the

north of the area, which must have completely filled in any pre-existing drainage channels in the underlying phonolites and alkali basalts. The valleys of these rivers have noticeably steeper sides and gradients north of the latitude of Narok than south of it, which must be due to rejuvenation from the north by uplift of the Mau massif as a result of Rift faulting. Near its confluence with the Uaso Ngiro the Narok river gradient steepens again under the influence of similar rejuvenating movements in the south-east.

The hot spring at Maji Moto, at the extreme northern tip of the Loita Hills, yields a small volume of water which flows out on to the plains in a shallow channel, and disappears within two miles of the source. Four small warm springs also rise along the Oletugathi fault line, probably a former eruption fissure, supplying small streams which enter the Seyabei river.

In dry seasons the misfit appearance of many of the streams which trickle through deep gorges in the volcanic country and in the Loita Hills is very striking. It is likely that in the past a great deal more water flowed in these rivers, although even nowadays they fill up for short periods in a good rainy season. Most of the streams have cut narrow, steep-sided channels, often over 10 ft. deep, in the alluvial and bouldery flood deposits flooring the valleys, giving further indications that the climate is now drier than in the past. A line has been drawn on the physiographic map (Fig. 1) joining the knickpoints in the major channels, to mark the western limit of the rejuvenating effects of vulcanicity and rift faulting. In the north of the area the line commences its westward swing to pass south of the rejuvenated Mau highlands.

Erosion Surfaces

The altitude in the middle of the Loita Plains is slightly more than 6,200 ft. The sub-Miocene peneplain must lie at shallow depth beneath this level and has been identified in adjacent areas to the west and south (Williams, 1964, p. 7, Saggerson, 1966, p. 7). The major inselbergs, rising to between 350 and 400 ft. above the plains, include the chain from Narasha (6,535 ft.) through Lekanga (6,571 ft.) to Ol Donyo Rasha (6,600 ft.).

Summit levels in the Loita Hills themselves are between 7,300 and 7,600 ft. which is 700 to 1,000 ft. higher than the surrounding inselbergs, and between 1,100 and 1,400 ft. above the level of the Loita Plains.

No erosion surfaces corresponding to older peneplain levels were seen in the Loita Hills, but it is probable that some of the summits in the Loita Hills and Mara River-Sianna areas are remnants of a Cretaceous surface, about 1,300 ft. above the sub-Miocene, which has been recognized elsewhere in Kenya. Saggerson (1966, p. 7) has recognized two other bevels intermediate between the Cretaceous and sub-Miocene surfaces, about 450 and 800 ft. above the latter. The reasonably uniform summit heights of major inselbergs on the Loita Plains may represent the lower of these, but there is no recognizable bevelling; the inselbergs are either undulating ridgebacks or conical in shape.

The westerly drainage in the south-west of the area indicates that the underlying sub-Miocene peneplain there probably slopes down again across the boundary into the adjacent Mara River area, as suggested by Williams (1964, p. 7). North of the line from Narasha to Ol Donyo Rasha, however, the plains rise towards Ngore Ngore, with an inselberg summit at 6,813 ft., 200 ft. higher than the inselbergs farther south. The superficial ash cover in the north-west corner is probably thicker than in the south, for although the plains are more undulating here they expose no quartzite in valley floors. The north-westward rise of the plains may be due to a considerable increase in the amount of ashes deposited or, more probably, there has been a real rise in the peneplain associated with the uplift of the Mau massif region, coupled with only a moderate increase in ash deposition.

IV—SUMMARY OF GEOLOGY

The oldest rocks exposed are quartzo-felspathic gneisses, quartzites and mica-quartzites of the Kenya Basement System, believed to be of late Precambrian age. The gneisses are exposed in windows within volcanics in the south-eastern part of the area, and quartzites form the Loita Hills and the inselbergs rising from the Loita Plains. The rocks represent an original series of arenaceous shallow-water sediments which have been metamorphosed, recrystallized and folded.

Vulcanicity in the area is thought to have commenced in the Miocene with the eruption of a melanephelinite lava series in the south-east, on the downwarped sub-Miocene peneplain. The lavas are between 600 and 900 ft. thick along the ridge extending south from Legorinyo, which is probably close to the fissure or line of vents from which they were erupted, and they are well developed further south in the Loita Hills area. They skirt the quartzite hill north of Legorinyo, and become less widespread north of it. The lavas north-west of Legorinyo may be the products of another eruptive centre. In the south of the area the basic lavas are intruded by a highly porphyritic nephelinite.

Extrusion of phonolites followed later in the Miocene, the main mass forming the high ground between Ntuka and Inkitintini where two different phonolite types are distinguishable, reaching a maximum combined thickness of about 900 ft. These were probably derived from local eruptive centres, and differ from other phonolites originating from the Mau highlands exposed farther north in the Narok river.

The melanephelinite lavas were subsequently downfaulted eastwards along the Naitiami fault, and the Pliocene(?) Kirikiti basalts of the Magadi area were later erupted on to them, wedging out near the fault scarp.

The Naitiami melanephelinite scarps had suffered considerable erosion and retreated about $1\frac{1}{2}$ miles by the early Pleistocene, when deposition of tuffs and ashes filled many irregularities in the older lava surfaces. Some of the pyroclastic rocks were laid down in temporary lakes occupying part of the present-day Uaso Ngiro, Seyabei and Olongoirenito valleys. The tuffs and ashes are thickest in the north-east and thin westwards across the Loita Plains; in the south of the area they are preserved only in valleys.

After deposition of the pyroclastic rocks had commenced the Enkorika fault was initiated and the Naitiami fault moved again. The Enkorika fault threw down about 350 ft. in the south-east, and terminated near Enkorika. The renewed Naitiami fault terminated near Legorinyo, and its maximum throw was about 400 ft. in the south of the area.

The deposition of the pyroclastic rocks was punctuated by flows of basalt, alkali basalt, plateau trachyte and orthophyre-type trachyte lavas, and by two movements along the Oletugathi fault. The four olivine melanephelinite plugs distributed about the northern part of the area may also belong to this episode. The plateau trachytes are similar to those in the Magadi area described by Baker (1958, p. 18) and extend south and east outside the area, but are exposed northwards only as far as Enkorika. The orthophyre-type trachytes, which form the Angata Naado platform, are the equivalents of the orthophyre-type trachytes in the Magadi area.

In the Narok area, therefore, the bulk of volcanic activity took place at two widely separated periods, Miocene and Pleistocene, and erosion of the first Naitiami fault

scarp must have proceeded during a long interval in the Pliocene. The Tertiary to Pleistocene volcanic history of the area is summarized below:—

Pleistocene	Final ash phase Orthophyre type trachytes Plateau trachytes . . . Second Oletugathi fault . . . Alkali basalts of the Oletugathi plateau Tuffs and ashes, in part waterlain . . . First Oletugathi fault . . . Alkali basalts of the Enamankeon plateau . . . Second Naitiami fault . . . . . . Enkorika fault . . . Tuffs and ashes, in part waterlain
Pliocene	. . . Erosion of first Naitiami fault scarp . . . Kirikiti basalts (in Magadi and Loita Hills areas) . . . First Naitiami fault . . .
Miocene	Phonolites Kishalduga melanephelinite lavas . . . Arching of sub-Miocene peneplain . . .

V—DETAILS OF GEOLOGY

1. Metamorphic Rocks

The metamorphic rocks in the Narok area are of late Precambrian age. They are part of a meta-sedimentary succession and display a foliation which is parallel to boundaries between rock types and is therefore believed to mark the original sedimentary bedding. The stratigraphic succession is similar to that proposed by Saggerson (1966, p. 12) for the same rocks in the Loita Hills area.

For descriptive purposes the rocks have been divided into a semi-pelitic group exposed locally in the east of the area, and a more important psammitic group of quartzites and muscovite quartzites forming the Loita Hills. The two groups are considered under the following headings:—

(1) Metamorphosed semi-pelitic sediments

Garnetiferous biotite gneisses with amphibolites and associated calc-silicate rocks.

(2) Metamorphosed psammitic sediments

(*a*) Coarse-grained quartzites.

(*b*) Laminated quartzites.

(*c*) Muscovite quartzites.

(1) Metamorphosed Semi-pelitic Sediments

Semi-pelitic gneisses and amphibolites are almost entirely confined to the south-east of the area, where they are exposed in windows in the volcanic rocks along the Olongoirenito and Esukoroi rivers and in the Uaso Ngiro near Legorinyo. Along the Olongoirenito river in the south-eastern corner of the area the biotite gneisses are finely banded with alternating pink quartzo-felspathic bands and dark biotite-rich layers, liberally spotted with small red garnets. The strike of the rocks in the river is generally slightly west of north. Joints are developed more or less perpendicular to the strike, and are sometimes filled with irregular pink quartzo-felspathic pegmatite veins not more than a few feet thick, which join with concordant pegmatites in the foliation of the rocks.

In thin section these semi-pelitic gneisses (specimens 50/445-6*) show intergranular gneissic textures with quartz, microcline and minor amounts of oligoclase; the large grains of quartz and felspar are often surrounded by aggregates of smaller grains. Biotite is poorly oriented and pleochroic from pale olive to very dark green. Pink rounded almandine garnets and accessory zircon complete the mineral assemblage.

In this section of the Olongoirenito river the semi-pelitic rocks contain amphibolite sheets and lenses and smaller calc-silicate inclusions. The amphibolites (specimen 50/487) are weakly foliated and are composed of hornblende and pale green diopside with oligoclase, quartz, garnet, sphene and accessory apatite. The hornblende contains relics of diopside in varying stages of resorption. The calc-silicate lenses (specimens 50/453, 454) are usually distinguished by their pale green colour and are formed by granular pyroxenes (hedenbergite and diopside) together with clinozoisite and plagioclase. Small amounts of rutile and corundum are also evident in the thin sections.

North-west of Legorinyo summit (1° 20′ S., 35° 57′ E.) finely banded biotite gneisses with amphibolite bands are exposed in the northern side of the Ntuka gorge. Smaller outcrops in the river-bed about a mile down-stream are similar, with amphibolite bands and concordant and cross-cutting quartzo-felspathic pegmatites. The amphibolites in these two groups of outcrops are different; in the more westerly exposure the amphibolite (specimen 50/573) is a compact rock similar to that described above from the lower Olongoirenito valley. It is rich in hornblende and quartz, poor in diopside and plagioclase (oligoclase), and contains small amounts of brown biotite and rutile in place of sphene and garnet. From the second exposure the amphibolite (specimen 50/582) is a more friable rock of simple composition, consisting of untwinned medium plagioclase, hornblende and quartz; a calc-silicate inclusion in it (specimen 50/583) is seen in thin section to be a simple granular aggregate of green pleochroic hedenbergite with very dark green hornblende possibly derived from the hedenbergite, pale yellow pleochroic epidote and a little interstitial quartz.

Round Legorinyo itself the biotite gneisses are interbanded with a variety of quartzites, grading from white and massive, through flaggy, to micaceous types. The white quartzites form small northerly trending ridges, separated by broad micaceous bands occupying the valleys between them, and pass eastwards through a narrow zone containing pink quartzo-felspathic pegmatites into very coarse, sparsely biotite-bearing quartz-felspar granitoid gneiss, devoid of foliation, and almost pegmatitic in places, with amphibolite bands which strike in the same direction as the quartzites. The coarse gneisses (specimen 50/547) contain microcline and appreciable amounts of oligoclase, occasionally intergrown with quartz. An amphibolite collected here (specimen 50/546) is a simple friable variety with quartz and oligoclase similar to the second sample from the Ntuka river described above.

Coarse quartzo-felspathic gneiss was not seen south of the Uaso Ngiro, but white micaceous quartzites continue southwards to a point immediately north-west of Legorinyo summit, where banded biotite gneisses with some slip-folding (Fig. 4 (*b*)) are interbedded with massive quartzites up to 30 ft. thick.

(2) Metamorphosed Psammitic Sediments

The rest of the metamorphic rocks in this area are composed almost entirely of quartz and muscovite and form the northern part of the Loita Hills and the surrounding inselbergs. The rocks represent an original shallow-water sandy sedimentary series, and are variable in texture and composition, so that the groups described below and delineated on the map indicate only the principal rock types to be found within given boundaries.

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*Numbers 50/445, etc., refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

Three main groups of quartzites are recognized, differing only slightly from those defined by Saggerson (1966, p. 16) and Williams (1964, p. 13):—

(*a*) Coarse-grained quartzites.

(i) Granular pink variety.

(ii) Compact white variety.

(*b*) Laminated quartzites.

(*c*) Muscovite quartzites and subordinate schists.

(*a*) *Coarse-grained Quartzites*

(i) *Granular Pink Variety.*—The more common rocks are coarsely granular mica-poor quartzites (Plate II (*a*)) which are sometimes white in colour, but more typically pink, due to iron oxide staining on the surfaces of the quartz grains, which average about 0.5 cm. across. They form the major ridges of Lengijabi, Lolua, Maji Moto, Olchorro Dapash and Entingaser, as well as the summits of other smaller ridges in the south-east of the hills and many of the inselbergs and ridges rising from the surrounding plains. An exceptionally coarse white quartzite with grains exceeding 2 cm. in size forms part of the Olkunyailie ridge in the south-east.

The rocks are well jointed, most often perpendicular to the strike, and usually have a flaggy foliation parting parallel to the original bedding. In a few places the flat surfaces of flags display ripple marks, and sometimes the flaggy parting has the appearance of crude current bedding. The rocks may also be so uniformly granular that structural directions in them become virtually impossible to determine, as for instance at the north-western end of the Lolua ridge. A crude form of carious weathering is common in these granular rocks.

By variation in grain size, mica content, scale of lamination and to a lesser extent colour, the coarse-grained quartzites grade into any of the other quartzite varieties forming the Loita Hills.

(ii) *Compact White Variety.*—Some of the coarse quartzites are compact, white in colour, and distinctive from a distance (Plate II (*b*)); they are best developed in the inselbergs round the Loita Hills. The white quartzites are almost structureless; some outcrops have a weak foliation, but current bedding and ripple marks were not observed. Joints are usually developed perpendicular to the strike, but when both joints and parting are equally spaced only faint streaks of slightly darker rock parallel to one set of fractures shows which is the original bedding plane.

As in the granular rocks, flaggy and micaceous intercalations are common, and lenticular bands of massive and flaggy white quartzite are developed within the muscovite quartzites of the Loita Hills and as lateral variations of pink granular quartzites. At the northern end of Goitigo ridge the quartzite is locally dark in colour, due to a higher concentration of disseminated iron ore.

Bands of white quartzite form chains of ridges and isolated hills on both the eastern and western sides of the Loita Hills and in the ridges around Munterabi, and are found as scattered outcrops on the plains in the north-western quarter of the area. The most easterly band is marked by a north-south chain of outcrops above the west bank of the Narok river between the Kollobisho and Uaso Ngiro valleys.

In thin section both the granular pink quartzites and the compact white quartzites are seen to contain large interlocking quartz grains, rarely exhibiting strain extinction, and having irregular sutured boundaries. There are abundant, evenly distributed and

well oriented muscovite flakes up to 0.5 mm. in length, both within the quartz grains and penetrating the boundaries between them. The quartz in most of the slides examined contains rare, small, irregularly rounded inclusions of fresh microcline. In the slide of specimen 50/503, a white quartzite from Lembere, a large grain of apatite was observed; a similar rock from about 2½ miles west of Lengijabi (specimen 50/591) contains rare flakes of green-brown biotite and a small amount of opaline silica.

Dark bands in the coarse quartzites are due to enrichment in iron ore; a dark quartzite (specimen 50/590) from the hill three miles south-south-east of Narasha has quartz grains of very variable size with highly irregular and interpenetrative boundaries, much iron ore in elongate and sub-parallel crystals, and a little altered microcline.

The green colour of some of the compact quartzites is due either to varying amounts of fuchsite (Winchell 1951, p. 369), pleochroic from pale blue to green, sometimes coupled with green-brown biotite, as in specimen 50/517 from Oloirien, or to a very pale green muscovite (specimen 50/521a from Olchorro Nyukie). Darker shades of green in the quartzites are due to the presence of iron ore and coloured micas.

(*b*) *Laminated Quartzites*

The coarse quartzites grade into the medium- to fine-grained, laminated, frequently cross-bedded and ripple-marked mica-poor quartzites. They are usually granular and stained pink by iron oxide on grain surfaces. The best developed current bedding was usually observed in the granular varieties, while the whiter and more compact variety is more finely laminated (Plate II (*c*)). Ripple marks (Plate II (*d*)) appear to be equally well preserved in both varieties. There is a tendency for the more granular rocks to be dominant in the south-east of the hills, round Olkunyailie and Oloirien, while the more compact variety predominates in the north-west round Osilalei, from where the rocks grade southwards into muscovite quartzites, probably as a result of lateral facies change.

Good exposures of steeply dipping current bedded quartzites can be seen along the ridge on the north bank of the Olkunyailie river near its source. A gorge section near the head of the Oloirien river exposes more than 200 ft. of laminated quartzites in which the cross-bedding has been disturbed by folding. An impressive occurrence of folded cross-bedding, with displacement along planes of truncation between units, forms a knoll on the north bank of the Oloirien river where it emerges onto the Lembere plain (Plates III (*a*), (*b*) and (*c*)). Sketches made at some of the localities are shown in Fig. 2. Although only a few measurements of cross-bedding were taken they were found to be of assistance in interpreting the structure and stratigraphy in this part of the Loita Hills.

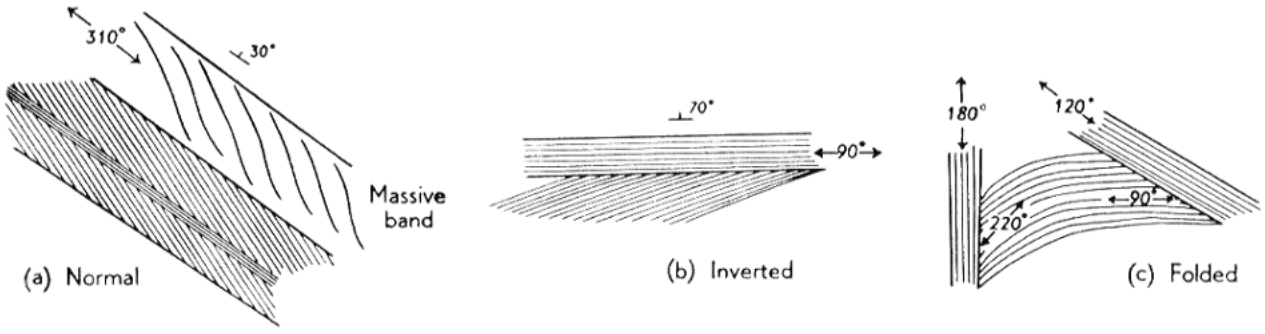


Fig. 2—Diagrammatic sketches of current bedding

Some of the outcrops display the asymptotic relationship of lower foreset beds with bottomset beds of the same unit (Fig. 2 (*a*), (*b*)), while in others can be seen the wide variety of inclination, about 10° to 40°, between adjacent units (Fig. 2 (*c*), Plate III (*a*), (*b*)). There is usually too little data to say whether the variation in angles of

inclination is typical and how much of it is due to different angles of exposure or to deformation. Authorities differ on the maximum inclination of undisturbed foreset beds to the horizontal (as represented by the adjacent bottomsets). Twenhofel (1950, p. 555) cites 43°, Pettijohn (1957, p. 168) 36°, and Shrock (1948, p. 224) 33°. Twenhofel also states that greater inclination is consequent upon more rapid deposition of coarser material, and that simple compaction will lead to reduction of the cross-bedding angles. As Pettijohn points out, deformations can either increase or decrease the angle of inclination; a maximum of 50° was observed in certain quartzites in the U.S.A., but the measured maximum did not exceed 40° in the Narok area.

