GEOLOGY OF NORTHERN TURKANA

DEGREE SHEETS 1, 2, 9 and 10

(with coloured geological map)

by

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ABSTRACT

The report describes the geology and topography of that part of north-west Kenya north of latitude 3° N. and west of Lake Rudolf, an area of approximately 13,100 square miles. The area was mapped in reconnaissance style and the work of earlier writers has been drawn on to supplement the writers' observations.

The area is sub-divided into five main physiographic units, (*a*) the Uganda Escarpment, (*b*) the mountain ranges, (*c*) the intra-montaine plains, (*d*) the Lotigipi Swamp and (*e*) the Lake Rudolf coastal plain. An account is given of the geological history of the area with special reference to the erosion surfaces recognized. A detailed description is given of the various rock types, which comprise Basement System gneisses, Tertiary sediments and volcanics, Pleistocene to Recent lake beds, and superficial deposits. One major and many minor intrusions were mapped.

A brief chapter discusses the economic minerals present in the area, none of which shows promise of development, and the water supplies.

FOREWORD

The mapping of the North Turkana area is something of a departure from the usual mapping of the Kenya Geological Survey in that it was done in very rapid reconnaissance style, the 13,000 square miles being covered in less than five geologists' man-months. That it was possible to produce a fairly detailed map in such a short time is due mainly to the excellent R.A.F. air photographs which cover the area, and to the relatively simple geological succession of crystalline Precambrian rocks largely covered by Tertiary and Quaternary sediments and Tertiary volcanic rocks. The work of earlier investigators, notably Arambourg, Fuchs and Champion, also proved invaluable in compiling this report.

North Turkana marks the northernmost extension in Kenya of the Gregory Rift Valley, which there is essentially a broad downwarp, in contrast to the markedly faulted rift in Central Kenya. The present intensity of research on rift valleys as part of the study of the Upper Mantle has made the Lake Rudolf area a particularly interesting target for study.

In recent years great interest has also been shown in the sediments of the area, first studied in detail by Arambourg in 1932-33, on account of their richness in mammalian fossils. Professor Arambourg in 1967 announced the finding at the north end of Lake Rudolf of hominid remains which may prove to be among the earliest yet known of man's ancestors, and in 1969 Mr. Richard Leakey found an even older skull. Palaeontological research there will undoubtedly accelerate in the coming years.

L. D. SANDERS,
Commissioner of Mines and Geology.

12th September 1969.

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Geological Map of Northern Turkana. Scale 1:500,000	At end

I—INTRODUCTION

The area described in this report is approximately 13,100 square miles in extent and comprises all that part of Kenya lying north of latitude 3° N. and west of Lake Rudolf. The western boundary of the area is the Uganda border, the north-western and northern boundary follows the Sudan border, and in the extreme north-east touches Ethiopia. The area comprises all or part of Kenya degree sheets Nos. 1, 2, 9, 10 and 11 (Directorate of Overseas Surveys Nos. 1, 2, 3, 4, 9, 10, 11, 12, 23, 24, 25 and 26), and lies in the northern part of Turkana District, Rift Valley Province, the District being administered by the District Commissioner at Lodwar. A District Officer is based at Lokitaung.

The mapping was done in reconnaissance style, that part of the area north of latitude 4° N. and east of longitude 35° E. being mapped by R. G. Dodson, Geologist, over a period of about six weeks, while the remainder was mapped by J. Walsh, Geologist, ably assisted by S. Dodhia, B.Sc., then Trainee Geologist, over a period of three months. Owing to the very short time available for the survey it was necessary to make widely spaced traverses over the area, with more detailed work on areas of special interest. Much use was made of the excellent R.A.F. air photographs which cover the area.

Population

The region is very thinly populated, entirely by Turkana tribesmen. Except for relatively few fishermen on the shores of Lake Rudolf and a handful of town dwellers the tribes are nomadic, moving from place to place with their livestock (camels, cattle, goats, sheep and donkeys) as grazing and water supplies permit. Permanent water is available in Lake Rudolf, from a shallow borehole at Lodwar, and from many of the larger rivers which, although dry for most of the year, locally hold sub-surface water obtainable from wells dug in the river beds. Near Lokichogio, at Lokitaung and at various places in the Muruasigar and northern Lothidok hills are small permanent springs.