At Enkiu two exposures of unusual laminated quartzite with patchy pink and purple discoloration were seen, one at the head of the Olkunyailie valley and the other about two miles to the south-west. They are apparently concordant with the surrounding rocks, and at the more southerly locality appear to pass upwards into more normal laminated quartzites. The texture in thin section resembles that of an unmetamorphosed arkose. Specimen 50/523, from the Olkunyailie river, is very fine-grained, the quartz particles seldom exceeding 0.1 mm. in diameter. They are set in a brown iron-stained amorphous base, mainly siliceous in composition. The quartz shows little sign of recrystallization, though there are few larger grains, up to 0.25 mm. across, which have presumably grown at the expense of smaller ones, and partly enclose them. The second outcrop to the south-west (specimen 50/525) consists of angular quartz grains averaging about 0.5 mm. across in a turbid base composed mostly of fibrous kaolinite and sericite speckled with iron ore.

These relatively unaltered sedimentary rocks are included in this section of the report because of their apparent structural conformity and upward gradation into obviously recrystallized rocks. The reason for their unaltered condition remains obscure, and the possibility that they are sediments of much later age (possibly Tertiary) cannot be ruled out.

(*c*) *Muscovite Quartzites and Subordinate Schists*

Muscovite quartzites are widely developed in the south-western part of the Loita Hills in this area. They grade northwards into laminated quartzites, presumably as a result of lateral facies change. In the south-eastern part of the hills they are also interbanded with laminated quartzites, and repetition of the association between laminated and mica-rich rocks in the outcrops round Olkunyailie and Oloirien is considered to be due to folding.

Typically grey and rather granular in appearance, the rocks contain appreciable amounts of muscovite, easily visible in hand specimen. Like the other groups the muscovite quartzites have variable lithology and frequently contain local bands and lenses of flaggy and massive pink and white quartzites. Rocks with more muscovite than usual have a schistose appearance, and there are numerous places where pockets and lenses of coarse muscovite enrichment can be found. The more typical granular muscovite quartzites exhibit carious weathering, due to irregular masses of quartz, and some surfaces display cross-bedding and ripple marks.

Because of their relatively high mica content the rocks were not competent during folding, and are commonly contorted (Plate III (*d*)); there is much variation of strike and dip even in small exposures, making measurement very difficult. More regular contortions in the form of small open or isoclinal folds are sometimes found.

Specimen 50/509, from the Oserolembere ridge, is a typical grey, granular, slightly flaggy muscovite quartzite, with elongated quartz grains forming a crude lineation. In thin section the quartz mosaic is seen to contain ragged but well-oriented flakes of muscovite and very pale brown to colourless biotite. Specimen 50/527, a finer-grained

variety from Enkiu, has a more regular and uniform quartz mosaic with poorly oriented muscovite marginal to the quartz grains. Patches of brown amorphous silica and a little kaolinite are also present. Specimen 50/507 is a coarse, pink, flaggy rock from a band in the muscovite quartzites forming Olkunyailie hill; the flaggy parting shows appreciable surface concentration of muscovite, but the remainder of the rock is identical to the coarse quartzites previously described. From the mica-rich rocks in the eastern part of Olkunyailie, specimen 50/512 is soft and schistose, with kaolinite speckling and an overall pink coloration due to iron oxide; the slide shows well-developed muscovite and quartz, and traces of felspathic alteration products. A typical mica-rich pocket on Oserolembere (specimen 50/511) contains pale green muscovite flakes up to 1 cm. across, with granular quartz. The coarse mica foliation is corrugated in these outcrops.

(3) Metamorphism and Metasomatism

Biotite gneisses in the area represent original semi-pelitic sediments, and the amphibolite bands within them are possibly the reconstituted remains of thin impure limestone beds. The quartzites of the Loita Hills have undergone little chemical change during recrystallization from sandstones, and preserve many original sedimentary features.

The mineral assemblages in the amphibolite bands and their calc-silicate inclusions can be referred to the almandine-diopside-hornblende sub-facies of the amphibolite facies (Turner and Verhoogen, 1951, p. 459, and cf. Saggerson, 1966, p. 25). The present mineral composition of some of the rocks has also been achieved by chemical addition of material not originally present in the sediments. The widespread growth of microcline in the semi-pelitic sediments indicates that potash metasomatism has taken place, but there is little or no evidence of similar metasomatism in the amphibolites and quartzites.

In all the quartzites examined from the Loita Hills small muscovite flakes and sometimes iron ore crystals are enclosed within the larger quartz grains, particularly in the coarser varieties. The quartz of these coarse-grained rocks also contains rare, small blebs of usually fresh microcline, while in the finer-grained types varying amounts of felspar alteration products are almost entirely confined to the interstices between grains, though some were also found as inclusions. It is considered that there has been no metasomatic action in the arenaceous rocks, and that almost all the chemical constituents now present were components of the original sediments, redistributed during recrystallization which accompanied folding.

The most convincing evidence of a high metamorphic grade without metasomatism in the quartzites comes from the Uaso Ngiro exposures near Legorinyo where coarse and micaceous quartzites are interbanded with biotite gneisses and associated amphibolites. They must have been subjected to the same metamorphic processes as the surrounding more pelitic and calcareous rocks, but like the latter proved to be impervious to metasomatizing fluids.

The occurrence of almost pure quartzites among granitized rocks has been reported from many other parts of Kenya, including the areas to west and south (Williams, 1964 and Saggerson, 1966). Joubert (1957) mapped quartzites interbanded with quartzo-felspathic gneisses in the Namanga-Bissel area, and noted the resistance of these rocks to granitizing fluids. He traced the felspathization of quartzites into gneisses and suggested (op. cit. p. 29) that the first stage of granitization of the quartzites was the introduction of muscovite, possibly along bedding planes. The presence of muscovite in quartzites of the Narok area is considered to be due to recrystallization of detrital flakes in the original sediments, particularly since junctions between quartzo-felspathic gneisses and quartzites were always seen to be clearly defined and sharp. In the Kitui area, Sanders (1954, p. 37) accounted for a similar association by suggesting that differential re-fusion removed felspathic constituents from initially more arenaceous

arkosic sediments. This would lead to progressive enrichment in quartz with almost pure quartzites as the end product. Though possibly active on a small scale, such a mechanism is not considered to have had a widespread effect in the present area, in view of the considerable amount of virtually felspar-free rocks preserving sedimentary features which would probably have been obliterated at the temperature required to fuse felspar.

Original Nature of the Psammitic Sediments

Current-bedding, ripple marks and possibly even sun-cracks preserved in the rocks are proof of the very shallow and sometimes littoral origin of the sediments, which were probably deltaic. The grain size of the coarse quartzites cannot be due to re-crystallization alone; if it were there would be no finer-grained quartzites, and the crude ripple marks and current-bedding structures would not have been preserved. Prior to metamorphism the quartzites must originally have been almost pure sandstones with some mica and probably a little felspar, as well as other minor constituents. The finer-grained quartzites thus represent original finer-grained sands. The laminated compact rocks are best developed in the north-west part of the Loita Hills, while the best current-bedding is seen in the south-east. The laminations are probably a form of graded bedding and indicate that the sediments probably accumulated under less turbulent conditions than the strongly current-bedded micaceous sand. The lack of mica in the rocks enabled them to behave relatively competently during folding. By comparison the muscovite quartzites formed from micaceous sands were contorted to a far greater degree, with sedimentary features only rarely preserved.

2. Volcanic Rocks

Volcanic activity in the Narok area extended from the Miocene to the close of the Pleistocene. The dominantly sodic compositional trend of the lavas and the frequent shift of eruptive centres with corresponding sudden changes in lava type are typical of the Rift Valley volcanic province.

For purposes of description the volcanic rocks have been divided into groups, tabulated below with their estimated relative ages:—

(7) Pyroclastics	Pleistocene
(*a*) Tuffs	
(*b*) Ashes	
(6) Olivine melanephelinite plugs	
(5) Angata Naado trachytes	
(4) Plateau trachytes	
(3) Alkali basalts	
(*a*) Seyabei olivine basalt	
(*b*) Ildungisho basalt	
(*c*) Alkali basalts	
(2) Phonolites	Miocene
(*a*) Group I phonolites	
(*b*) Group II phonolites	
(1) Kishalduga melanephelinites	
(*a*) Melanephelinite lavas	
(*b*) Olivine melanephelinite lavas	
(*c*) Oligoclase tephrite lavas	
(*d*) Anorthoclase-bearing lavas	
(*e*) Nephelinite lavas	
(*f*) Intrusive nephelinites	

(1) Kishalduga Melanephelinites

These rocks extend into the present area from the north-east corner of the Loita Hills area immediately to the south, where they have been described and figured by Saggerson (1966, p. 28, Fig. 5). Their eastern limit follows the line of the dissected fault

scarp ridge of the first Naitiami fault extending south from Legorinyo, suggesting that the original fissure or line of vents coincided with the later Naitiami fault line. There may have been a second and smaller eruptive centre north-east of Entapot. The base of the lavas can be seen in only two places. At Legorinyo, in the Uaso Ngiro valley, the lavas rest on the down-warped sub-Miocene surface, and lap round the former inselbergs which rise above it. Here the thickness of the pile is about 900 ft., and must be close to the maximum, although northwards the lavas rapidly disappear due to thinning and burial beneath later volcanics. In the Olongoirenito valley farther south the thickness has decreased to about 500 ft. because of a dome in the sub-Miocene surface. The lava base has an appreciable westerly dip on the western side of this feature. South of the area boundary the thickness again increases to 900 ft. (Saggerson, 1966, p. 28). Around Legorinyo the flat, upper surfaces of individual lava flows make bench-like features in the lava terrain. Exposures are insufficient to enable thicknesses of individual flows to be measured, but they probably average about 50 ft. In the area to the south the lavas have a gentle westward tilt, possibly due to movements associated with rift faulting (Saggerson, 1966, p. 30), but no regional tilting was detected in the present area.

Most of the lavas are basic in composition, dark and heavy rocks, often amygdaloidal and rich in pyroxene phenocrysts, with less common olivine or olivine pseudomorphs. Good outcrops are found only in river sections where the more amygdaloidal lavas usually show spheroidally weathered surfaces. Elsewhere the ground is scrub-covered and littered with rounded boulders of lava, and the underlying rocks are obscured by soils and white calcrete deposits.

(*a*) *Melanephelinite lavas*

The bulk of the succession is made up of rocks rich in augite, with olivine represented only by pseudomorphs and with nepheline and analcite in place of felspar. Specimen 50/444 from the Olongoirenito valley is typical. The hand specimen is rich in pyroxene phenocrysts and contains a number of bronze-coloured olivine pseudomorphs and white amygdales. In thin section the subhedral, elongate, pale yellowish brown augite phenocrysts are seen to be twinned and zoned, and sometimes occur in glomeroporphyritic aggregates, marginally corroded and packed with granular iron ore. A turbid and faintly pleochroic serpentine mineral, together with a little calcite, forms pseudomorphs after olivine, and there is much granular nepheline, usually in aggregates, and iron ore in irregular grains. The groundmass of the rock consists of augite laths and iron ore granules set in an isotropic base, probably of analcite. There are also irregular interstitial and ophitic flakes of foxy-red to yellow biotite, small patches of greenish serpentine and some yellowish brown staining of the isotropic base, perhaps due to oxidation. The amygdales are composed of isotropic analcite and other zeolites with fibrous and spherulitic habit. Other rocks collected from this group are similar, but vary in minor details. Augite phenocrysts are variable in amount, and may even be absent altogether (specimen 50/442 from the upper Olongoirenito valley). The augite in these lavas is probably highly titaniferous, judging from the colour, and it has a fairly small optic angle. Nepheline is not always positively identifiable in the groundmass (e.g. specimen 50/465 from the lower Kishalduga valley) so that some of the rocks may be almost melazeolitites, although paucity of nepheline may be due to late-stage alteration. Brown iddingsite is occasionally present in the olivine pseudomorphs but red biotite is rare, while the groundmass staining varies in intensity and colour from greenish to yellow-brown. In specimen 50/464, from the lower Kishalduga river, the amygdales contain well-developed natrolite in large elongate crystals.

A poorly exposed junction between two flows was seen in the Kishalduga river about three-quarters of a mile north of the confluence with the Olongoirenito. A grey lava poor in amygdales and porphyritic pyroxene passes downwards into finer-grained, finely

vesicular and scoriaceous rock, with a distinct pink colour due to oxidation. This flow has been disturbed by a vertical fracture and the underlying flow has a gentle westerly dip. The overlying tuffs are horizontal.

A well-preserved ancient weathered melanephelinite surface was found in the Ntuka gorge, just downstream from the waterfall, where there is a well-exposed undulating contact between reddened melanephelinites and the overlying thick tuffs. In thin section (specimen 50/476) the lava is seen to have been altered to brown iron oxide and calcite, which vein one another, while pale green pyroxene phenocrysts are the only unaltered minerals remaining.

The northernmost melanephelinite exposures occur in the Uaso Ngiro valley, where the rocks are seen below phonolite and ashes in stream channels. Although possibly originating from a different centre these lavas only differ from those described above in being slightly more densely charged with granular iron ore. In the Leshota river just downstream from the Naitiami fault-line a current-bedded grit deposit, composed of small, rounded melanephelinite grains, forms part of the valley wall. In thin section (specimen 50/494) the grains are seen to be derived from a fine-grained sparsely porphyritic variety of melanephelinite with much red-brown iddingsite, presumably pseudomorphing olivine. Fragments of augite also occur in the sediment.

(*b*) *Olivine melanephelinite lavas*

Augite-rich olivine-free lavas occur up to a height of about 5,850 ft. in the succession. The only specimen of olivine melanephelinite collected, 50/447, was taken near the Olongoirenito river at 5,900 ft. It is probably fairly representative of the 200 to 300 ft. of such rocks which are thought to make up the top flows of the melanephelinite series (cf. Saggerson, 1966, p. 28). The rock contains phenocrysts of augite and green olivine up to 3 mm. across. The olivine appears to be a normal magnesian variety, and is slightly altered marginally and along cracks, to brown and green serpentine. In other respects there is no appreciable difference between this rock and the augite-rich lavas described above.

(*c*) *Oligoclase tephrite lavas*

A sample (50/452) from near the base of the succession in the Olongoirenito valley at about 5,650 ft. altitude contains oligoclase, but otherwise resembles the melanephelinites. It was collected just above the junction with the gneisses some two miles west of Ildungisho, and contains augite phenocrysts, faintly pleochroic from pale yellow to pale violet, in a fine-grained basaltic groundmass of small random oligoclase laths, intersertal granular augite and iron ore, and patches of pale green chlorite, in a partly isotropic zeolitic base. Nepheline may be present but was not identified.

In the lowest lava of the Olongoirenito succession (specimen 50/483 from Emugur Olmoruo) irregular amygdaloidal patches contain anisotropic zeolites and a little acicular oligoclase. None of the other rocks examined from the melanephelinite series contains any trace of plagioclase, but a calcareous band (specimen 50/578) in a clay deposit just south-east of Olonganaiyo contains fragments of melanephelinite with iddingsite pseudomorphs together with fragments of a similar basic lava carrying appreciable amounts of well-formed plagioclase laths, determined as andesine.

(*d*) *Anorthoclase-bearing lavas*

Specimen 50/490, collected from about 3½ miles north-west of Ildungisho, differs appreciably from the other lavas in this series. The augite phenocrysts are similar, although one large augite aggregate is associated with dark green-brown serpentine. The groundmass consists of irregular patches and veins of anisotropic zeolite, with

felspar needles, nepheline, a little aegirine and rare partly altered olivine, in a matrix of augite, felspar, iron ore and zeolite. The patches are associated with dark green serpentine, small irregular flakes of red to yellow biotite and irregular, elongate, simply twinned anorthoclase phenocrysts, sometimes in crudely radiating sheaves and crowded with granular augite and iron ore. The anorthoclase is extensively resorbed and cannot have been in equilibrium with a dominantly melanephelinitic magma. A similar lava, much younger in age (specimen 43/227), was collected by R. M. Shackleton from the vicinity of Il Pejeta, in the north of the Nyeri area.

(*e*) *Nephelinite lavas*

A section in the Olongoirenito river, 5½ miles east of the Narok-Narosura road at a height of about 5,850 ft., exposes the following succession:—

Tuffs	c. 8 ft.
Greenish weathered upper lava surface(?)	c. 2 ft.
Nephelinite (not distinguished on map)	c. 20 ft.
Amygdaloidal melanephelinite	c. 10 ft.

The lowest lava (specimen 50/461, a melanephelinite already mentioned above) exhibits good spheroidal weathering, and the numerous amygdales in it, often more than an inch across, are mainly formed of calcite.

The overlying nephelinite (specimen 50/460) is non-amygdaloidal, lighter in weight, faintly greenish and only sparsely porphyritic. The junction with the lower lava is not marked by an erosional break, but is gradational. The lava is rich in nepheline microphenocrysts, occasionally well formed but usually shapeless and veined with alteration products, particularly round the margins. The acicular purplish augite phenocrysts, as well as the minute needles and prisms of augite in the groundmass, often have a green colour, indicating a gradation to aegirine-augite. Yellowish-brown and minutely fibrous serpentine also forms irregular patches enclosing groundmass minerals. Iron ore is present as small grains in the groundmass of the rock and as smaller, better-formed granules in the numerous relatively clearer patches of late-crystallizing analcite, which also enclose a little pyroxene, occasional apatite and rare sphene. This rock is very similar to nephelinite samples from Kilimanjaro lavas in the Taveta area (Bear, 1955, p. 32) and the Ngong Hills region (specimen 51/72).

The weathered rock (specimen 50/462) overlying the nephelinite may represent an altered upper surface. It is green and highly veined in hand specimen, and in thin section is seen to be composed of brown serpentine veined with calcite and containing much spherulitic zeolite material.

Further up the Olongoirenito river there are two restricted exposures of similar lava, richer in nepheline and poorer in porphyritic augite. Specimen 50/456, from blocky jointed lava exposed in the river banks at 1° 30′ S., 35° 53′ E. approximately, is a dark, almost flinty rock. It contains numerous microphenocrysts of fresh, euhedral nepheline showing square and hexagonal sections up to a half millimetre across, accompanied by twinned microphenocrysts of pale green augite and irregular iron ore grains. The groundmass is crowded with small nephelines, not more than 0.1 mm. across, and fine-grained prismatic and acicular pale green augite, which in some crystals is seen to darken terminally to the colour of aegirine. There is much minutely granular iron ore and scattered grains of dark, pinkish brown perovskite, often in elongate crystals. The base is isotropic, with patchy yellow-brown staining, and there are a number of rounded amygdaloidal patches of dark brown amorphous matter. In one part of the slide a

large amygdale of zeolite and nepheline containing a number of pale green ragged augite laths is adjacent to a large purplish augite phenocryst, typical of those in the melanephelinites, but grading marginally to a pale green colour and suggesting that the nephelinites are differentiation products of a melanephelinite magma. Specimen 50/471, a flinty green rock from the circular outcrop about a mile downstream from the last-mentioned exposure, consists mainly of an extremely fine-grained greenish isotropic groundmass in which are set euhedral nepheline microphenocrysts up to 0.5 mm. across, often in glomeroporphyritic aggregates, and much well-formed, second-generation nepheline, up to 0.1 mm. There are rare grains of iron ore and perovskite. The matrix is mainly composed of minutely acicular pale green augite, and there are irregular calcified patches. The rock is also irregularly veined by coarser material similar to the groundmass of specimen 50/456 but containing more zeolite associated with pale green augite and aegirine needles, granular perovskite aggregates and minutely granular iron ore which partly rims the irregular veins.

The nephelinite lavas are probably differentiation products of a more basic magma erupted on flows of melanephelinite from a centre about five miles west of a main fissure or line of vents.

(*f*) *Intrusive Nephelinite*

Highly porphyritic nepheline-rich rocks are exposed in bouldery outcrops along a mile-wide strip between the Kishalduga and Olongoirenito rivers, about four miles west of the Narok-Narosura road. In the Olongoirenito river they are flanked on either side by the two restricted nephelinite lava exposures just described, and it is possible that the porphyritic rocks fill the vents from which the nephelinite lavas were erupted.

An intrusive contact between porphyritic nephelinite and melanephelinite lava can be seen on the north bank of the Kishalduga river at latitude 1° 28′ S., longitude 35° 54′ E. The intrusive porphyritic nephelinite is greenish in colour and crowded with rectangular nepheline phenocrysts up to 2 cm. long, which are etched out on weathered surfaces and give the rocks a very distinctive appearance. In thin section (specimen 50/468) the nepheline phenocrysts are seen to be penetrated in a number of places by a groundmass composed of small euhedral nepheline crystals, acicular augite and granular and acicular iron ore, set in an isotropic analcite base, frequently stained yellowish brown. There are also large irregular grains of iron ore, some poikilitically enclosing smaller nephelines, rare microphenocrysts of purplish augite and a patchy calcification.

The Kishalduga melanephelinite series is one of the largest occurrences of basic, virtually felspar-free lava so far mapped in Kenya, and is certainly the oldest melanephelinite series which can be reliably dated. The suite of tephrites, basanites, melanephelinites and nephelinites, described by Binge (1962) from the Kericho area, is similar to the Kishalduga series but is likely to be younger since those lavas are underlain by the Miocene Kericho phonolites. In the Narok area phonolites of similar age to the Kericho phonolites rest on the melanephelinite series. Melanephelinites and nephelinites also form part of the sequence in the Ngong Hills, which Sikes (1939, p. 19) considered to have been erupted from a north-south fissure as were the Kishalduga melanephelinites. Both Sikes (op. cit.) and Gevaerts (1957, p. 7), however, consider the lavas to be Pliocene in age, rather than Miocene. Baker (1958, p. 15) described a small occurrence of olivine-free melanephelinites from among the Ol Keju Nero basalts near Olorgesailie, and correlated them with the Kirikiti basalts, which he considered to be of Pliocene age. Elsewhere in the country there are demonstrably younger melanephelinites and olivine melanephelinites, including possibly younger lavas forming plugs in the present area.

(2) Phonolites

Phonolites are widespread in the east-central part of the Narok area. They form the Olenguluo plateau and overlie a nearly flat surface of melanephelinite lavas some two miles west of Entapot. In this region the phonolites reach their maximum thickness of about 900 ft., and are of two distinct types. The more widespread lower group, with a maximum exposed thickness of about 400 ft., underlies the northern part of the area as an extension of the Mau lavas, and is seen almost as far south as Olomorooj. The lavas of this group have been termed Group I phonolites. Lavas of the upper group, designated Group II phonolites, have a maximum thickness of about 500 ft., and are confined to the region round Olenguluo and to the low dome-shaped hills of Olomorooj further south.

(a) Group I Phonolites

The older phonolites seem to have formed flat flows in the plateau country of eastern Olenguluo overlooking the Uaso Ngiro river, and benches some 50 to 75 ft. high in the gorge of the river are thought to mark junctions between individual phonolite flows. The lavas have grey and pitted weathered surfaces; they are dark, hard, flinty rocks containing roughly rectangular phenocrysts of nepheline up to 2 cm. long with rarer tabular alkali felspar crystals of similar size, and are often amygdaloidal. In many outcrops the phenocrysts are aligned and the amygdales streaked out in the direction of flow. A columnar jointed flow was seen in the Narok river some $3\frac{1}{2}$ miles north-west of Narok, and flaggy jointing is often developed with random and rapidly changing orientation, even in small outcrops, and is probably due to local flow contortions in the original lava.

In specimen 50/431, from the Narok river two miles north-west of the town, the sanidine and nepheline phenocrysts are fresh. The former is seen as tabular Carlsbad-twinned crystals up to 3 mm. long in section, in a glomeroporphyritic, interpenetrating aggregate; the crystals are corroded terminally and margined by granular iron ore inclusions. The felspar phenocrysts are sodic, and have refractive indices in the range 1.519 to 1.528. Nepheline also occurs in aggregates of marginally corroded and rounded crystals up to 2 mm. across. Microphenocrysts of euhedral apatite and iron ore, often together, are also present. The fine-grained groundmass consists of numerous alkali felspar needles, probably similar to the phenocrysts, not exceeding 0.1 mm. in length, irregular ophitic grains of pale augite, a little reddish brown to colourless biotite, much granular iron ore and probably nepheline. The base is largely isotropic analcite with brown staining. Associated with the phenocrysts are anisotropic zeolites, sometimes spherulitic in habit. Two other samples (50/424 and 427) from about two miles upstream from Narok and at about the same altitude (6,200 ft.) are similar and may belong to the same flow.

Specimen 50/419 collected near Narok prison is typical of the Group I phonolites in this northern region. It is similar in general appearance to those just described but kataphorite and ophitic cossyrite have become important constituents at the expense of augite, which persists however in ragged microphenocrysts and groundmass granules and is sometimes marginally gradational to aegirine. The only other noticeable difference is an increase in the area of groundmass zeolite enrichment, mainly analcite, in which radiating aggregates of small riebeckite needles can be seen. The thin section of specimen 50/531 from $1\frac{1}{2}$ miles south of Narok was seen to contain a very dark green pleochroic amphibole, associated with calcite, iddingsite(?) and apatite.

Many of the weathered Group I phonolites are pink in colour and in thin section show only nepheline and acicular felspars in an amorphous matrix.

(*b*) *Group II Phonolites*

On air photographs this group of phonolites can be distinguished from the phonolites of Group I by a less dense vegetation pattern and also by the domed and lobed terminations of the lava flows, suggesting that the Group II phonolites were more viscous than earlier flows.

The rocks are readily distinguished in the field, having a smooth brown weathered surface and few phenocrysts. Fresh surfaces are usually dark grey, as in the Group I lavas, but the rocks are often speckled and streaked with pink due to local enrichment in analcite, as in specimen 50/566 from Olenguluo. Ferromagnesian minerals are less abundant than usual in the rocks of this group, so that the ophitic mossy aggregates of aegirine, cossyrite and kataphorite are conspicuous in a mainly isotropic and lightly brown-stained groundmass. No augite was seen and iron ore is rare. Other samples from this group are similar, though usually richer in dark minerals and correspondingly less speckled. Phenocrysts of both nepheline and sanidine, the former often in glomeroporphyritic aggregates, are visible in some of the thin sections. Specimen 50/565, from the top of the succession at Olenguluo, differs from other specimens in containing granular aegirine almost to the exclusion of soda-amphiboles.

The low domed hills of Olomorooj are also formed of Group II phonolites, and their shape resembles the bubble-like cumulo-domes which result from local eruption of viscous magma (Cotton, 1962, p. 156). The phonolites forming the northern hill are more streaked and speckled than any others seen in the area. Examination of thin section 50/497 shows that there has been some alteration, the zeolitic component being more turbid than in specimen 50/566 described above. A microphenocryst of aegirine-augite was seen in the thin section of specimen 50/496 from the same locality.

A single flow of Group II phonolite (specimen 50/541) is intercalated among the Group I flows of the Uaso Ngiro gorge. It was found about 200 ft. below the top of the Group I succession on the east side of the gorge about five miles downstream from the Narok confluence.

Schoeman (1949, p. 28) described phonolites of Miocene age from the Sotik area (the southern extension of the Kericho phonolites, Binge, 1962, p. 25), some of which are almost identical in appearance to the Group I phonolites of the Narok area.

The restricted outcrop of the Group II phonolites in the Narok area suggests that they derived from a local eruptive centre at Olenguluo from which one or more early flows erupted among the Group I lavas before the main extrusions of the more viscous aegirine-rich lavas. It is also possible that some of the Group I lavas in the south Narok and Uaso Ngiro valleys were erupted from this local centre. The time interval between the last Group I flow and the commencement of the main phase of Group II lava extrusion is not possible to assess.

The Miocene phonolites of this region can probably be correlated with the Miocene Uasin Gishu phonolites north of the Kavirondo Rift Valley, and also with the widespread Kapiti and Rumuruti phonolites on the east side of the Gregory Rift Valley, which are also of Miocene age.

(3) Alkali Basalt Series

The rocks included in this group are the alkali basalt flows capping and interdigitating with the tuffs and ashes in the Seyabei and Uaso Ngiro valleys, as well as two outcrops of more normal basalt, one in the Seyabei river and another, much smaller, near Ildungisho.

(a) *Seyabei Olivine Basalt*

A two-mile strip of dark columnar-jointed olivine basalt (specimen 50/550) is exposed in the bottom of the Seyabei valley about three miles south of the main Nairobi road. It is composed of ragged plagioclase laths, including microphenocrysts up to 1 mm. long, some of which have extinction angles corresponding to a mid-labradorite composition, although much of the groundmass felspar may be less calcic. Olivine occurs as fresh microphenocrysts and as small grains in the groundmass. Purplish augite also occurs in the groundmass as ophitic aggregates which have mostly been converted to acicular and dusty iron ore. Intersertal patches of analcite, stained green and brown, are also present, thus giving the lava a basanitic character.

(b) *Ildungisho Olivine Basalt*

Overlying the tuffs in the south bank of the Olongoirenito river at the base of the Ildungisho trachyte plateau there is a small exposure of vesicular lava (too small to distinguish on the map) originally thought in the field to be a trachyte, but found on examination in thin section (specimen 50/478) to be basalt. It has many olivine pseudomorphs, both as brown and green phenocrysts and as grains in the groundmass, which also contains labradorite and granular purplish augite, and iron ore in grains and large irregular masses. The lava overlies tuffs containing fragments of plateau trachyte (specimen 50/480) and is therefore much younger than the trachytes, so that correlation with the alkali basalt series further north in the Seyabei valley is possible.

(c) *Alkali basalts*

Thick ashes and tuff bands outcropping between the Uaso Ngiro and Seyabei rivers are capped by extensive flows of alkali basalt, usually less than 50 ft. thick, forming the plateau country of Oletugathi and Enamankeon. They overlap the ashes at two places to rest on older lavas, on melanephelinites north of Legorinyo and on phonolites four miles downstream from the Narok-Uaso Ngiro confluence. Small exposures of similar lavas outcrop among the ashes in the sides of the Seyabei valley south of the Narok-Nairobi road and there is a long strip exposed along the lower part of the valley north of the Seyabei Mission. The alkali basalts are almost certainly the products of quiet fissure eruptions, probably along the Oletugathi fault line.

Specimen 50/537 from the Uaso Ngiro valley approximately ten miles south of Narok is composed mainly of sub-parallel, ragged, slightly zoned oligoclase-andesine laths, with microphenocrysts of andesine-labradorite up to 1 mm. in length. The specimen also contains microphenocrysts of purplish and slightly pleochroic augite, which is also present as granules in the groundmass. Apart from granular iron ore the only other constituent is reddish brown iddingsite pseudomorphing elongate microphenocrysts and groundmass granules of olivine. The specimen was taken from alkali basalts forming the Oletugathi plateau; the basalt rests on about 400 ft. of tuffs and waterlain ashes, and is thickest just north of Enkorika where at least 75 ft. of lava are exposed without visible base.

The small outcrops of alkali basalt at various levels in the sides of the Seyabei valley, above the Enamankeon flow, represent later flows erupted during the continued deposition of partly waterlain pyroclastics on the downthrow side of the Oletugathi fault. Two samples were collected from adjacent small flows on the eastern side of the river about 1½ miles south of the Narok-Nairobi road. Specimen 50/556 is vesicular and rich in tabular andesine-labradorite phenocrysts averaging 2 cm. across. The groundmass contains many ragged laths of oligoclase-andesine, prismatic and granular pale purplish augite, granular iron ore and patches of amorphous brown material. There are also patches of interstitial grey fibrous zeolite. The overlying fine-grained lava (specimen 50/555) is highly vesicular, but unusual in that many of the vesicles are filled with small,

curved, yellow flakes, probably of stained analcite. The rock is closely similar to the alkali basalt of the Oletugathi flow, the first to be described above, but contains in addition iddingsite pseudomorphing groundmass granules and elongate microphenocrysts of olivine.

The lavas exposed along the north Seyabei valley have about the same gradient as the river, for the upper surface maintains a more or less uniform height of between 50 and 100 ft. above the valley floor along the length of outcrop. The lavas must therefore have flowed down the southern slopes of the Mau highlands, and may have originated from a northerly continuation of the Oletugathi fissure.

(4) Plateau Trachytes

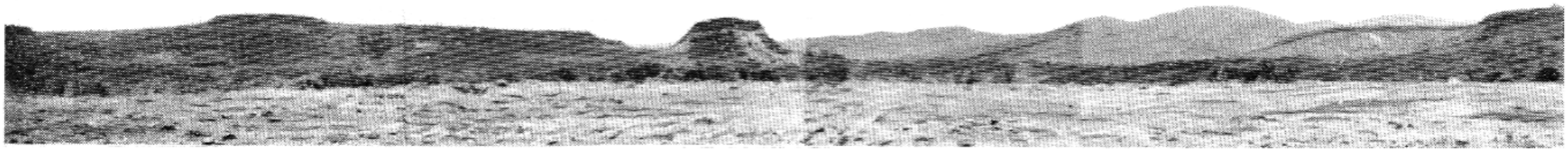
Up to 500 ft. of Pleistocene plateau trachytes occur in the south-east of the Narok area, probably the products of quiet fissure eruptions along the Naitiami fault line. Together with similar lavas in the area to the south (Saggerson, 1966, p. 32), the trachytes are a thicker north-westerly extension of those forming the Lengitoto plateau in the Magadi area, considered by Baker (1958, p. 18) to be early flows of the extensive lava sheets now covering much of the southern Rift Valley floor, although the latter must have been erupted from fissures east of the Naitiami fault line.

The lavas thicken northwards from the Lengitoto plateau into the present area, at the expense of the Kirikiti basalts which probably thin in the same direction and have in addition been overlapped by the trachytes. The trachyte outcrop seems to stop abruptly at the latitude of Enkorika where it is thought to have formed the southern barrier of the earlier Pleistocene lakes in this region. Between 400 and 500 ft. of lavas are exposed in the south-eastern corner of the area where they may have dammed the Olongoirenito river to form a small lake. The series thins northwards and at Legorinyo trachytes banked against the melanenephelinites are only a few tens of feet thick.

In some outcrops the trachytes have a random flaggy parting due to the weathering of flow laminations; they have a thin, dark brown weathering skin, but fresh surfaces are grey and often have a pronounced sheen. In thin sections specimen 50/476 from Ildungisho is closely similar to the plateau trachytes in adjacent areas (Baker, 1958, p. 18; Saggerson, 1966, p. 32). Rare microphenocrysts of clear, tabular, Carlsbad-twinned sanidine about 0.5 mm. long are set in a groundmass of flow-oriented sanidine laths. The remainder of the groundmass is made up of intersertal and ophitic cossyrite and kataphorite, and less important aegirine. There is also a reddish brown alteration product, apparently derived from the cossyrite, and a few small ophitic quartz grains.

The steep sides of the hills at Ildungisho expose vesicular trachytes marking the upper and lower limits of individual flows. In the vertical face overlooking the north side of the Olongoirenito river at Emugur Olmoruo rough columnar jointing is displayed, and at the base of the cliff blocky, flow-brecciated and vesicular trachytes are exposed. Specimen 50/479 from this locality has a cryptocrystalline base containing rounded inclusions of trachyte poor in ferromagnesian constituents and often iron-stained, with numerous irregular shards of clear but corroded soda-rich sanidine having refractive indices in the range 1.519 to 1.528. There is also much fine-grained prismatic alkali felspar in the glassy base.

Good exposures of fresh trachytes displaying complex flow laminations may be seen in the Leshota gorge section at latitude 1° 23′ S. near the eastern margin of the mapped area. Specimen 50/505 from this locality has a fine light and dark grey banding and contains elongate sanidine phenocrysts up to 1.5 mm. long, usually dusted with iron ore and containing rare apatite inclusions. The remainder of the rock is composed of flow-oriented alkali felspar laths, probably sanidine, often with iron ore dusted cores, and appreciable amounts of ophitic cossyrite, kataphorite, aegirine and yellowish staining.