Climate and Vegetation

Rainfall is low over the whole area and especially low at lower altitudes, and this combined with the very high temperatures which obtain throughout the year (at Lodwar maximum shade temperatures vary between 80° F. and 104° F.) have reduced the region to semi-desert except for a few favourable localities on high ground such as Muruasigar, which supports a few square miles of dense forest. Rainfall statistics for the five stations in the area, supplied by the East African Meteorological Department, are as follows:—

Station	Total Rainfall (Inches)				Yearly average and number of years recorded
	1959	1960	1961	1962	
Lodwar	12·05	4·90	19·62	7·96	6·51 (37)
Ferguson's Gulf	12·68	4·16	19·97	8·00	8·68 (9)
Lokitaung	13·59	9·90	35·47	12·38	15·70 (26)
Todenyang	NR	0·50*	NR	19·08	7·58 (9)
Lokichogio	18·52	15·82	37·62	14·28	20·62 (8)

NR—Not Recorded.

*0·45 Inches of this total fell in one day.

The majority of the yearly rainfall occurs in two seasons, from March to June, with a peak in April, and from October to December, with a lesser peak in November or December.

The exceptionally heavy rainfall of the latter half of 1961 still showed its effects in 1963, when areas which in 1958 had appeared completely denuded of vegetation were still carrying a sparse cover of grass and low scrub. The water level of Lake Rudolf in 1963 was several feet above the average level recorded in the previous few years. At the time of mapping, the water level was seen to be steadily falling, and where reference is made in the map and this report to the lake level it is taken as 1,230 ft. O.D., the average level before the 1961 rains.

For most of the year an easterly wind prevails. It is particularly strong near the lake shore, rising after sunset and blowing steadily until the following noon, when it is usually followed by several hours of dead calm.

Acacia thorn scrub, with larger acacia trees along river courses, is found everywhere in the map area, accompanied by xerophyte succulents on the lava outcrops. Doum palms are common along the larger sand rivers and along the lake shore, and euphorbia is fairly common. The fairly high alkali content of the lake waters, particularly in the shallow swamps formed as a result of the present high water level, greatly limits the range of species of vegetation. Along the low-lying shores of Ferguson's Gulf a careful search disclosed only four species, doum palms, sometimes with xenophobic succulent creepers, very coarse wiry grass, and occasional clumps of reeds.

At a few localities near the townships and along the Turkwel and Tarach rivers small plots are planted with maize in favourable seasons, but the total area under cultivation amounts to only a few dozen acres of the thousands of square miles mapped.

Communications

From Lodwar good earth roads run south-west to Lorugumu and Kitale, north to Lokitaung and north-east to Ferguson's Gulf, the latter road being somewhat difficult in patches near the lake due to loose sandy surfaces. The road running south to Lokichar is also difficult due to loose sand, and may be blocked for several months of the year by the flooding of the Turkwel River. The only other regularly maintained road is that to Lokichogio, branching westwards from the Lodwar-Lokitaung road. In the Pelekech hills and near Lokichogio this road is very rough, and flooding of the Tarach and Napas rivers sometimes closes the road for many days in times of rain. Most of the other roads shown on the map are merely unsurfaced tracks, generally passable only by Land-Rovers or similar vehicles. Much of the flat area away from the hills can be traversed at will by Land-Rovers, with only occasional gullies to be avoided, and the beds of several of the larger rivers crossing the Lothidok Range can be followed over much of their length by the same vehicles, though progress is generally very slow, seldom as much as five miles an hour. The roads are closed to all but essential traffic during the two rainy periods of the year.

At Lodwar, Lokitaung and Lokichogio are well-maintained airstrips usable in dry weather by large transport planes, and in emergency by commercial air-liners. In addition there are many small airstrips used mainly by aircraft of the Kenya Police Air Wing.

Apart from a few launches with outboard motors at the Fisheries Department camp at Ferguson's Gulf the only craft on Lake Rudolf are rough dug-out canoes and small rafts of lashed tree trunks used by the Turkana fishermen.