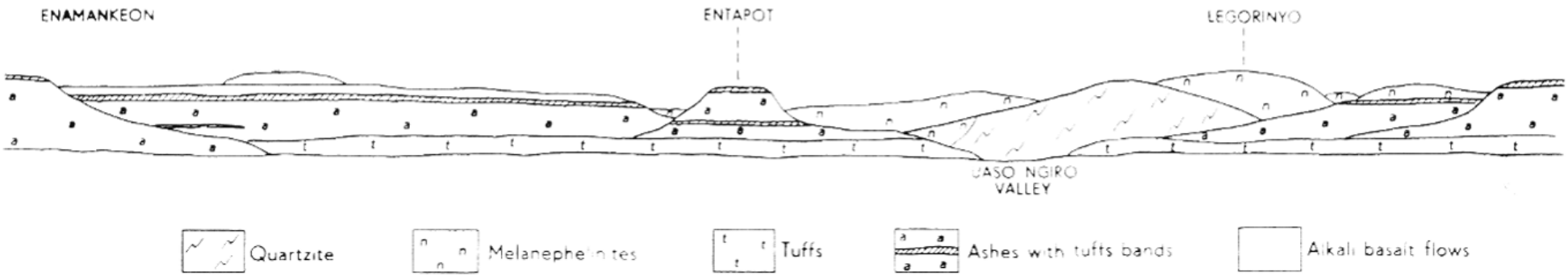


PLATE I

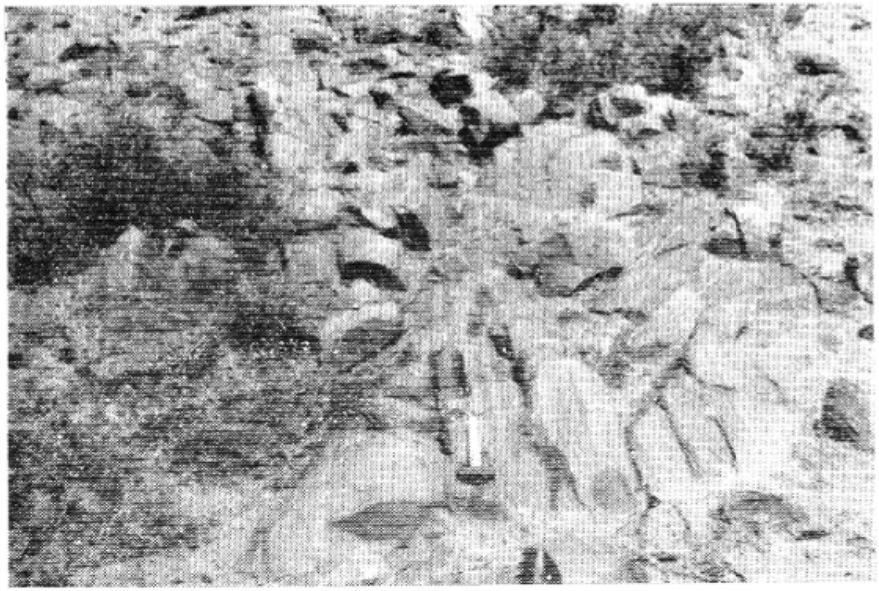
Panoramic view of the country round Entapot, showing plateau of ashes capped by tuff and andesite, with rolling higher ground of melanephelinite lavas in the background



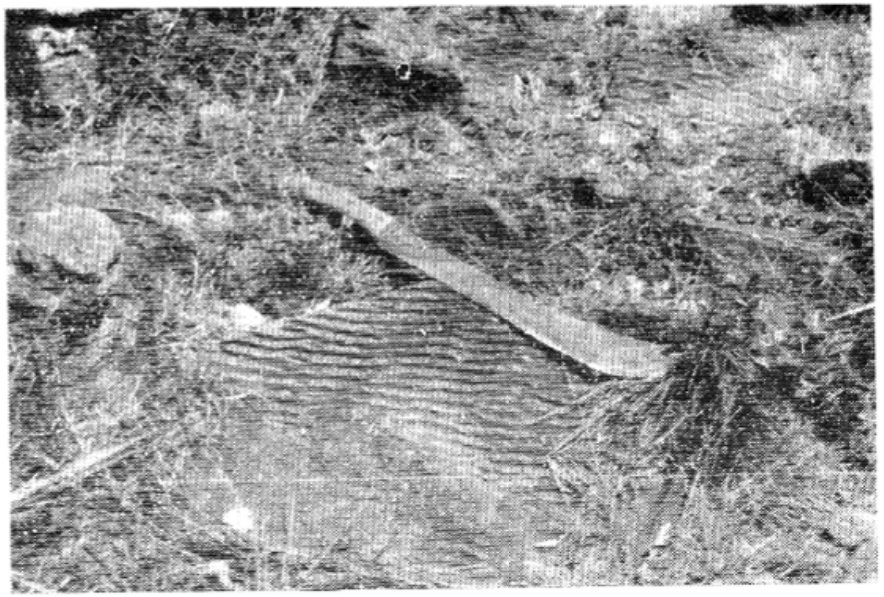
(a) Typical coarse granular quartzites, ridge north of Lengijabi



(b) Typical coarse white quartzites, Uaso Ngiro valley

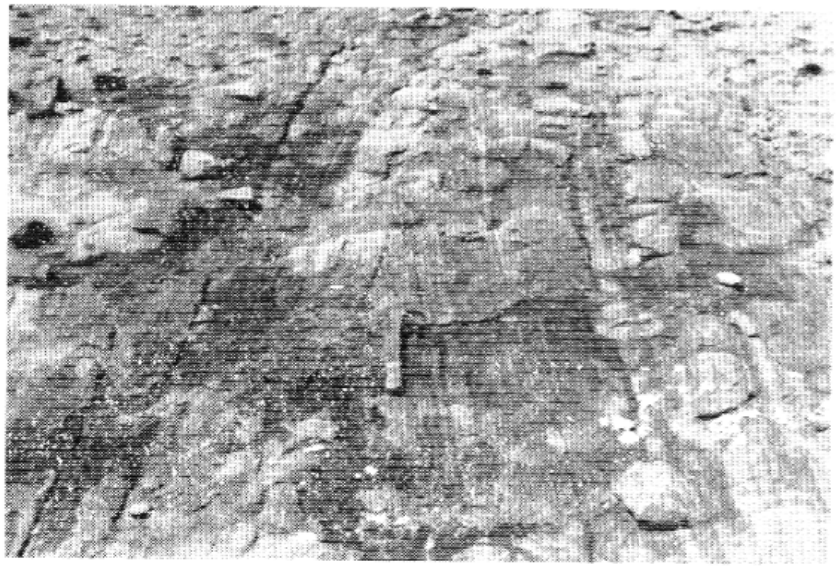


(c) Typical finely laminated white quartzites, north of Lolua



(d) Ripple marks in laminated quartzites, Oloirien river valley

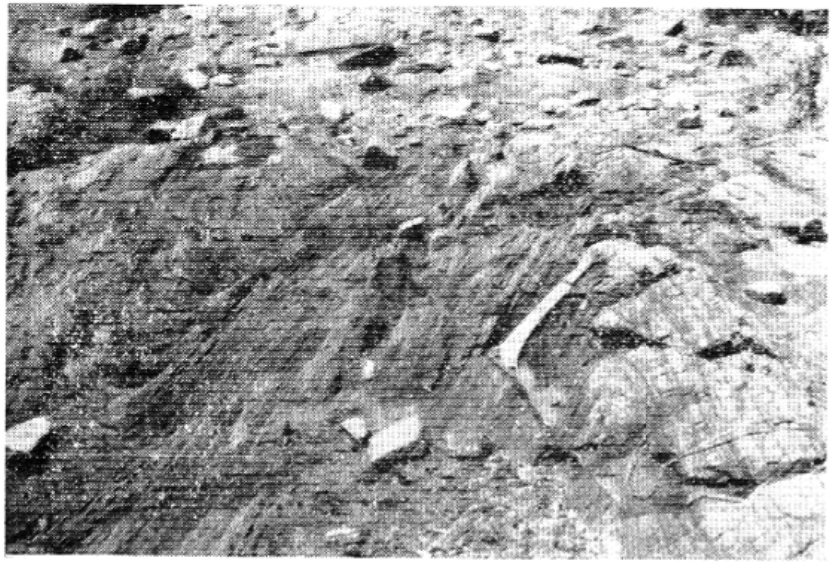
PLATE II



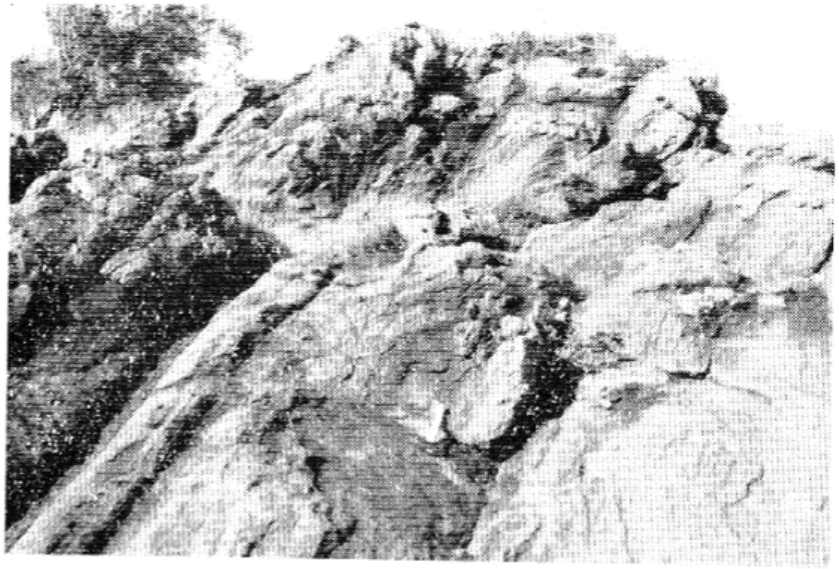
(a) Low-angle cross-bedding in laminated quartzites, Oloirien river valley. The rocks are less finely laminated than those in Plate II (c)



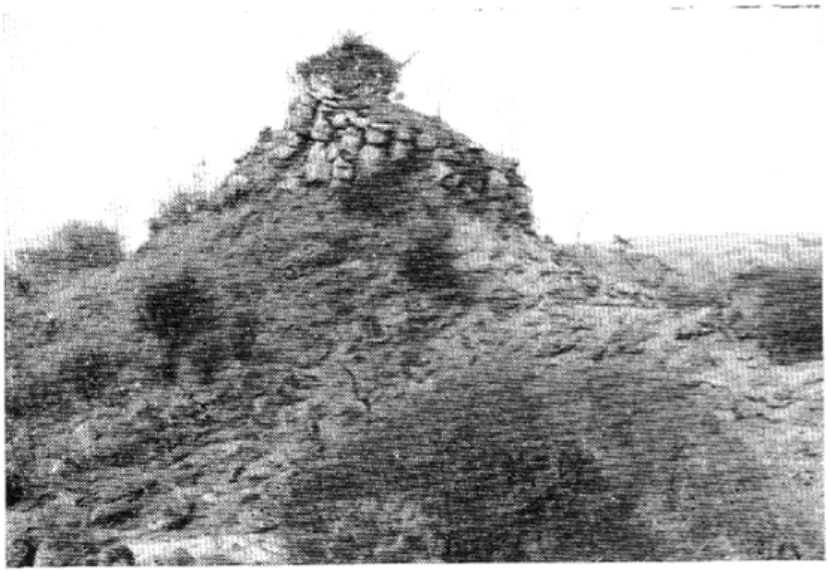
(b) High-angle cross-bedding in laminated quartzites, Oloirien river valley. Small anticlinal fold with southerly plunge in the foreground



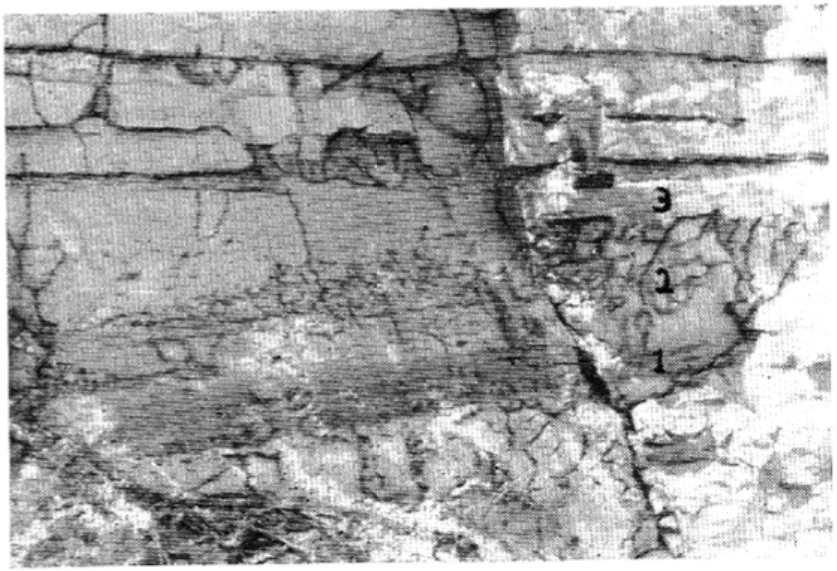
(c) Minor north-plunging anticline and syncline in cross-bedded laminated quartzites, Oloirien river valley



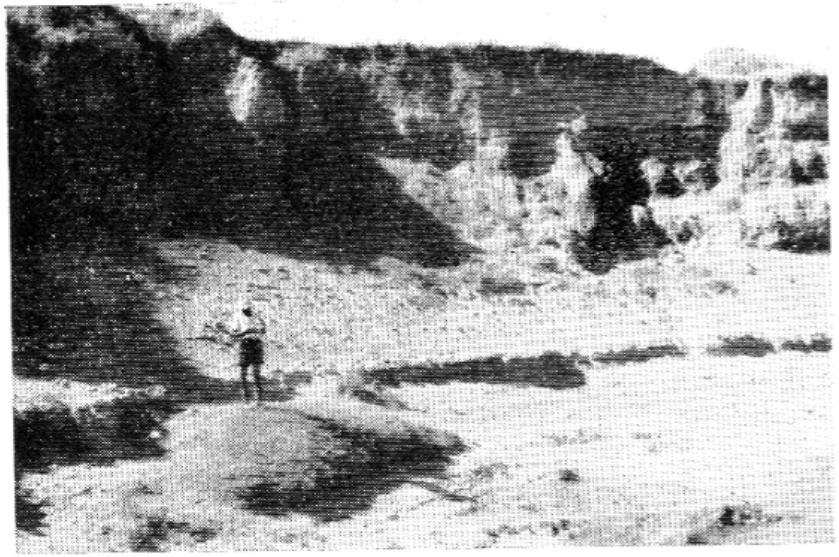
(d) Contorted muscovite quartzite, north-east of Lengijabi



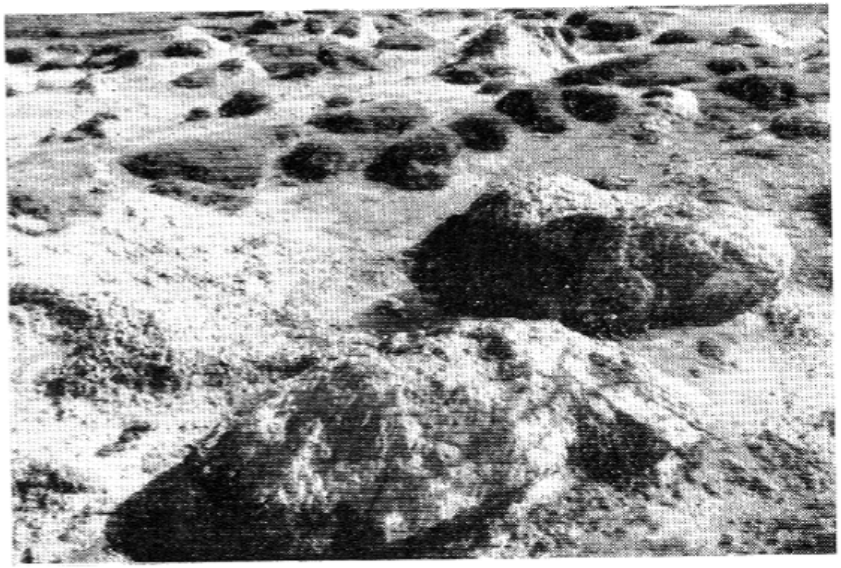
(a) Blocky-jointed plateau trachyte capping ashes, Enamatishorecki depression



(b) Typical section in well-bedded ashes, Ntuka river valley—Bed 1 consists chiefly of coarse pumiceous fragments, Bed 2 consists of pink ashes with a curved fracture, Bed 3 consists of finely laminated ashes



(c) River deposits, mainly ashes, in the Uaso Ngiro valley near Ol Olong'a. The hard band at the base of the section is calcareous



(d) Nodular limestone mounds in the Masandare valley, near Ol Donyo Rasha

PLATE IV

At the southern end of the Enkorika ridge chilled trachyte is exposed near the contact with melanephelinite. The trachyte (specimen 50/561) is a light grey flinty rock grading into darker and more vesicular lava. The paler rock consists of glass with felspar crystallites, in which are embedded large, irregular corroded sanidines; the groundmass of the darker and more rapidly chilled lava is almost black with iron ore dust, and contains much spherulitic felspar and included fragments of clear alkali felspar.

At two places on the Naitiami scarp, very thin trachyte cappings overlie ash deposits. The first of these occurrences is a mile SSE. of Legorinyo. There appear to be two levels of trachyte separated by ashes at the more southerly exposure at Enamatishorecki, about two miles north of the Leshota valley. Here a shallow depression, about 50 yards across, is rimmed by ashes and trachytes and floored on the north side by highly vesicular lava, possibly trachyte. In the middle of the depression is a small mound of ashes with a thin capping of blocky jointed trachyte dipping northwards at about 25° (Plate IV (*a*)). The rock forming the capping (specimen 50/584) is a typical grey plateau trachyte with small black and yellow phenocrysts. Rare irregular phenocrysts of sanidine, about 1 mm. across, were seen in thin section, marginally corroded and packed with iron ore. Elongate Carlsbad-twinned microphenocrysts of the same mineral are abundant. The flow-oriented groundmass is composed mainly of small felspar prisms, probably sanidine, with intersertal cossyrite and kataphorite and trace amounts of aegirine. Among the grey ashes exposed on the west side of the depression fragments of yellow and grey, highly vesicular and fragile pumice were found (specimen 50/586) carrying well-formed crystal fragments of anorthoclase up to 0.5 cm. across, with refractive indices in the range 1.524 to 1.533, and displaying multiple twinning on cleavage flakes.

The small channel which drains the depression cuts through a 6-ft. bank of brown and green current-bedded sediments of varying grain size and then flows eastwards along the southern edge of the main trachyte outcrop. The finer sediments (specimen 50/588) are mainly waterlaid ashes and are composed chiefly of elongate glass shards. Slides of the coarser sediments (specimen 50/587) show that they also contain appreciable amounts of volcanic glass, but carry in addition rounded inclusions of trachyte, fragments of felspar and pyroxene, and numerous rounded grains of basalt of uncertain origin, not unlike the Seyabei basalt exposed further north. Two other slightly larger rounded fragments from the coarser sediments were identified as iron-stained vesicular aegirine-trachyte and kataphorite-trachyte, both probably anorthoclase-bearing. Neither fragment resembles the plateau trachytes described above, but resemble trachytes described by Thompson and Dodson (1963, p. 26) from the Naivasha area.

The shallow, roughly circular Enamatishorecki hollow and the pumiceous ashes near it must be the result of a local minor explosion, but the disposition of the lavas is difficult to explain. The rock of the capping is identical with the plateau trachytes described from the main succession and could represent a small final extrusion of trachyte on the ashes, or a large trachyte block which was disrupted by the explosion.

(5) Angata Naado Trachytes

The youngest lavas in the area form the flat plateau of Angata Naado. Two trachyte flows, neither exceeding 50 ft. in thickness, are distinguishable on air photographs; the upper flow is more extensive than the lower. The flows were erupted close together during further ash deposition, and rest on a virtually flat ash or tuff surface. The only detectable irregularity in the ashes below the lavas occurs 2½ miles NNW. of the Angata Naado Trading Centre, where the lower trachyte terminates in a slight depression.

The trachytes are usually vesicular and weather dark brown; freshly broken surfaces are grey. Specimen 50/559, from two miles south of the trading centre, contains greenish tabular felspar phenocrysts up to 1 mm. across. In thin section it is similar

both to the orthophyre-trachytes of the Magadi area and to the "older trachytes" described by Thompson and Dodson from the Naivasha area (1963, p. 26). The felspar phenocrysts display Carlsbad-twinning and have refractive indices in the range 1.524-1.533, diagnostic of anorthoclase. Clear signs of multiple twinning are visible only in cleavage flakes; margins of phenocrysts are corroded, dusted with iron ore and traversed by cracks containing brown alteration products. The trachytes also contain euhedral microphenocrysts of pale green augite, sometimes in aggregates, which are often associated with iron ore grains of similar size. Some of the larger iron ore grains are pseudomorphs of olivine. The groundmass is almost entirely composed of prismatic alkali felspar, with intersertal kataphorite, cossyrite, iron ore, pale pyroxene and rare traces of aegirine. Small amounts of quartz occur in the groundmass of this specimen, but no quartz has been recorded from similar lavas in the Magadi and Naivasha areas. Specimen 50/554, also taken from the top flow about five miles farther north, is very vesicular and generally similar to the rock described above; no pyroxene microphenocrysts were seen in this specimen; the ferromagnesian minerals of the groundmass are altered, and iron ore pseudomorphing olivine was seen in the thin section.

The mineralogical and textural features of the phonolites and trachytes seen in the area are summarized below:—

Mineral constituent	*Phonolites*	*Plateau Trachytes*	*Angata Naado Trachytes*
Felspar phenocrysts	Sanidine	Sanidine	Anorthoclase
Felspathoid	Nepheline	—	—
Pyroxene	Augite or aegirine	Aegirine	Pale green augite
Amphiboles	None, or Kataphorite and cossyrite	Kataphorite and cossyrite	Kataphorite and cossyrite
Texture	Random	Trachytic	Trachytic

(6) Olivine Melanephelinite Plugs

Four plugs of olivine melanephelinite protrude through the ash cover in the northern part of the area. They form the rounded tree-covered hills of Mutunyi, Morijo Narok and Masandare, and a small outcrop adjacent to a quartzite ridge five miles south-east of Ngore Ngore.

The rocks are dark, compact and rich in porphyritic olivine, the larger phenocrysts being visible in hand specimen. Examination of thin sections shows that they are also rich in pale purplish augite and completely free of felspar, its place being taken by nepheline, with or without zeolites. The olivine is often euhedral and elongate, though rarely exceeding 0.5 mm. in length, and may be slightly enriched in the fayalite molecule. The olivine is usually fresh but invariably corroded marginally, and in specimen 50/557, collected south-west of Mutunyi, it is brown-rimmed and altered to green serpentine. This specimen is also rich in nepheline to the exclusion of zeolite, but the summit rock of Mutunyi (specimen 50/528) contains both these minerals and some of the purple augite in it forms small microphenocrysts. Specimen 50/536 from Morijo Narok is closely similar but finer grained and without pyroxene microphenocrysts. A large (2 mm.) olivine phenocryst seen in the thin section has been so corroded that the margin has a scalloped appearance. Two specimens from the north-west of the area, 50/593 from Ngore Ngore and 50/594 from Masandare, are similar but are slightly enriched in the smaller olivine crystals and have irregular ophitic veins and patches of a dark sodic mica, pleochroic from colourless to yellow and foxy red. Iron ore is ubiquitous in these rocks as stellate clusters and as groundmass granules.

The age of the plugs is uncertain, for they are all surrounded by final ash deposits and no contact with other lavas or tuffs is exposed. Saggerson (1966, p. 35) has described and figured practically identical rocks, also forming small plugs, from which ignimbrites appear to have flowed down valleys cut through plateau trachytes in the north-east corner of the Loita Hills area. The ignimbrites hence post-date the trachytes by an appreciable period, but the olivine melanephelinite plugs of the Narok area appear to be eroded vents or cones of even greater age. It is difficult to deduce their position in the Narok volcanic sequence; they are probably not of the same age as the Kishalduga lavas, since they are found at a considerable distance from the latter, and fill scattered vents rather than fissure systems.

The olivine melanephelinite plugs are similar in composition and texture to the olivine melanephelinites of the Kishalduga melanephelinite series. They differ only in containing smaller olivine crystals and little or no porphyritic augite.

There are several recorded occurrences of melanephelinite lavas among the later Tertiary and Pleistocene volcanics of Kenya. The Laikipian basaltic and basanitic suite on the eastern slopes of the Aberdare mountains (Shackleton, 1945, p. 3) are probably late Pliocene in age, and include olivine melanephelinites almost identical to those of more recent age in the Narok and Loita Hills areas. Melanephelinites and nephelinites occur in Pleistocene lavas of the Kilimanjaro sequence in the Taveta area (Bear, 1955, p. 32). Olivine melanephelinites were also found among the dominantly basaltic Pleistocene lavas of the Nyambeni mountains, north-east of Mount Kenya; they are rich in microporphyritic olivine and also contain large pale green augite phenocrysts (Rix, 1967). Olivine melanephelinites similar to those of the Narok area form cones in the Sultan Hamud area (Searle, 1954, p. 22); they are located at the north-western limit of the basanitic lavas of the Chyulu range.

(7) Pyroclastic Rocks

Deposition of pyroclastic material continued throughout the later stages of the volcanic history of the area and probably outlasted the period of lava extrusion. For descriptive purposes the pyroclastic rocks are subdivided into (*a*) Tuffs and (*b*) Ashes. If sufficiently friable to be cut with a knife or crumbled in the fingers they have been termed ashes, otherwise they are called tuffs. The tuffs are considered to be the products of hot ash falls welded together by their own heat.

(*a*) *Tuffs*

Tuffs are widespread in the area forming thick accumulations in several of the larger river valleys. Although best developed in the north-eastern part of the area, exposures are generally poor because of the thick vegetation. Good exposures can be seen in the Narok river valley near the confluence of the Narok and Uaso Ngiro rivers. Other good exposures were found in the Uaso Ngiro especially near the Ntuka confluence where up to 200 ft. of tuffs form sheer gorge walls, and there are also less important exposures in the south-east corner of the area, in the valleys of the Olongoirenito and Leshota river systems, where tuffs rest on melanephelinites and plateau trachytes in the valley floors and sides.

The rocks are usually medium to pale grey in colour, but are sometimes green, yellow, pink or purple, occasionally calcified, and brown when weathered. They are usually light in weight due to their content of fragmentary pumice. Blocky jointing can be seen in the tuffs and they are often flaggy parallel to the deposition plane, especially the less vesicular and more compact types. Good columnar jointing is to be seen at several places along the sides of the Uaso Ngiro valley, but jointing elsewhere is not usually pronounced and the vesicular tuffs make a good freestone which is quarried near Narok for building purposes.

Stratigraphy of the tuffs is commonly sub-horizontal, but there are abrupt irregularities in the topography on which they were deposited and steeply dipping layers are sometimes exposed. For example, just up-stream from Emugur Olmoruo in the Olongoirenito river the tuffs dip steeply to the north-east with a vesicular base resting on secondary limestones derived from melanephelinite. A tributary channel nearby exposes tuffs with a yellow base resting on a low dome or ridge of melanephelinite, and a similar steep contact can be seen higher up the Olongoirenito river between tuffs and nephelinites.

Samples of tuff were taken from the Narok river exposures, along the Uaso Ngiro, Seyabei and Ntuka rivers, and from the melanephelinite terrain in the south-east of the area. When examined in thin section most are seen to have a brown or grey glassy base containing fibrous glass shards with patches of spherulitic and fibrous felspar or zeolite, frequently with dark rims. Iron ore is commonly present as finely disseminated dust and as irregular masses, and there are numerous inclusions derived from other rock types. The glassy base contains vesicles rimmed with zeolite.

Specimen 50/533 from the Narok river is a vesicular tuff in which the pumice patches are filled with yellowish white zeolite in well-developed prisms and fibrous aggregates. A tuff containing obsidian shards aligned sub-parallel to the deposition plane is distinctive at various levels in the pyroclastic sequence in the north of the area. One of the horizons marked by these tuffs is directly above phonolites in the Narok river about four miles up-stream from the town, and a second is located in the Uaso Ngiro river about two miles below the Narok confluence, again directly above phonolites. A similar tuff strata was also found forming the river bed between one and two miles south of Narok, and another in a tributary stream north of Nairaserasa. In thin section (e.g. specimen 50/426 from the Narok river) the obsidian is relatively clear and pale brown or violet in colour.

Inclusions are numerous in the tuffs; the more common are irregular and often corroded felspars, usually sanidine, but anorthoclase and oligoclase were also seen. Other felsic minerals identified were quartz and nepheline. Mafic crystal fragments include brown biotite similar to that in the gneisses, pale green aegirine-augite, kataphorite, green-brown hornblende and olivine rimmed by iron ore. Almost every tuff examined also contained fragments of trachytic or phonolitic lava, usually altered and dusted with iron ore, with felspar, kataphorite, aegirine, cossyrite and analcite. Many of these lithic inclusions are similar to the phonolites and trachytes seen in the present area.

The tuffs exposed among the melanephelinites in the south-east corner of the area often occur as angular blocks locally littering the surface of the ground, especially in the smaller outcrops on the valley sides. As well as containing the inclusions listed above, these tuffs also carry distinctive fragments of pale purple augite and augite-rich melanephelinite, and in specimen 50/459 from the Olongoirenito river an oligoclase tephrite fragment from the Kishalduga melanephelinite series was identified.

The compact tuffs are more readily subject to calcification than the vesicular varieties. Calcified tuffs were found in the Kishalduga valley immediately east of a porphyritic nephelinite intrusion, and in the Ntuka river at Lomoroi. Strongly calcified tuff beds also occur in the Uaso Ngiro section at the head of a small tributary valley about two miles downstream from the confluence with the Narok river. They resemble pink or grey limestones with inclusions protruding from the weathered surfaces. In thin section (specimen 50/539) these rocks are seen to be normal tuffs rich in calcite, both as veins and patches, and pervading the groundmass. Stratigraphic calcification of the tuffs has probably occurred by a similar process to that producing surface limestone sheets.

There are two places where very compact rocks of presumed pyroclastic origin occur. One is on the north bank of the Uaso Ngiro river due north of Legorinyo summit, just east of the gneisses, and the other on the right bank of the river, in the eastern part of Olenguluo. Specimen 50/549 from the first mentioned exposure is pale grey and crowded with crystals of clear sodic sanidine, with refractive indices in the range 1.519-1.528. The base is a uniform grey glass, slightly crystallitic, the fibrous crystallites being locally concentrated in sub-parallel streaks. The base also contains patches of dendritic iron ore and brown material, one of the latter showing perlitic structure. The profuse shards of clear sanidine show less good alignment than the crystallites. There is in addition an elongate shard of trachyte, the only xenolith in the slide. The other hard rock, specimen 50/567 from Olenguluo, is pale grey and almost granular, with what appears to be fine brown siliceous veining, and in thin section is similar to the sample just described. These rocks are very compact and uniform and may be ignimbrites, products of incandescent ash flows, rather than of the merely hot ash falls which formed the normal, mainly vesicular tuffs. Saggerson (1966, p. 34) identified ignimbrites in the area to the south.

Two of the tuff samples collected in the Uaso Ngiro section bear a striking resemblance to waterlain ashes described later. One is part of the great thickness of tuffs which underlie the ashes round Entapot. In the Ntuka river-bed, just up-stream from the Uaso Ngiro confluence, there is a long exposure of blocky jointed, dark green-grey tuffs with white speckling, which thin section examination (specimen 50/580) shows to be composed of cellular non-uniform dark glass, with only small xenocrysts of alkali felspar. They contain numerous and often large cavities, usually either ellipsoidal or cylindroidal in shape, the latter sometimes branching. The vesicles are wholly or partly filled with brown and white conchoidally fracturing amorphous material sometimes of botryoidal habit, and probably siliceous. One of the vesicles (specimen 50/581) shows a surface of slaggy fused glass, suggesting that the original gas temperature in the cavity was fairly high. The material partly filling the cavity consists of brown amorphous silica surrounded and veined by similar material, white in colour and with blue-grey streaks. These amorphous deposits may be the condensation products of original gaseous fluids in the cavity, or they could have been deposited epigenetically from percolating groundwater. The other sample of ash-like tuff, specimen 50/568 from Olenguluo, is also green with white speckling, but is finer grained. It overlies the second of the two very hard tuff exposures described above. In thin section it is composed simply of sub-parallel glass shards in a glassy base, with elongated vesicles.

(*b*) *Ashes*

There are probably more than 200 ft. of ashes in the north-eastern part of the area, for the most part resting on tuffs of similar thickness. They thin to west and south-west over the Loita Plains. Along the Ngore Ngore road they are at least 50 ft. thick. Like the tuffs, ashes cover undulating terrain so their thickness is variable from place to place.

In the central eastern part of the area ashes are well exposed along the Uaso Ngiro and Seyabei rivers. They are older than most of the ashes seen elsewhere for they underlie alkali basalts, while the remainder mostly post-date the basalts. The older ashes are thought to have accumulated mainly as waterlain sediments in lakes, and are rare in the south-east of the area. Although not distinguished on the map, the two groups of ashes, older (waterlain) and younger (sub-aerially deposited), will be described separately. Fig. 3 shows the approximate extent of the two groups.

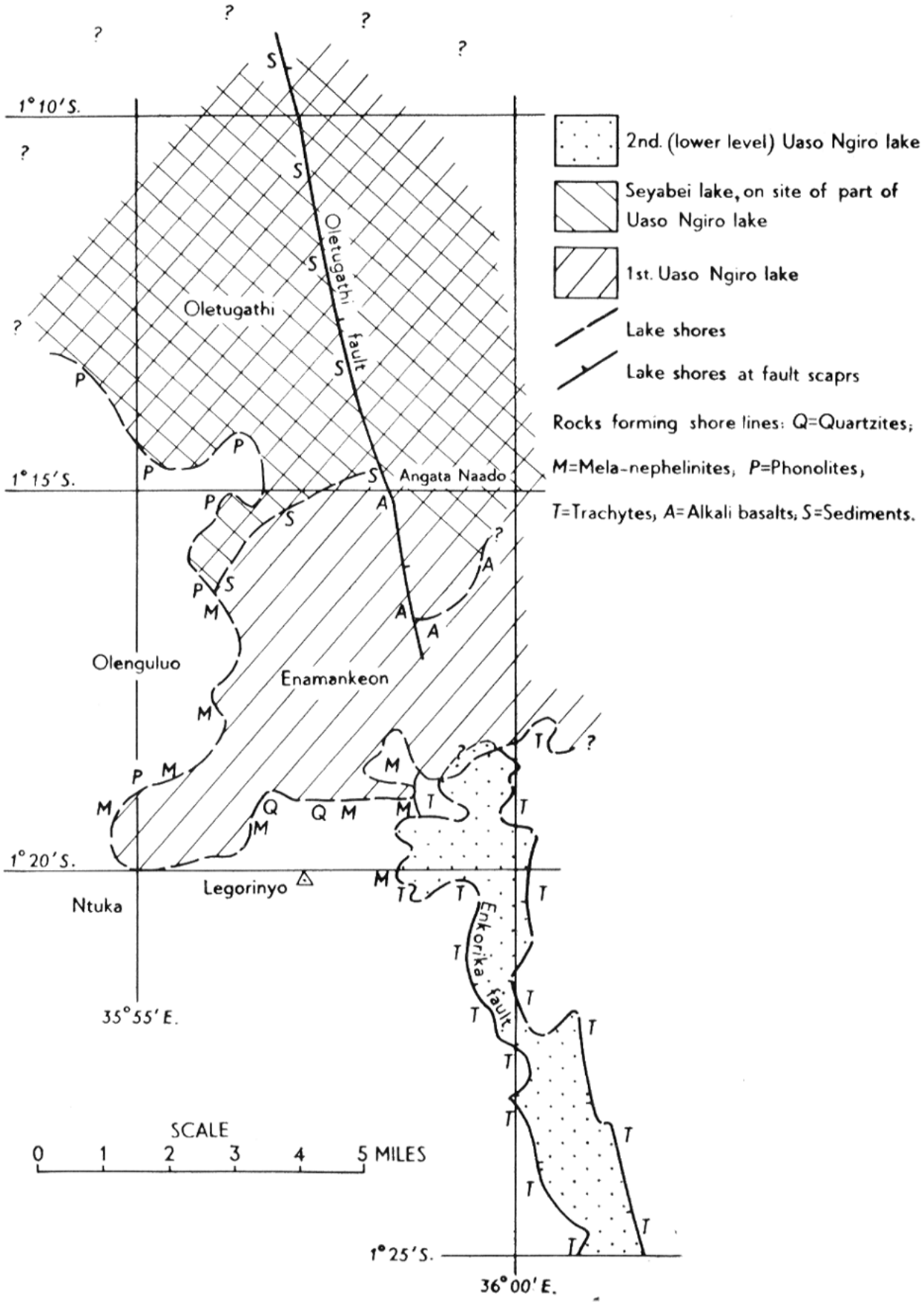


Fig. 3—Sketch map illustrating the extent and relationships of the postulated Pleistocene lakes

Older (Waterlain) Ashes of the Uaso Ngiro, Seyabei and Olongoirenito Lakes

In the Uaso Ngiro valley some 200 ft. of waterlain ashes overlie a similar thickness of tuffs. There are two thin tuff bands in the ashes, each between 10 and 20 ft. thick. One is near the base of the succession and is developed locally round Entapot at an altitude of about 5,400 ft. The other, near the top of the sediments, is much more persistent, and extends from well north of Entapot down the Uaso Ngiro valley and round to the valley west of Enkorika. It also caps the numerous erosion residuals in the Uaso Ngiro valley (Plate I). Between the Uaso Ngiro and Seyabei rivers the sediments are capped by the Enamankeon alkali basalt in the south and the Oletugathi alkali basalt in the north, the two flows being separated by a thin layer of ashes. The Seyabei river section exposes about 400 ft. of ashy sediments with local tuff bands, possibly equivalent to those in the Uaso Ngiro section.

Often laminated and sometimes current-bedded, the sediments are thought to have been deposited in large bodies of shallow standing water, supplied with fine pyroclastic debris both from southward-flowing rivers and from direct ash falls. Only the softer ashes are considered to have been waterlain, and the thin tuff bands and the thick tuffs beneath the ashes in the Uaso Ngiro valley were probably deposited sub-aerially, still with sufficient heat to compact into relatively hard rocks.

It seems that the lavas forming the southern barrier of the lake (across the site of the present Seyabei river) were downfaulted along the Enkorika fault line after a sedimentation phase had built up the level of the deposits to 200 ft. As the lake commenced to drain away the extensive tuff band near the top of the succession in the Uaso Ngiro valley was then sub-aerially deposited on the emerging sediments. The Seyabei basalt and Enamankeon alkali basalt erupted shortly afterwards, the latter forming an extensive capping to the sediments. It was subsequently downfaulted along the Oletugathi fault line and tilted to the north, the fault being hinged at Enkorika. This dammed the embryo Seyabei river and formed the Seyabei lake, which was bounded on the west by the Oletugathi fault scarp. The northern part of the western lake shore was composed of soft sediments and subject to rapid erosion, so that ashes which were deposited in this second lake probably overlap on to older sediments of the first lake, and may even incorporate some of them west of the fault (Fig. 3). Finally it is believed that the Oletugathi alkali basalt welled out to cap the later sediments, and the lake probably emptied at the same time. Shortly afterwards the Oletugathi flow was also downfaulted by a further movement along the Oletugathi fault. Between the two main alkali basalt flows there are local outcrops probably of the same lava in the ashes along the Seyabei river; they presumably represent flows erupted during the second phase of sedimentation, possibly on to a temporarily dry lake surface.

Near the confluence of the Seyabei and Uaso Ngiro rivers the ashes are much thinner and are thought to have been deposited in another younger lake. The wide Uaso Ngiro valley at Enkorika would then have been formed by rapid erosion of soft sediments capped by lavas, and the sediments would be correlatable with Baker's discovery of waterlain pyroclastics beneath the Lengitoto trachytes in the Magadi area (1958, p. 18). There is a small, downfaulted exposure of trachyte in the Uaso Ngiro river close to its point of departure from the area, and the overlying 50 ft. or so of well-bedded ashes forming the river banks show no signs of disturbance. It therefore seems that the sediments post-date the Enkorika fault, and were banked against the trachyte plateau both here and further north near Enkorika.