Game is now very scarce over the map area, except close to the Uganda border where a ten-mile wide strip is closed to grazing to lessen the risk of cattle-raiding along the border. In the closed strip are found several varieties of gazelle and antelope, and occasional elephant and giraffe. A very fine leopard with cubs was seen

near Lokichogio. Large herds of topi graze the coastal plain north of Todenyang. Crocodile and hippopotamus are numerous in the lake, which is abundantly stocked with Nile perch (often exceeding 200 lb. in weight), tilapia and catfish. The shores of the lake are inhabited by incredible numbers of birds.

Most of the area is closed to visitors but Ferguson's Gulf is becoming increasingly popular with anglers and bird-watchers, and permission to visit the lake may be obtained (in advance) from the District Commissioner, Lodwar. Intending visitors must satisfy the administrator that they are self-sufficient with water and food in case of breakdowns, and must travel with two vehicles in company, one of which must be a Land-Rover or lorry.

Maps

The whole area is covered by R.A.F. air photographs taken between 1957 and 1959 at a scale of approximately 1:80,000. From these photographs the Survey of Kenya compiled a series of topographic maps at a scale of 1:100,000, which were used in conjunction with the air photographs for the present survey. The 1:100,000 maps are all of the Y633 series, Nos. 1, 1a, 2, 2a, 3, 3a, 4, 4a, 9, 10, 11, 12, 23, 24, 25 and 26. These maps contain only rough form-lines, and on the geological map accompanying this report the form-lines have been amended and extended as necessary to conform with spot-heights taken during the survey. All these spot-heights were taken with a Thommen pocket altimeter, suitably corrected for diurnal variations, or calculated from sightings taken by clinometer, and all based on the accepted pre-1961 level of Lake Rudolf of 1,230 ft. O. D. Such contours must therefore be taken as only approximate. Geological information was plotted directly on to air photographs and transferred on to the 1:100,000 base maps, being photographically reduced to the final printed scale of 1:500,000.

II—PREVIOUS GEOLOGICAL WORK

Lake Rudolf was discovered by Count Teleki and Lieut. von Höhnel in 1888. In a book by the latter (1894)* mention is made of the lavas near the lake and the raised lake beaches. Descriptions of rocks collected during the expedition were made by A. Rosiwal (1891) and F. Toula (1891). In his account of the East African rift valleys, E. Suess (1891) referred to the work of the Teleki expedition and listed some of the fossils identified from raised beaches on the east of the lake, and from an examination of the fauna of the lake deduced a former connexion between the lake and the Nile River system.

H. S. H. Cavendish (1898) is the first explorer known to have travelled down the western shore of the lake, in 1897. He climbed Mount Lubur (Labur) which he described (loc. cit. p. 387) as a crater nearly two miles across. The mountain now known as Labur is a sharp peak of sediments, and there is no recognizable crater anywhere in the Labur range.

In 1898 and again in 1901 Major H. H. Austin (1899 and 1902) travelled from the site of present-day Lodwar to the lake shore north of Ferguson's Gulf, and referred to the arid sandy and stony deserts of that region.

Capt. M. S. Wellby in 1899 crossed the south-west corner of the map area in his journey from the southern end of the lake to the Uganda Escarpment, apparently passing just east of Muruasigar. He described (1900) sandstones capping the hills near the lake (the Turkana Grits) and surprisingly referred to "wonderfully fertile" valleys north-west of the Turkwel.

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*References are quoted on p. 37.

In the account of his 1902 journeys in the area Count du Bourg de Bozas (1903) mentioned the lavas of the area as contrasted to the granitic rocks of the Uganda Escarpment, and also described some of the Quaternary beaches of Lake Rudolf.

An expedition by the East African Syndicate visited the western shores of the lake in 1903 (J. W. Brooke, 1905) and the report again referred to raised beaches 500 feet above the lake at Labur.

The first reliable map of Turkana was made by A. M. Champion (1937) in the early 1930s. Champion was the chief administrative officer of the area, and his mapping and excellent naturalist studies were made in the course of his almost daily journeyings through his territory. Many of the rocks collected by Champion were described by W. Campbell Smith (1938) and much of Champion's and Smith's work is drawn on in the present report.

V. E. (now Sir Vivian) Fuchs made two visits to Lake Rudolf, and gave accounts of his work in three reports dated 1934, 1935 and 1939, the latter including a geological map covering much of the present area. Many references to Fuchs' work are made in later chapters of this report.

In 1932/33 C. Arambourg led an expedition to Northern Turkana, and his work, which included anthropology as well as geology, is reported in several different publications, of which those dated 1933, 1935, 1943, 1947 and 1959 are relevant, and which are referred to in later chapters.

F. Dixey (1944 and 1948) gave brief accounts of the geology of Turkana with special reference to the Miocene and Quaternary sediments, and gave a more lengthy discussion on the geological history and erosion surfaces of the area. Again, much reference is made to Dixey's work on later pages.

A report by W. A. Fairburn and F. J. Matheson of the Kenya Geological Survey on the area to the south of the western half of the present area, the Loiya-Lorugumu area, is in course of publication (Report No. 85). They describe Basement System rocks, Turkana Grits and Tertiary lavas, and report the dominant structural trend over that area to be north-north-west to south-south-east.

R. G. Dodson in his report on the area south of Lodwar (Report No. 87, in course of publication) refers to Basement System rocks, Turkana Grits, Tertiary lavas and Pleistocene sediments of the raised lake beaches.

That part of Uganda adjacent to the present area and lying between 3° 30′ and 4° N. was mapped by J. P. MacGregor of the Geological Survey of Uganda (1962). That area consists of a series of metamorphosed gneisses of the Basement System with a few basic vents and dykes of Tertiary age, possible coeval with the lavas of Turkana.

An expedition from the Harvard Museum of Comparative Zoology, led by Prof. Bryan Patterson, was working on the mammalian fauna of the sediments of the Lothidok area during the present survey. Full reports of their findings are to be published later.

III—PHYSIOGRAPHY

Topography and Drainage

The area is divisible into five main physiographic units:—

The Uganda Escarpment.
The mountain ranges.
The plains.
The Lotigipi Swamp.
The Lake Rudolf coastal plain.

The Uganda Escarpment

The border between Kenya and Uganda follows the foot of the Uganda Escarpment (sometimes known as the Turkana Escarpment) along roughly the 3,000-ft. contour. The summit of the escarpment in Uganda varies from an average elevation of about 6,000 ft. to above 8,000 ft. on peaks. Within the map area the escarpment is cut in Basement System gneisses, and only along a few miles in the south-west do Tertiary lavas rise above the 3,000-ft. contour and abut the escarpment. For reasons discussed in a later chapter it is not considered that the Uganda Escarpment is a fault or a fault-line scarp, and its present state of dissection is considered to be due in the main to erosion cutting back westwards. Slopes on the escarpment are always steep, and average 20° from the horizontal, though locally vertical faces hundreds of feet high are developed.

The Mountain Ranges

The situation and form of the major mountain ranges are largely dependent on the phase of volcanism responsible for their emplacement, and subsequent tectonic movements which tilted the layered volcanic succession. The tilting was accompanied by or resulted in a series of roughly north-south aligned step-faults situated in and between the present ranges. Erosion of the series of elongated fault blocks evolved the mountain forms typical of the region. They are characterized by stepped steep-sided scarp slopes with contrasting gently inclined dip slopes, the latter usually coinciding with the angle of tilt.

The Labur range in the north-east of the area has a more complex composition and form. Uplift in the northern part of the range has exposed a wedge-shaped foundation of Basement System rocks which is overlain by a succession of sediments of the Turkana Grits series which now dip to the south-west, and which thin out northwards until the overlying volcanic rocks are in contact with the Basement System rocks. Erosion of the respective rock types exposed on the eastern flank of Labur has produced slope profiles characteristic of each of the rock series. The Basement System rocks are eroded to gently rounded hummocky hills with sandy convex slopes. Sediments of the Turkana Grits series are considerably more resistant to erosion and thus often form protective caps over Basement System rocks. The margins of the sandstone and quartzite horizons are eroded mainly by scarp retreat, and frequently form impressive cliff faces. The volcanic rocks, which comprise a considerable thickness of lava with intercalations of ashes and agglomerates, form stepped profiles on the eastern slopes due to differential rates of erosion in the lavas and softer volcanic deposits.