Two small outcrops of sediment in the lower Olongoirenito valley suggest that a small lake was formed there when the river was dammed by the plateau trachytes banked against the Naitiami fault scarp.

The older ashes are usually grey in colour, often with a green tinge, although at the north end of the Enkorika ridge are low mounds of grey, yellow and white ashes, and just to the north, in the elongate gully at the southern end of the Oletugathi fault, are multi-coloured ashes. White ashes (possibly kaolinized) were discovered between the Enamankeon alkali basalt and the main tuff band on the eastern side of the Enamankeon plateau. They are almost all well-bedded soft rocks, often finely laminated (Plate IV (*b*)) and locally current-bedded. A good exposure of laminated, mainly grey sediments, dissected by numerous gullies, can be seen in the Uaso Ngiro valley about two miles NNE. of Entapot, where there is a gap in the Enamankeon alkali basalt outcrop. Only in one place were sediments seen to be lying appreciably out of the horizontal, about three miles north of Entapot, on the left bank of the river, where laminated beds dip 30° to the west. A small-scale, curved fracture pattern similar to that often seen in marls is developed in less well-laminated deposits, and numerous thin bands of coarser material contain unsorted fragments of pumiceous material up to a few inches across (Plate IV (*b*)). Occasionally boulders of lava were found among the sediments, as at the north end of the Enkorika ridge where large trachyte boulders rest on sediments and are capped by tuff. In the Olongoirenito valley there are only 10 feet of well-bedded, pale grey sediments with a small-scale, curved fracture pattern, which form the north bank of the river about half a mile up-stream from Emugur Olmoruo, and are overlain by boulder beds. In a tributary valley just downstream from there the banks are formed of grey, heavy sandy limestone showing both graded and laminated bedding.

Specimens 50/542 and 50/544, both from the Uaso Ngiro section, are soft green-grey rocks with whitish speckling. The former is well laminated and comes from the relatively steeply dipping exposure just mentioned. Both rocks are composed of unoriented fragments and shards of fibrous glass and numerous small xenocrysts of alkali felspar. Specimen 50/481, from the Olongoirenito river, is slightly vesicular and consists of dark brown and green glass fragments, some slightly rounded, and small cleavage fragments of alkali felspar. The sandy limestone from the same locality (specimen 50/485) is composed of rounded grains of different rock types, chiefly melanephelinite, trachyte and tuff, as well as containing augite fragments, the whole being cemented by calcite.

Younger (Sub-aerially Deposited) Ashes

Most of the ashes in the area are probably younger than those exposed in the Seyabei and Uaso Ngiro valleys, because the presumed alkali basalt in the north Seyabei river is overlain by thick tuffs and these by thick ashes. The widespread but thinner ash cover to west and south is almost certainly part of the younger group, and as it almost always forms gentle slopes it probably obscures older ashes in many places where they would be exposed in steeper section, as they are in the Seyabei and Uaso Ngiro valleys. Even near the northern termination of the Oletugathi flow in the Uaso Ngiro valley the ashes forming the surface of the gentler valley slope may well be mainly younger, obscuring the underlying older group which was probably waterlain. There is a tuff band at the same level as the alkali basalt here, but it does not form a prominent feature as do the cappings farther south, and no steep sections are exposed.

The younger ashes, which are only poorly bedded, were almost certainly sub-aerially deposited, and as they are not protected by lava or tuff cappings (although there are tuff bands in them especially along the Uaso Ngiro river in the north of the area), weathering and soil formation in them has been rapid. They all have a brownish colour, are sometimes flaggy, and are usually crowded with calcareous concretions, which occur along irregular vertical cracks in the rocks or more rarely in the deposition plane, but most commonly as spherical bodies. The calcareous concretions, and sometimes also the weathered ashes themselves, contain small ferruginous concretionary bodies which also weather out and add to the surface layer of residual nodules. The concretionary

bodies are most numerous where the ashes have weathered to a rubbly friable brown rock which forms the sub-soil over most of the volcanic terrain. There is a good 15-ft. section in the Motoro river at the Narosura road crossing in the south of the area, where the flaggy ashes grade upwards to brown rubble and then to brown soils. The same sequence can be seen just west of Narok, above the right bank of the Narok valley, and in the permanent right bank tributary to the Narok river north of Nairaserasa.

Specimen 50/404 from Narok is similar in thin section to the older ashes described above, but it has a brown weathered appearance and is of slightly finer grain. Specimen 50/433, from the Kollobisho river, is a sample of hard and vesicular weathered ash, rather less altered than most. The glassy constituents have been replaced by an amorphous brown material, but some of the inclusions were identified as sanidine and altered trachyte—the only occurrence of trachyte in any of the ashes examined. Iron ores are also visible, as they are in the thin section of a calcareous concretion collected nearby (specimen 50/434) in which a fragment of aegirine-augite was seen as well. All the lime is concentrated in the concretions; no carbonate was detected in the host rock.

Although mainly sub-aerial, some of the younger ashes exposed along the rivers are clearly waterlain. For example, in a river section about 1½ miles south of Narok tuffs forming the river bed are locally overlain by a friable brown rock, indistinguishable from the weathered ashes described above, but containing water-worn rounded pebbles. Other well-bedded ashes, probably waterlain, are exposed in the Uaso Ngiro valley near Olong'a (Plate IV (*c*)).

Origin of the Pyroclastics

Most of the pyroclastics occupy the north-east quarter of the area, covering it to a depth of 400 ft. in places. There are also considerable quantities of volcanic ash in areas to the north and east. Thompson and Dodson (1963, p. 33) mapped thick ashes and tuffs in the Naivasha area, and concluded from their uneven deposition that the prevailing winds of the time were easterly, as indeed they still are. In the Narok area the deposits thin westwards; the source of the pyroclastics was therefore probably in or near the Rift Valley. The most striking features of the pyroclastic deposits are their immense volume and extent, and the widespread occurrence of tuff which constitutes a considerable proportion of the total. The degree of compaction in the latter suggests that the explosion products retained a fair amount of heat even after a wind-borne journey of as much as 30 miles. Much more detailed examination of these pyroclastics is required, with regard both to distribution and type of inclusions, before the problem of their origin can be satisfactorily solved.

3. Superficial Deposits

River Deposits

Probably the oldest river deposit in the area is a small quartzite *pebble bed*, now surrounded by black soil, seen on the left bank of the Uaso Ngiro river about a mile downstream from its confluence with the Narok river, and resting on tuffs 100 ft. above the river. The pebbles must have been laid down at an earlier stage in the evolution of the Uaso Ngiro, after the channel was filled by pyroclastics and before incision had commenced to form the present-day gorge.

Younger *boulder beds*, the boulders derived from surrounding lavas and tuff, are exposed in the sides of all the major river valleys in the east of the area, the youngest deposits overlain by them being the most recently deposited ashes. Boulders form a terrace between 30 and 50 ft. above the Uaso Ngiro river from Legorinyo eastwards. The boulders include all rock types over which the river has flowed, but the greatest proportion is of phonolite, which is a measure of the hardness of this lava as the outcrop ends some miles up-stream.

There is often a pale matrix of *sand* in the boulder beds, occasionally concentrated into lenses, which may be salt-bearing, as 1½ miles south of Narok. They are sometimes current-bedded, as in the Olongoirenito valley east of Ildungisho. On the east side of the river at Narok there is a bank of sand, including black and grey varieties and calcareous concretions. The grey and black sands and the concretions are composed mainly of unaltered fragments of volcanic glass and alkali felspar fragments cemented with coarse calcite in the concretions.

The yellowish and often structureless *alluvium*, formed mainly of altered ash, is frequently salt-bearing in the volcanic terrain. At Narok there is a fine section of crudely bedded salt-bearing alluvial deposits nearly 100 ft. high, containing some phonolite boulders, which is used as a cattle lick. The alluvium in the volcanic terrain is younger than the boulder beds, for wherever the two are seen together the alluvium is invariably on top and overlaps the boulder beds on to older bedrock. The alluvium consists mainly of pale brown amorphous altered glass with fragments of calcite, quartz, alkali felspar and oligoclase. Two samples of alluvium from the Narok salt lick were sent to the Soil Survey Section of E.A.A.F.R.O. at Muguga for examination by R. Scott. The water-soluble salt content does not exceed 0.2 per cent in the alluvium, which consequently has low electrical conductivity, but it is highly alkaline, with pH values between 8.5 and 10, due to the presence of sodium leached out of sodic lavas and tuffs. The samples were classified as non-saline alkali soils.

On the Loita Plains alluvial deposition has been widespread in the shallow, seasonal-stream valleys, and local pockets of pale *green clay* occur, which on air photographs show up almost white against the usual grey of the alluvium. One such pocket in the Olonkevin valley near the survey point, where the narrow winding channel is incised 8 ft. into ashes and ashy alluvium, is locally underlain by a hard sub-surface calcareous layer. The channel skirts the west side of a flat expanse of the clays into which wells have been dug, the level of water in them being about 10 ft. below ground level. Similar pans were found in other river valleys, usually containing more or less brackish sub-surface water. The clays have probably been accumulating over the years in shallow depressions, becoming annually saturated and retaining water longer than the coarser deposits of the surrounding country, so that the water table is locally higher in them and can be tapped from relatively shallow wells. The grey clay is semi-bentonitic, expanding and flaking when water is added, but it is too gritty to have thixotropic bentonite properties.

Stream-gullied *brown clays* with yellowish and whitish flecks, probably of altered felspar, form deposits up to 30 ft. thick at the heads of two valleys three and four miles ESE. of Olonganaiyo. A washed sample of the clay showed fragments of volcanic glass, magnetite, quartz and calcite. At the clay locality farther from Olonganaiyo a few thin *calcareous grit* bands were found near the base of the deposits. They are composed (specimen 50/578) almost entirely of rounded lava grains apparently derived from the Kishalduga melanephelinite series, but including felspathic varieties, whereas at both localities the clays are surrounded only by phonolites and tuff.

Deposits of boulders, sand and alluvium also occur along stream valleys in the Loita Hills, but are less well developed than elsewhere in the area because stream gradients are steep and the channels are narrow. *Sand* from the beds of two perennial streams, one from just south of Barkitabu in the south-west, the other from the Olkunyailie in the south-east, was collected and examined. Both are mainly quartz sands, containing also muscovite and iron ore. In the Barkitabu sand oligoclase, sanidine, hornblende, kyanite, andalusite and traces of zircon were also found.

The boulder beds are probably the products of torrential deposition during a recent relatively arid phase, but no doubt include the boulders of earlier deposits which have been re-worked many times and are now well rounded. The overlying alluvium in the

volcanic terrain is the product of a subsequent wetter phase, with large-scale flooding and hence quieter conditions of deposition, although on the Loita Plains alluvial deposition was presumably in progress while boulder beds were being deposited elsewhere. The relatively narrow channels, floored with sand and boulders, which have been incised into the river flood deposits all over the area, are considered to be the result of a return to dry conditions with occasional torrential downpours.

There are other less widespread river and stream deposits in the area. The current-bedded sediments, composed of melanephelinite grains in the Leshota valley and of unusual lava types in the Enamatishorecki depression, have already been described. Thin beds of redeposited *concretionary ironstone* derived from weathered ash were found in the Kollobisho river ENE. of Narok (specimen 50/432) and at Narok (specimen 50/438) where they overlie 100 ft. of salt-bearing alluvium. Both deposits carry felspar fragments; the deposit at Narok shows current and graded bedding and contains an appreciable amount of ash.

The river deposits are often thick. There are 30 ft. of boulder beds exposed in the Narok river just south of the town. About 50 ft. of assorted sediments, including current-bedded melanephelinite grits, occur in the Leshota valley, and nearly 100 ft. of alluvium are exposed at Narok, while other sections further up the same river expose up to 30 ft. of alluvium.

Terrestrial Deposits

Sand and quartzite boulder debris mantles shallower slopes in the Loita Hills and the bases of inselbergs, and occurs on the surrounding plains. On the western side of the Loita Hills there are large patches of boulder deposits, characterized by thick tree cover and thus readily distinguishable on air photographs. The deposits near the main mass of the hills are almost certainly torrential outwash products, for they contain blocks of every sort of quartzite, but the patches farther west may represent the remains of former more extensive solid outcrops.

Soil and lava boulder debris, mixed with ash, locally mantles the lower slopes of valleys in the volcanic terrain. It has not been differentiated on the map from fluviatile boulder beds and alluvium. In two places on the Engusero Nanyukie platform the debris has been spread as outwash fan deposits east of the Naitiami fault scarp.

Chemical Deposits

White finely crystalline trona ($Na_2CO_3.NaHCO_3.2H_2O$) is periodically deposited by evaporation in the salt and lime pans of the Masandare valley near Ol Donyo Rasha. Microscopic examination of the crystals (specimen 50/575) revealed only the presence of slender prisms of trona, but analysis of the sample (tabulated below) shows that other salts are also present, although in relatively insignificant amounts.

	Wt. per cent	
$CaCO_3$	11·73	Water-insoluble portion
$MgCO_3$	0·88	
R_2O_3	2·33	
SiO_2	6·31	
Cl'	3·12	Water-soluble portion
SO_4''	3·17	
CO_3''	19·20	
HCO_3	14·64	
K	3·55	
Na	21·89	
H_2O	13·44	(residual loss on ignition)
	100·26	

Analyst: J. Furst, Mines and Geological Department, Nairobi.

The trona is derived from waters, dark brown in colour, perhaps due to high algal content, which originate in salt springs about 100 yards west of the Narok-Narosura road. In wet seasons rain-water augments the spring supply, and the wide, flat valley immediately downstream is flooded (incidentally rendering the road impassable) and the surface of the ground is whitened by trona for a considerable distance downstream. The trona is re-dissolved and carried away during the succeeding rainy season, so that the deposit is never more than a thin crust. The springs emerge from among flat-lying *limestone sheets*, which were probably deposited by the spring waters, and for some distance downstream the ground is covered with small mounds of grey and white *concretionary limestone*, probably deposited over the years from evaporating flood waters in the flat valley (Plate IV (*d*)).

There are other saline springs at Olonganaiyo, although they do not deposit significant amounts of salts. A section of *rubbly bedded limestone* a few feet thick was seen here, indicating that the region must have been flooded to an appreciable depth in the fairly recent past. Similar limestone sheets are exposed along the main road in the shallow valley of the Masandare river north-west of Olonganaiyo. Both the Masandare and Olonganaiyo limestones are composed of impure calcite, with rare small felspar fragments. Analyses of some of these limestones are given below:—

	50/574	50/574a	50/597
$CaCO_3$	85·69	80·40	83·56
$MgCO_3$	3·16	3·45	5·06
R_2O_3	1·86	2·30	3·28
SiO_2	6·07	8·32	7·24
Cl'	0·03	0·10	0·01
SO_4''	0·18	0·17	0·04
CO_3''	0·18	0·48	—
HCO_3	0·73	1·10	0·49
K	0·40	0·52	0·40
Na	0·45	0·83	0·16
H_2O	1·44	2·59	—
	100·19	100·26	100·24

Analyst: J. Furst, Mines and Geological Department, Nairobi.

50/574—Grey, compact, concretionary limestone, Masandare.

50/574a—White concretionary limestone, Masandare.

50/597—Rubbly white limestone, Olonganaiyo.

Salts are also deposited on the surface from the evaporating waters of a small spring feeding a minor right-bank tributary to the Narok river one mile above the Uaso Ngiro confluence, where there is a salt lick much used by game animals. At least part of the salt may be trona. On an interfluve in the Olongoirenito valley about five miles east of the Narosura road the ground is whitened by a limestone deposit which may have been formed in the same way as that at Olonganaiyo, for the Olongoirenito river has some slightly salt springs along part of its course in the dry season.

Numerous *salt licks* were found in the fine sand and alluvium along many of the stream channels in the east of the area, and salty alluvium was found as far west as Oserolembere, in an east-west channel between two quartzite ridges. It is likely that

during floods the finer-grained river deposits are saturated with water-carrying salts in solution derived from tributary salt-spring streams. When they dry the salt remains and is concentrated into pockets a few feet across, which are excavated by cattle and game. The largest occurrence, as already noted, is at Narok, where the thick alluvium has been extensively pitted by animals.

Calcrete is not common as a secondary surface formation in the area and only small local sheets are found, mainly on the melanephelinite terrain where the gently sloping ground and adequate soil cover encourage upward capillary migration and evaporation of lime-bearing solutions derived from the leaching of underlying lavas. Calcified tuffs, described on page 30, may well have been formed by a process allied to the formation of surface limestone sheets. Otherwise secondary limestone occurs only as concretions in weathered volcanic ashes, where it contains small concretionary ironstone nodules. Conversely, it was also found as concretions in secondary ironstone derived from trachytes (*see* below).

Surface Ironstone is relatively widespread in the Loita Hills, where it is most frequently found along valley sides and floors. It is usually a brown, coarsely cellular rock, probably formed, like the limestones, by leaching and redeposition of hydrous iron oxide on soil-covered surfaces in shallow valleys, where water collects but does not readily drain away. In a more unusual development accumulated on a hillside about two miles south of the Olchorro Nyukie river, the rock is pale brown in colour and less coarsely cellular than usual, rather gravelly, and with faint signs of bedding. Lateritized gravels, rather soft and dark red in colour, were seen in the Lemesigyo valley near Enkiu. In stream beds the ironstone deposits are often massive and hard, firmly cementing angular quartzite blocks of varying size, and have presumably been deposited gradually from stream waters to form the compact rock. The occurrence of secondary ironstone was recorded in only two places among the volcanics, as a rubbly deposit on phonolites just east of the Uaso Ngiro river about five miles south-east of the Narok confluence and, as mentioned above, south of Enkorika, where at the edge of the trachyte plateau rubbly ironstone with calcareous concretions passes into a compact ferruginous crust which firmly cements angular blocks of trachyte.

Soils

R. Scott, of E.A.A.F.R.O., kindly examined and reported on the few soil samples collected in the area. The soils have been subdivided into four groups for purposes of description:—

(*a*) Mainly well-drained sandy soils, often pink from iron staining on grain surfaces, are confined to the quartzites of the Loita Hills and surrounding inselbergs, and the gneisses of the lower Olongoirenito valley. A sample of red sandy soil collected on the eastern side of the Oserolembere ridge is composed mainly of quartz and iron ore, with a little alkali felspar and altered volcanic ash. Areas of locally poor drainage are common round the Loita Hills, especially along stream valleys where the gradient has decreased abruptly on leaving the hills, and here patches of black soil are developed (*see* below).

(*b*) Dark red, ferruginous, slightly sandy soils, often forming banks a few feet high, are common on the gently undulating upper parts of the Loita Hills, on ridge tops and cols. They appear to be derived from the partly lateritized detrital mantle which has accumulated on the flatter uplands.