Basement System gneisses also form the exposed foundation of Muruasigar in the south-centre of the area. Here Turkana Grits and the lower volcanics are absent and rhyolites rest directly on the Basement System rocks, and the eastern face of the hill shows a very steep, locally vertical, face of rhyolite capping a less steep pediment of gneisses.

The Plains

Extensive plains occupy the central part of the area and the regions between the mountain ranges. The plains are covered with detrital material, red, grey and brown soils, rock brash, and gravel and pebble beds.

The Lotigipi Swamp

The swamp occupies an extensive basin in the core of a broad open syncline pitching gently northwards. To the casual visitor it would appear strange that a swamp could exist in such an arid region. The explanation is that, although the areas mapped as swamps are dry for most of the year they become true swamps in times of heavy

rain. The vast Lotigipi Swamp is an alluvial flood plain in which even the major rivers maintain their channels for only a few miles. Champion (1937, p. 116) records a sheet of water in the northern part of the Lotigipi sighted by the crew of an R.A.F. aircraft in 1931, and there was surface water in the swamp after the heavy rains of 1961. In 1963 the writers made three attempts to penetrate the swamp along river beds from east, south and west, but in every attempt soft and wet conditions forced them to turn back after little more than ten miles.

The Lake Rudolf Coastal Plain

The coastal plain along the margin of Lake Rudolf extends up to 15 miles inland from the lake shore to the Labur-Lothidok ranges, rising gently westwards to over 300 feet above the lake level. The plain shows a number of well-defined platforms, discussed at length in a later chapter, marking former lake levels. Most of the coastal plain is covered by fine textured and powdery, often diatomaceous, sands derived from the lake sediments. In many localities the prevailing easterly winds have heaped up the sands to form barchan dunes.

Drainage

The drainage pattern of the area centres around two major basins, Lake Rudolf and Lotigipi. The only perennial river entering the lake is the Omo, flowing southwards from Ethiopia into a delta at the northern end of the lake. All the other rivers of the area with the exception of the Turkwel are dry for most of the year, flowing for a few days or even hours after rain. The Turkwel river carries water into the lake for several months in a normal year. The river is approximately 200 miles long, rising on the slopes of Mount Elgon (where it is known as the Suam) to the south of the map area. For much of its length it runs from south to north, but just south of the map margin it begins to swing eastwards, finally to run from west to east into Lake Rudolf, its mouth forming an extensive delta.

Rivers draining the eastern slopes of the mountain ranges bordering the lake have west-east alignments, flowing directly into the lake. The rivers draining the western slopes of the Labur range flow initially along northerly or southerly courses before curving around or cutting through the range to flow eastwards into the lake.

Between Labur and Todenyang a basin of internal drainage is aligned roughly parallel to the lake shore. The basin lies about five feet below the surface of the surrounding coastal plain and is covered with fine alluvium deposited by numerous small seasonal streams. The basin is a remnant of Sanderson's Gulf, which has dried up within living memory.

The watershed between Lake Rudolf drainage and that of Lotigipi follows a roughly north-east to south-west line from the Moruerith hills to the north of Muruanachok, thence running westwards across the plain to Nangulechom, and then due south through the peak of Muruasigar. All the drainage west and north of this line flows into the Lotigipi Swamp. Too little is known of that part of the swamp to the north of the map area to be able to determine the ultimate destination of water entering the swamp. It is certain that the majority of the water is lost by evaporation and percolation, but it is possible that in times of unusual floods water may flow westwards into the Kibish River and thence to the Omo, eventually flowing into Lake Rudolf.

Erosion Surfaces

Assessments of the physiographic history of Northern Turkana is complicated by two considerations, first, post-Miocene tectonic activity which has greatly affected the original sub-Miocene bevel, and secondly that post-Miocene erosion has been related to the Lake Rudolf and Lotigipi basins, being therefore subject to the effects of fluctuations of base level during advance and retreat of the lake level.

Brief accounts of the erosional history of Northern Turkana were given by Fuchs (1935, pp. 132-133; 1939, pp. 267-268), Champion (1937, pp. 105-106) and Arambourg (1943, pp. 212-214). A more complete account, in places drawing on the work of these three authors, was given by Dixey (1948, pp. 2-4 and 25-31).

Fuchs' interpretation of the present topography is of an original Central African peneplain which in late Oligocene times was fractured to form the Uganda Escarpment. Erosion of the escarpment gave rise to the material redeposited as the Turkana Grits which in turn were covered by Miocene volcanics.

Dixey's summary states that the Turkana Grits and later volcanics were deposited on the somewhat irregular sub-Miocene surface, and that later Miocene dissection bevelled the area, forming the Uganda Surface to the west and leaving remnants of the same surface on the mountain ranges of Turkana at a little more than 4,000 ft. After the major faulting of the area the end-Tertiary peneplain bevelled the lower ground to form the Turkana Plain, but the surface so formed was subject to slight faulting and folding leading to variations in the level of Lake Rudolf. However, later authors (e.g. McConnell, 1955) point out that the Uganda Surface and the sub-Miocene peneplain are one and the same. Further, the present writers disagree with Dixey's contention that the surfaces of the northern Turkana ranges show evidence of peneplanation. Admittedly many show a vague concordance of summit levels at above 4,000 ft. but where such ranges have fairly even summits this is due to the attitude of the lavas capping them.

The sequence of events in the area appears to have been as follows:—

(1) Maturation of the sub-Miocene peneplain across adjacent parts of Uganda and northern Kenya.

(2) Warping of the surface, perhaps accompanied by minor faulting, to form a shallow basin centred just west of the present Lake Rudolf.

(3) Erosion of the warped surface, cutting back to the west to initiate the formation of the Uganda Escarpment, and deposition of the debris as the Turkana Grits in the lowest parts of the basin.

(4) Extrusion of the volcanic succession in and near the basin, successive flows spreading farther and farther to the west as the basin filled.

(5) Major faulting east of the Uganda Escarpment, re-establishing the basin and forming the proto-Lake Rudolf.

(6) Erosion contemporaneous with the formation of the end-Tertiary peneplain, but with a local base-level which varied with the fluctuations of the lake level.

The fact that the sub-Miocene surface was warped down to initiate renewed erosion and the deposition of the Turkana Grits explains the somewhat irregular surface of Basement System rocks over which the lavas spread. The depth of dissection is not known, but the Basement/lava contact east of the major fault below Muruasigar peak shows variations from level of up to 150 feet over a distance of less than a mile. Fig. 1 shows an attempted reconstruction of the sub-Miocene surface (i.e. the contact between Precambrian rocks and Tertiary sediments and lavas) as it is today. The contact is exposed in the Labur Hills, at and near Muruasigar, and near the Uganda Escarpment. Elsewhere the position of the contact is inferred from considerations of land-forms and assumed thicknesses of lavas and sediments. The conjectural contours at Lotigipi, west of Labur, and under Lake Rudolf are extrapolations of the slope of the surface. It will be seen that this map agrees in broad detail with that of W. Pulfrey (1960) except that Pulfrey does not show the high at Muruasigar. In that part of his map he may have been misled by Fuchs (1939, p. 242) who appears to refute Arambourg's contention (1935, map p. 15) that the eastern scarp of Muruasigar is in Basement System rocks, though Fuchs' own map shows them to occur. In

fact the Basement/rhyolite contact east of the peak was found to be just below 6,000 ft. (Arambourg himself appears to have been influenced by this statement of Fuchs', since his later map (1943) omits the Basement System rocks east of the peak!)