(*c*) The more common soils in the area are those derived from volcanic ashes, brown in colour and widespread on flat and gently undulating ground in the area. They are similar to the Chestnut Soils of the United States which typically have a calcareous subsoil, which takes the form of rubbly weathered ash with calcareous concretions in the Narok area, and occur on volcanic ash plains in semi-arid regions at altitudes

between 4,000 and 6,000 ft. Locally the brown soils give way to black varieties where the drainage is poorer, particularly near the shallow stream valleys on the plains. Similar dark soils were found in places among the melanephelinites; they are also derived from ashes which have been washed down into poorly drained basins. Brown and black soils also occur in the outwash fan deposits, containing a high proportion of ash, on the trachyte platform east of the Naitiami scarp, where they are clearly poorly drained. Both the brown and black soils swell and flake in water, but the latter do so more readily, which is indicative of a high montmorillonite clay content. Their dark colour is due to the presence of reduced iron.

(*d*) Finally there are red soils, mainly confined to Engusero Nanyukie, which are also derived from volcanic ash. Their red colour is due to oxidation of the iron minerals under conditions of relatively good drainage, in contrast to the poorly drained plains farther west. They are thought to be relic soils formed during a former more humid climatic phase.

Artefact Flakes

A number of artefact flakes were found in the area. They are chiefly of obsidian, with less amounts of white chalcedony, phonolite and possibly hard tuff. Dr. Leakey, of the National Museum, Nairobi, identified them as waste flakes, the debris resulting from human work, and therefore valueless for determining the culture to which they belong. Saggerson (1966, p. 39) found many flakes of obsidian in the Loita Hills area, and regarded them as derived from far to the north-east, where supplies of obsidian are abundant (cf. Thompson and Dodson, 1963, p. 31). A fairly large humanly struck flake of silicified ironstone (specimen 50/499) was found in the Olkunyailie river near Lomoroi. In the extreme north of the area, just west of the Seyabei river, a large and well-formed hand-axe made out of phonolite (specimen 50/596) was picked up on a forest track.

Erratic Blocks

Erratic blocks were found in many parts of the area. Fragments of tuff, phonolite and quartzite were collected in the Kollobisho river west of Narok. The former clearly originated in the Mau uplands, but the quartzite is more difficult to account for, since the source of the river must lie some distance east of the metamorphic terrain in the area to the north. In the Uaso Ngiro valley a melanephelinite fragment was found about a mile up-stream from the nearest outcrops of these rocks. Round Kishalduga in the south-east of the area there are quartzite boulders on hilltops above the level of the plains further west. Conversely, blocks of tuff, trachyte, phonolite and intrusive porphyritic nephelinite were found on the margin of the dissected volcanic terrain, well above and often several miles west of any possible source. Melanephelinite and tuff fragments were occasionally found on the Lembere Plains on the east side of the Loita Hills, and at about 7,000 ft. in the south-western part of the hills round Lemesigyo an amygdaloidal phonolite fragment was found. In the vicinity of Narasha, as already mentioned, there are a number of phonolite blocks, probably derived from the phonolite flows exposed a short distance to the west. All the other erratic blocks in the area, however, could only have been carried by man to where they were found, because they are at greater altitudes than any possible nearby source.

VI—STRUCTURE

1. Metamorphic Rocks

The area has been divided into a number of sub-areas for the purpose of structural analysis. They are shown in the structural map (Fig. 6—at end) which summarizes the structural measurements and their interpretation.

A summary of the structures as envisaged in each of the five sub-areas is given below and each of the sub-areas is dealt with in detail in the following pages:—

Sub-area 1.—Homogeneous monoclinic structure. Mainly symmetrical open folding, with most axes plunging to the NNE. at low angles.

Sub-area 1a.—Insufficient data, but apparently homo-axial with 1.

Sub-area 2.—Homogeneous monoclinic structure. Probably mainly asymmetrical open folding, with most axes plunging to the north at low angles.

Sub-area 3.—Structures uncertain. Inferred to be isoclinal folds, overturned to the south-west, with axes trending approximately north-westerly, perpendicular to those of sub-area 1.

Sub-area 4.—Structures uncertain. The pattern is suggestive of a local swing in the regional axis to nearly east-west.

Lineations and Slip Folds

Almost all the lineations observed occur on foliation surfaces. Usually they take the form of closely spaced grooves, but sometimes they result from preferred alignment of quartz or of corrugations in the foliation of muscovite-rich rocks. Most of the lineations are parallel either to the axial trend of recognizable folds or to the strike of vertical foliation, which must itself be parallel to local fold axes. Furthermore, in the stereograms of sub-areas 1 and 2 the lineations group themselves about the statistical axis. Except where there is evidence to the contrary therefore (*see* below), it has been assumed that the lineations are fold-axis or *b*-lineations (Weiss, 1959, p. 26).

Slip-folds occur at many localities in the Narok area. Their axes were always seen to be closely parallel to the direction of dip, and are thus distinguishable from those of other minor folds which are close to the direction of strike. These slip-folds are considered to have been formed by adjustments along the line of strike. Some of the slip-folds observed in different rock types of the present area are reviewed below.

Among the biotite gneisses in the east of the area small-scale slip-folds are often seen, tailing off into more regular foliation (Fig. 4). A very strong lineation plunging steeply to the east, and so coarsely developed as to resemble straight ripple marks, was seen on a slab surface in the Olongoirenito valley. It is thought to be closely related to the axes of the slip-folds here, and to an *a*-lineation (Weiss, 1959, p. 26).

In the locally more schistose muscovite quartzites north of the Olkunyailie river where it emerges on to the Lembere Plains, slip-folds between 10 and 30 ft. in amplitude are developed, almost isoclinal and with very sharp closures, so that at first sight they could be mistaken for current bedding. In the main mass of the muscovite quartzites, however, slip-folds are smaller and less acute, because the rocks are less micaceous and more granular. Lenses of coarsely crystalline quartz often occupy the cores of the small folds (Fig. 4 (*c*)).

Sub-area 1

The stereogram for sub-area 1 (Fig. 6) gives a picture of fairly homogeneous monoclinic symmetry for this sub-area, with mainly open folding and an undulating but dominantly NNE.-plunging statistical fold axis (β). The major structures in the sub-area comprise the large Maji Moto synform, which is thought to be in part recumbent, and the partly overturned Entingaser syncline, which is flanked on the west by the open symmetrical Lengijabi anticline. At its simplest the Maji Moto synform is outlined by the band of coarse granular quartzites which extends from Lolua to Maji Moto, and is underlain by laminated quartzites. The smaller-scale open folding in the latter has the same orientation as the main structure and is summarized on the structural map.

North-east of Lengijabi coarse granular quartzites, probably underlain by the same micaceous and laminated quartzites, outline the closure of the Entingaser syncline, which has a gentle SSW.-plunging axis and is open here but appears to become overturned to the south-east a short distance farther south.

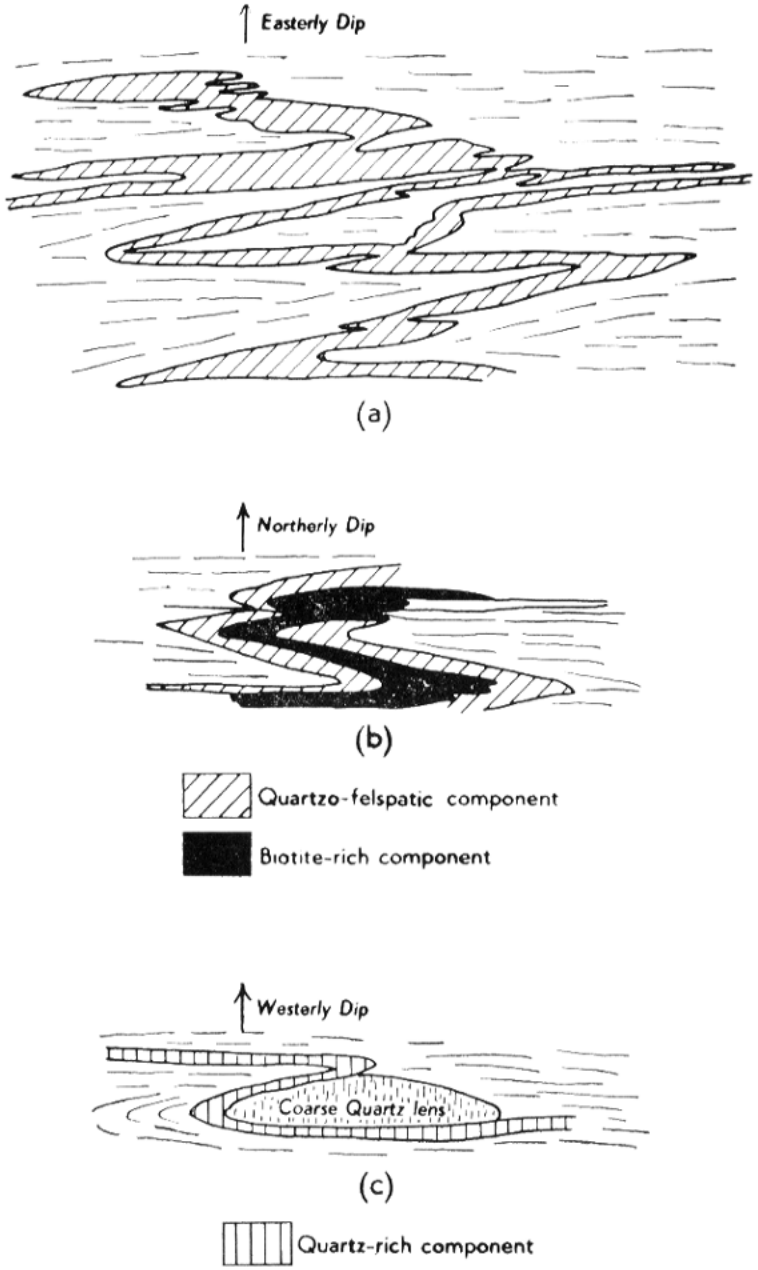


Fig. 4—Slip-folding in biotite gneisses and muscovite quartzites in the Narok area

(a) Slip-folds in biotite gneisses, Olongoirenito valley
(b) Slip-folds in biotite gneisses, Uaso Ngiro valley
(c) Slip-folds in muscovite quartzites, Entingaser valley

Due east of the small isolated hill of coarse granular quartzites which is separated, probably by erosion, from the main band at the closure of the syncline, an open anticlinal structure is revealed by opposing dips in the underlying laminated and micaceous quartzites. It cannot be traced very far owing to the south-easterly overturning which seems to be prevalent farther south. On the western limb of the Entingaser syncline minor open folding is well displayed. Three miles north-east of Lengijabi there is a good outcrop of muscovite quartzites in which can be seen a small open syncline with a gentle SSW. axial plunge, and close to it a monoclinal fold, its vertical western limb striking SSW. Less than a mile to the south a large symmetrical open anticline, also

with a SSW. trend, can be traced out in valley wall outcrops of coarse granular quartzites and muscovite quartzites. The adjoining syncline on the west is less obvious but its nearly horizontal axis can be followed for at least 3½ miles SSW. from here. One and three-quarter miles along this axis there are small undulations in nearly flat-lying muscovite quartzites, and a similar distance further on opposing dips were measured on either side of a ridge crest. Just south of this the axis may have been displaced slightly westwards by a small cross-fault.

Other small folds observed in this sub-area include a small open asymmetrical anticline four miles north of east from Lengijabi, outlined in a band of flaggy white quartzite among mainly vertical muscovite quartzites, and there may be another such fold in similar rocks three-quarters of a mile to the south-east. Finally it is of interest to note that about two miles ESE. of Lengijabi a northerly plunging lineation with a westerly curve was seen in granular muscovite quartzites. It is presumably a reflection of minor lateral swings in the major fold axes.

The Maji Moto synform and the Entingaser syncline have opposing plunges due to an axial culmination trending more or less north-west along the Entigaser valley. The coarse quartzite band outlining both structures has been removed by erosion over the crest of the culmination to expose the underlying laminated and micaceous rocks. Further south lineations indicate a return to shallow northerly plunging axes.

At Olchorro Nyukie there is an exposure of inverted current-bedding in the band of laminated quartzites stretching from there to Maji Moto, which indicates that the original top of the band must now be on the west side. The coarse granular quartzites forming the Lolua ridge and the west side of the Maji Moto ridge are therefore both underlain by laminated quartzites, so the laminated quartzites of the Maji Moto ridge and of Osilalei are probably part of the same band. The greater expanse of these rocks at Osilalei is considered to be at least partly due to repetitive folding about axes which are nearly horizontal over the culmination there.

The band of coarse granular quartzites outlining the Maji Moto synform is thought to have been recumbently folded in the vicinity of Olchorro Dapash, so that a double thickness of the rock is exposed there. The axial plane of the recumbent fold is considered to have been further folded about the same axis by the Olchorro Dapash syncline and anticline (Fig. 5 (*a*)). The ridge of coarse, granular quartzites which stretches southwards from there would then be the keel of the Olchorro Dapash syncline, its relatively great length being due to axial flattening over the culmination. Its termination in the south, and that of the limbs of the Entingaser syncline, are considered to be due to lensing out.

The "island" hill of Lemesigyo is formed of coarse, granular quartzites. On its north side are exposures of inverted cross-bedding and on its south side there is normal cross-bedding. The fold must therefore be an overturned syncline on the flank of the Lemesigyo anticline (*see* below) and at its eastern end gives the impression of being involved in the complex folds of sub-area 3. The coarse quartzites in the core of the fold are then presumably part of the band which outlines the Maji Moto synform and the Entingaser syncline.

According to the exposures of cross-bedding there, the muscovite and laminated quartzites which abut the coarse quartzites of Ole Lialatus are not inverted. Therefore the Ole Lialatus quartzites underlie them and so must be equivalent to the band which forms the NNE. ridge through Lengijabi. This band can be traced round the anticlinal closure at Osilalei before it disappears, and is presumably that exposed as part of the opposing limb of the Lengijabi anticline, in the ridge four miles north-west of Lengijabi, where some of the overlying laminated quartzites also crop out.

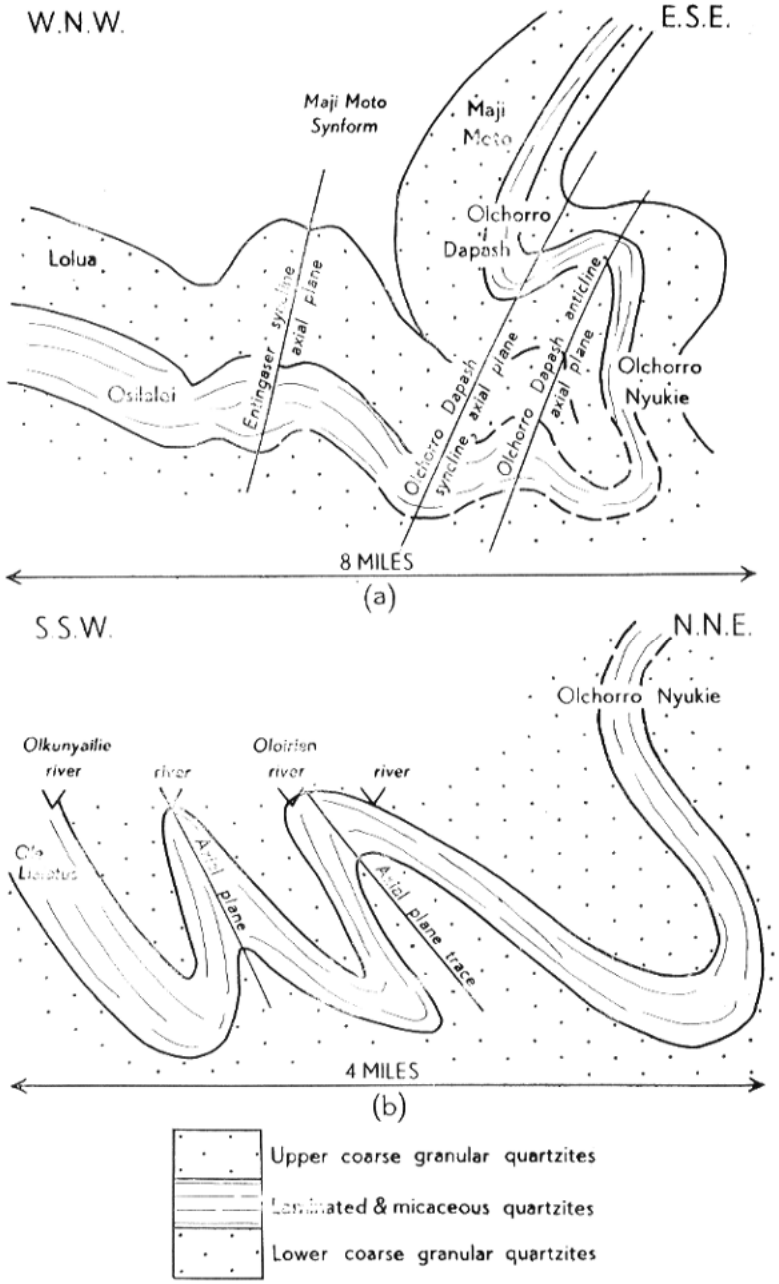


Fig. 5—Diagrammatic tectonic profiles (as defined in Weiss, 1959, p. 47), summarizing the main features of the structural patterns envisaged for the major part of the Loita Hills (sub-areas 1 and 3)

At Olchorro Nyukie there is an irregular syncline with a gentle anticlinal flexure in the closure, outlined by coarse granular quartzites, and a small, steeply north-plunging overturned fold, its axial plane trace trending approximately east-west, which seems also to be part of this structure. The muscovite quartzites forming the eastern part of the Olchorro Nyukie ridge curve away to strike south-eastwards and give the impression of having been almost torn apart from the band of coarser rocks to become involved in the folds of sub-area 3.

Sub-area 1a

The measurements made in the poorly exposed north-west corner fall within the limits of the stereogram for sub-area 1, and indicate that the two are homo-axial. The steeper foliation dips in this sub-area suggest a more compact degree of folding than obtains in most of sub-area 1. There is an indication of synclinal folding in the opposing dips of quartzites at Ngore Ngore.

Sub-area 2

The stereogram for this block indicates a slightly less homogeneous field than in sub-area 1, but it includes data for a wider area from only isolated exposures. The stereogram suggests that the folding is open in style, with fold axes mainly plunging just east of north at low angles. There are three lineations which plot in the foliation pole girdle of the stereogram. The steep, easterly plunging lineation in the lower Olongoirenito valley in the south-east corner of the sub-area is thought to be an *a*-lineation associated with local slip-fold axes. A south-easterly plunging lineation was measured among the somewhat abrupt strike changes in the white quartzites south-east of Maji Moto, and there is a westerly plunging lineation in the coarse, unfoliated gneiss just north of Legorinyo. The trend of both the latter is close to that of the inferred overturned folds in sub-area 3.

Closures of two open synclines are displayed in the muscovite quartzites of Olkunyailie hill and in a white quartzite ridge north-west of Legorinyo.

In the biotite gneisses of the Ntuka gorge, north-west of Legorinyo summit, the nose of a small, gently northerly plunging anticline is exposed, its axis parallel to a well-developed lineation. Just up-stream small-scale irregular corrugations are developed about a similar axis in banded biotite gneisses dipping gently west.

Sub-area 3

In a small area between sub-areas 1 and 2 the folding appears to be much more complicated, as indicated by the stereogram. The direction of plunge of lineation varies by 180° forming an irregular girdle, while the strike of vertical beds, which must be parallel to the trend of local fold axes, varies from east-west to north-south.

Very tight but symmetrical minor folds were seen in the laminated quartzites near where the Oloirien river emerges on to the Lembere Plain (Plate III (*c*)). The folding is complicated by varying truncation angles among the different cross-bedded units (Fig. 2 (*c*), Plates III (*a*), (*b*) and (*c*)), and there has undoubtedly been displacement along boundary planes between units. The rocks are more contorted in the eastern part of the outcrop where they grade into less competent muscovite quartzites. The impression gained at this exposure was that the axial planes of the small folds strike more or less NNW. with axial plunges varying between northerly and southerly.

On the evidence available for this sub-area it is suggested that between Oloirien and Ole Lialatus there are five NNW.-trending folds (only the two anticlines are shown on Fig. 6) overturned to the south-west, of which the most northerly, a syncline, is thought to pass into the closure of the Maji Moto synform under Olchorro Nyukie in sub-area 1. The rocks involved in these folds are thus considered to be the same bands as those forming the western part of the hills. The disappearance of the coarse, granular quartzites in south-east Oloirien and Olkunyailie is therefore attributed to lensing out, as it is further west in sub-area 1.

The semi-circular outcrop pattern in the south-western part of this sub-area is suggestive of a large, gently north-plunging anticlinal structure, which is termed the Lemesigyo anticline. Its axial trend is close to that of the four north and NNE.-plunging lineations in the sub-area, and it may be co-axial with the Olchorro Dapash anticline further north. The north-westerly trending folds of sub-area 3 are regarded as fairly large-scale isoclinal corrugations on the eastern limb of the Lemesigyo anticline. In the triangular outcrop of laminated and muscovite quartzites in the north-west of the sub-area there is an indication in the differing trends of steeply dipping and vertical beds of transition from north-westerly to north-easterly trending fold axes, giving the impression of a fan-shaped arrangement of the folds in the transition zone. What must already be a very complex pattern in this region is still further complicated by the presence of an outcrop of inverted cross-bedding, dipping steeply to the south-east.

Sub-area 4

In the stereogram of this sub-area the spread of lineations is greater than for any of the other sub-areas, while the concentration of foliation poles may be a reflection of south-easterly overfolding. Some of the lineations are similar in orientation to those of anomalous trend in sub-area 2, and to the axes of postulated north-westerly trending folds in sub-area 3. In the strike of vertical beds there is a relatively small variation, indicating a swing in the regional axis between north-east, south-west and almost east-west.

Exposures are very scattered in this region, and there is not enough data to explain satisfactorily some of the features encountered in the field, or to confirm the tentative deductions made from the stereogram. The anticline at Munterabi appears to be relatively simple, although there is a suggestion of easterly axial swing in the strike of vertical beds on the eastern limb. The most puzzling pattern occurs on Ol Donyo Rasha, where north of the hill vertical beds and lineations trend north-north-east, but on the hill itself vertical beds strike north-east, while the lineation trend is mainly just north of east, a divergence of about 30°. In addition the lineations plunge alternately to east and west with almost bewildering frequency, sometimes within only a few feet. It is considered that the anomaly is due to small-scale corrugations of fold axes, and that the lineations are not true *b*-lineations.

Faults

Only two faults are shown in the metamorphic terrain, both of them inferred, for no clear evidence of faulting was seen. The fault south of Lengijabi is inferred from an apparent lateral shift in a long SSW-trending synclinal axis where it crosses a stream valley there. The other possible fault occurs beneath a linear spring line, visible on air photographs, near the north end of the discontinuous Oserolembere ridge.

Joints

Jointing is best developed in the coarser quartzites, usually either perpendicular to the strike, in which case the joint plane is vertical or steeply inclined, or parallel to the foliation dip to give a flaggy parting. Both types frequently occur together. Sometimes there are joints perpendicular to the foliation, for example on Lengijabi ridge. The strongest development of joints was seen in the vicinity of Olchorro Dapash.

Some measurements of joint directions were made, chiefly on vertical or steeply inclined planes, and the poles to these planes were plotted on a stereogram incorporated in Fig. 6. Statistically there are two dominant sub-perpendicular directions of jointing, representing the "ac" and "bc" directions, with reference to a regional "b" fold axis trending east of north. The less important "bc" joints could also be regarded as "ac" joints, with reference to a WNW.-trending subsidiary "b" axis of folding, such as appears to be present in the area, most prominently displayed in sub-area 3. It is interesting to note that both of the pegmatites measured in the area, in the Uaso Ngiro valley near Entapot, and west of Lengijabi, appear to have filled dominant "ac" joint fractures. The position of the lesser maxima may be referred to the oblique or hkO joint system (Weiss, 1959, p. 44), which is symmetrically disposed about regional axial trends.

Conclusions

In adjacent areas to west (Williams, 1964) and south (Saggerson, 1966), the existence of two sets of folds with mutually perpendicular axes have been demonstrated, which the authors consider to be the result of two periods of folding. The only fold axes which are traceable into the Narok area from the Loita Hills area to the south are those which become the Lemesigyo anticline and the Olkunyailie syncline. The Entingaser syncline may also have a counterpart in the Loita Hills area.

The structures in sub-area 3 of the Narok area suggest that it is a region of folds having axes more or less at right angles to the regional trends determined for the larger and virtually homogeneous sub-areas 1 and 2. This mutually perpendicular arrangement of fold axes is recognized by some authorities as evidence for more or less synchronous folding, (cf. Weiss 1959, p. 28). The complete lithological uniformity between the quartzites of sub-areas 1 and 2 and those of sub-area 3 also points to a single episode of folding, since a second period of folding in sub-area 3 would be expected to exert some detectable influence on the lithology of the rocks affected by it.

It has also been pointed out (*B. H. Baker, verbal communication) that a statistically homogeneous joint pattern is unlikely to be developed in areas affected by two or more independent deformations, and is further evidence that the folding in this region is the result of one orogenic episode only.

2. Volcanic Rocks

The Narok area is just outside the zone of later Rift Valley faulting, but was affected by the earlier episodes. The oldest fault in the lavas is undoubtedly the Naitiami fault, thought to be a branch of the ancient Sonjo fault in the Loita Hills area, (Saggerson, 1966), which formed the great Nguruman Escarpment. The latter probably initiated Rift Valley subsidence in these parts (Baker 1958, p. 61), but is thought to be antedated by the Miocene Kishalduga melanephelinite series which were erupted on to the down-warped sub-Miocene peneplain in the Narok and Loita Hills area. Saggerson (op. cit.) estimated the throw of the main Sonjo fault to be about 4,000 ft. in the south, decreasing northwards. The first movement along the Naitiami fault cannot have been more than 600 ft., since while further south thick Kirikiti basalts subsequently inundated the lower part of the scarp or scarps, there is no sign of them in the north-east of the Loita Hills area or in the south-east of the Narok area, and they may never have reached the scarp there.

There is a large mass of melanephelinites north-east of Legorinyo, east of the Naitiami fault line. This can be explained by postulating a north-easterly branch of the first Naitiami fault, which itself probably died out somewhere near Legorinyo.

In the early Pleistocene the Enkorika fault was initiated *en echelon* with the Lengitoto fault in the Magadi area. The Enkorika fault has a maximum throw of about 350 ft. in the present area, and dies out just north of Enkorika. It was shortly followed by renewed movement along the Naitiami fault, which again extended only as far north as Legorinyo, while the southern limit of the movement seems to have been near the Lengitoto plateau. The throw of this second movement did not exceed 400 ft. in the Narok area.

Subsequent major Rift Valley faulting, including movement along the Kirikiti and Lengitoto faults, never entered the present area but branched off from the Lengitoto fault about 2½ miles east of the boundary. Later faulting in the Narok area was on only a minor scale and took place in two episodes along the Oletugathi fault, which is an extension of the Enkorika fault, the latest movement having a throw of about 100 ft.

VII—ECONOMIC GEOLOGY

Minerals

No mineral deposits of economic importance were found in the area. Massive *felspar* and *garnet* occur in the gneissic area in the south-east, the former concentrated with quartz in rare pegmatites, the latter disseminated as small crystals in the gneisses. *Muscovite* is sometimes concentrated in small bands and pockets among the micaceous

*Thanks are due to B. H. Baker for critically reading this section of the report and making a number of helpful suggestions.

quartzites of the Loita Hills, but the flakes are too small to be of value. *Magnetite*, possibly titaniferous, and ilmenite occur as finely disseminated grains in the gneisses and quartzites and occasionally occur as banded concentrations in the latter. Small flecks of *kaolin* can be seen in the laminated quartzites and slightly larger amounts in the mica schists and white pyroclastics, but nowhere was it seen in economic concentrations.

The compact white *quartzites* in and around the Loita Hills are relatively free from impurities, except for finely disseminated muscovite and magnetite. They might prove suitable as road metal, aggregate for concrete, abrasives, and for glass manufacture, where sufficiently pure.

Crushed rock for roads and buildings could also readily be obtained from the *tuffs* and *lavas* in the east of the area, particularly the very hard phonolites which outcrop close to present-day roads. The tuffs near Narok are quarried for building stone, more vesicular varieties being preferred as they are lighter and easier to handle than the compact types and have better heat-insulating properties. Supplies of quartzite, lava and tuff in the area are adequate to meet foreseeable local demands.

Numerous streams in the Loita Hills contain *quartz sands* suitable for building materials. Sands of *volcanic glass* which might be of use as abrasive material occur locally in major rivers in the east. *Lateritic ironstone* (murram) occurs in places, although no deposits of economic size were seen.

Secondary *limestones* were found locally in the eastern parts of the area, but are scarce and probably too impure to be of economic value.

The *salt* deposits of the Masandare valley are uneconomic in their present state, but the construction of suitable evaporating pans might yield a salt crop large enough to repay the cost of extraction.

Four quartzite samples were assayed by the Mines and Geological Department, Nairobi, for *gold*. They were:—

50/517—Oloirien.

50/521—Olchorro Nyukie.

50/590—Narasha.

50/591—Ridge 2½ miles north-west of Lengijabi.

None of the samples contained more than the equivalent of 0.3 dwt. of gold per ton.

Eight samples of pyroclastics and older superficial deposits were analysed for their *phosphate* content, but none showed more than a trace.

Radiation Survey

A Redbox radiation ratemeter was used in the metamorphic terrain, but no anomalies were recorded. Readings were slightly higher among the volcanics, but the intensities of radiation recorded during the survey were no greater than would be expected for the rock types encountered.

Water Supplies

Water is mainly provided by the large perennial rivers in the north-east of the area, which rise in the Mau uplands, and most of the cattle of the district are watered at these rivers. Narok township is supplied from an M.O.W. pumping station situated in the Narok river immediately upstream from the administration offices. The water is not potable owing to its ammonia content, and must be purified before use. It is flocculated with alum and sedimented, filtered through a sand bed, chlorinated, and finally piped to the town. Another pumping station a short distance up-stream from the township supplies unpurified water for agricultural use. The Ngusur river is also tapped about nine miles up-stream from the town to provide an irrigation furrow for the residents.

The highly jointed quartzites of the Loita Hills make good aquifers, collecting rain water and condensation from the frequent mists which blanket the hills. The water trickles down joint cracks and fissures, collects underground in local reservoirs and emerges from perennial springs at different levels along many of the valleys. Because of the good grazing and plentiful water the hills are relatively thickly populated by the Masai. During wet seasons the streams usually flood but the water is either lost on the plains, particularly in the west and north where the water table is probably well below the surface, or flows into the larger rivers in the east. Two springs were found near the edge of the outwash deposits between Lolua and Maji Moto. They are unusually far from the quartzites, which here provide a roughly semi-circular catchment area. The water collects in the sandy deposits and emerges where the sands grade into volcanic soils.

Elsewhere on the Loita Plains water is obtained from wells dug either in the grey clays found locally along seasonal stream channels or near the quartzite inselbergs on which atmospheric moisture collects, as in the Loita Hills, and emerges from springs on the lower slopes where wells have been dug to increase the yield. The well water, particularly from the clays, is usually brackish during dry periods due to concentration of salts leached from the surrounding volcanic ashes. At Ngore Ngore in the north-west corner of the area two small dams were built some years ago to catch the perennial spring waters derived from one of the quartzite inselbergs. The springs are now dry except during and just after rainy seasons owing perhaps to the recent tendency towards an increasingly drier climate over the country as a whole.

The few small fresh-water springs in the volcanic terrain presumably originate in much the same way as those in the Loita Hills, atmospheric moisture condensing and trickling down joints and cracks to collect underground. They are confined to the phonolite terrain, except for the springs at Seyabei which emerge at the junction of alkali basalts with overlying tuffs.

The hot spring of Maji Moto at the extreme northern tip of the Loita Hills provides excellent drinking water when cooled and is much used by the Masai, who also wash in the warm water near the spring and water their cattle at the cooler water downstream. The water probably derives from an aquifer in the Loita Hills quartzite and must be of meteoric origin, for not only is it quite fresh but the major part of the gas which bubbles up in the spring has the composition of atmospheric air (*see* page 48). The source of the heat is difficult to account for, however, for the spring is several miles away from the nearest visible lava source although it is situated on the axis of the peneplain warp. There is warm, fresh water in some of the springs along the youngest Oletugathi fault, again probably meteoric in origin, the warmth being derived from the coincidence of a spring line with a former erupting fissure.

The three main spring-fed streams, Masandare, Olonganaiyo and Ntuka, rise on the edge of the plains where ashes give way to older bed rock in the stream valleys as the limit of rejuvenation further east is approached (Fig. 1). They appear to tap a variable water table near the junction of ashes with the almost planar underlying surface, for the saline Masandare and Olonganaiyo waters both emerge at about 6,000 ft. O.D. while the Ntuka springs of fresher water originate at about 5,800 ft. The salinity of these waters must be due to leaching of sodium salts from the surrounding pyroclastics. The markedly lower point of origin of the Ntuka and its lower salinity points to the spring waters being derived from a separate catchment to that of the other two, possibly associated with the nearby phonolites. The Olongoirenito channel in the south-east has weak and slightly saline springs downstream among the lavas. The small and very saline tributary to the Narok river about a mile up-stream from the Uaso Ngiro confluence rises in the tuffs at about 5,800 ft. altitude, possibly from another local basin. The Olonganaiyo and Ntuka streams, and to a lesser extent the Olongoirenito, are used to

water cattle all the year round. The Masandare water is generally much too saline, being greatly concentrated by evaporation in its wide and shallow valley, although after moderate rain it is sufficiently diluted to be drinkable by cattle. The nearby quartzite mass of Ol Donyo Rasha may well contribute an appreciable volume of water to the spring, particularly in rainy periods.

The only water-hole found in the area occurs in a seasonal stream channel east of the northern end of the Enkorika trachyte ridge, where there is a natural circular basin cut in the tuffs just below a small waterfall.

In March 1959, M. J. Wessels of the M.O.W. Hydrology Department made a hydrological reconnaissance in the Narok District, and a summary of his unpublished report follows.

The catchment area includes the southern and some of the south-western parts of the Mau massif, and is about 2,575 square miles in extent. Since most of the rain comes from Lake Victoria the eastern side of the Mau uplands is the rain shadow side. The rivers flowing off the Mau originate as spring flow and are therefore effluent. They become influent farther downstream, losing water to a falling water table. It is suggested that the boundary between effluent and influent zones may be the lower edge of the forest on the Mau.

The measurements summarized in the table below were made by Wessels on the rate of flow in the main rivers just before the rains were due (the rains subsequently failed). It will be noted that in dry seasons at least the Uaso Ngiro only becomes the largest river in the area below its confluence with the Narok and Seyabei rivers.

River	Locality	Date	Discharge, cusecs	Maximum estimated discharge, cusecs
Narok ..	Water supply point, Narok ..	17–3–59	0·72	1,000
Seyabei ..	Main road	18–3–59	4·61	2,000
Uaso Ngiro ..	Game Station	19–3–59	3·09	2,000
Maji Moto ..	Maji Moto	14–3–59	0·26	?

To improve water supplies, particularly necessary in dry years such as 1959, the Seyabei valley just below the Moyok confluence, near the main road bridge, was suggested as being a suitable dam site. A further series of dams was recommended along the Narosura road in the south of the area to catch floodwater off the Loita Hills, which now fills drifts for a short time but is then lost into the big rivers farther east. Such dams would both improve water supplies and help to control grazing.

Water Analyses

A number of water samples were collected during the present survey and later analysed by the Government Chemist. The analyses are reproduced in the accompanying table.

All these springs and rivers are the products of circulating groundwater, probably ultimately of meteoric origin, their differing salinities being due to varying amounts of salts they remove in solution from the rocks through which they pass at varying speeds. As already noted it is considered likely that the salts are mainly derived by leaching from pyroclastics, some from lavas and little from metamorphic rocks.

Water Analyses

	Ol Donyo Rasha Masandare Salt Spring	Olonganaiyo Salt Spring	Oletugathi Warm Spring	Ntuka River	Olkunyailie Loita Hills Stream	Barkitabu Loita Hills Stream	Seyabei Springs (Average of 2)	Seyabei River	Narok River
					Parts per million				
Alkalinity (as $CaCO_3$)									
Carbonate	2,435	50	40	nil	nil	nil	nil	nil	nil
Bicarbonate	1,250	810	355	135	70	100	182	49	116
Ammonia									
Saline	—	—	—	—	—	—	0·07	0·04	present
Albuminoid	—	—	—	—	—	—	0·05	0·16	0·08
Chlorides (as Cl)	210	78	16	7	12	10	10	5	9
Sulphates (as SO_4)	144	140	33	70	156	21	17	present	35
Nitrites (as NO_2)	0·9	nil	0·9	nil	nil	nil	nil	nil	nil
Nitrates (as NO_3)	present	nil	present	present	present	present	nil	nil	nil
Calcium (as Ca)	9	24	12	17	7	15	—	—	—
Magnesium (as Mg)	1	12	1	3	3	5	—	—	—
Iron (as Fe)	nil	0·2	0·2	6·8	6·4	0·2	0·7	3·6	1·2
Silica (as SiO_2)	130	70	90	30	55	30	78	40	16
Total Hardness	25	110	35	55	30	60	30	20	40
Total Solids	4,700	1,385	660	370	540	220	340	250	320
Fluorides (as F)	11·8	13·1	8·2	3·8	1·6	2·0	6·1	1·3	2·4
pH	>9·6	8·5	8·7	8·1	7·8	8·3	7·0	6·9	7·0

Analyst: Government Chemist, Kenya.

Gas Analysis

The gas which bubbles slowly up at the Maji Moto spring was also sampled (it took about nine hours to collect 1½ litres) and was analysed by the East African Scientific and Industrial Research Organization as follows:—

Inert gases, including nitrogen	76.5
Oxygen	12.0
Hydrogen	0.5
Carbon Dioxide	8.0
Carbon Monoxide	tr.
Methane	2.5
Unsaturated hydrocarbons	0.5

The proportion of nitrogen to oxygen in the atmosphere is about 5 to 1, and the proportion of inert gases to oxygen in this sample is 6.3 to 1. It is therefore probably mainly atmospheric in origin, but the carbon dioxide, hydrocarbons and the 16.5 per cent excess inert gases may be juvenile.

The probable mineral composition of the water from the Maji Moto spring, calculated by the East African Industrial Research Organization from a water analysis, is as follows:

	Parts per Million
Calcium Bicarbonate	87.9
Magnesium Bicarbonate	49.4
Sodium Bicarbonate	52.1
Sodium Chloride	30.2
Sodium Sulphate	32.8
Silica	37.0

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