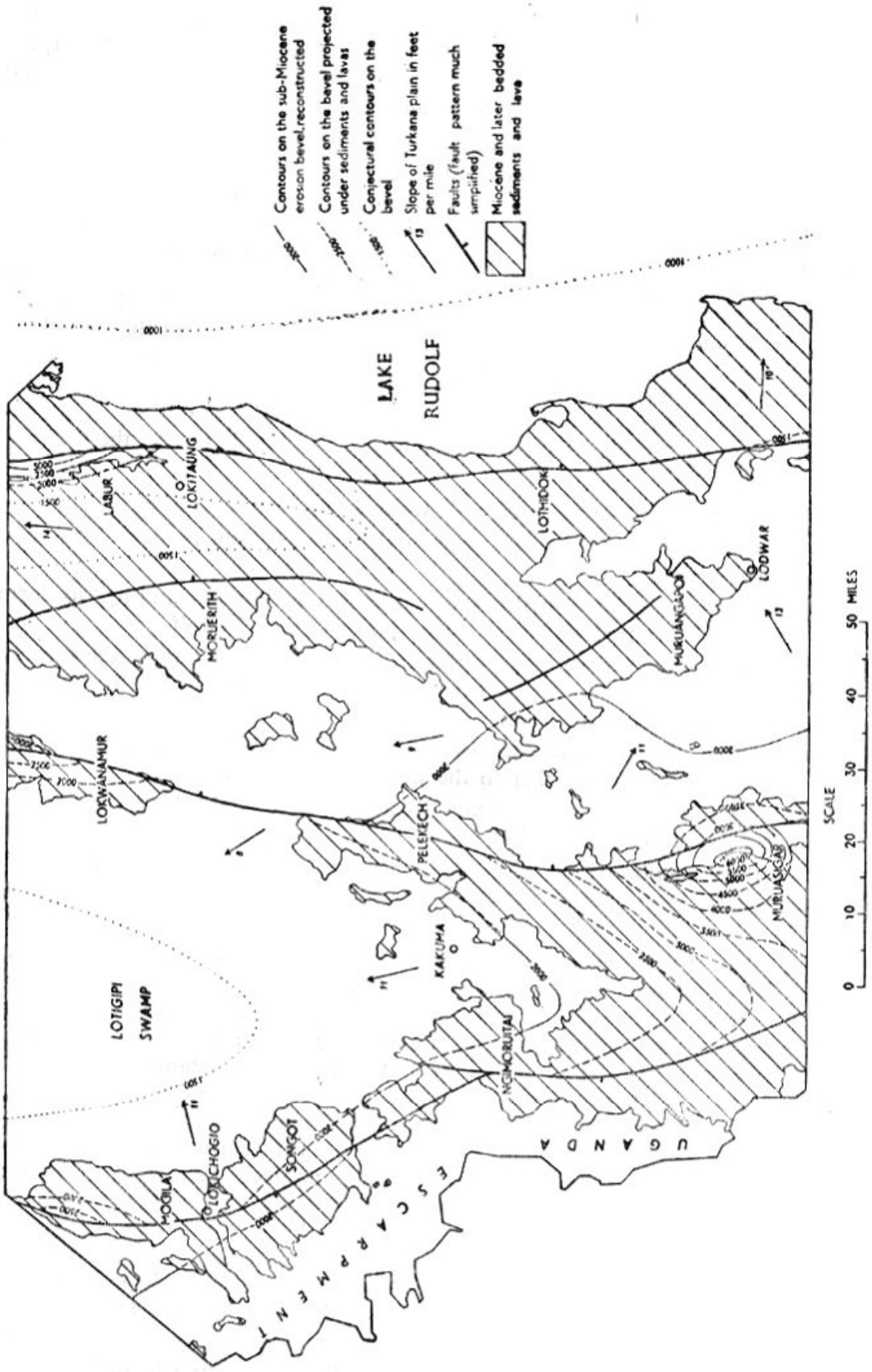


Fig. 1—Erosion surfaces of Northern Turkana

The Turkana Plain is the result of erosion contemporaneous with the end-Tertiary peneplanation elsewhere in Kenya. Its present form was dictated by the major faulting which followed the emplacement of the lavas of the area, and the varying base-level of erosion, the water-level of Lake Rudolf. It will be seen from Fig. 1 that the slope of the plain, which is a series of flats between the major ranges, is generally fairly low, averaging little more than 10 feet per mile. But its slope is only locally directed eastwards towards the present lake—at Lotigipi and west of Labur the slope is down to the north. For reasons given in a later chapter the writers suggest that at various times in its history Lake Rudolf spread across the north of the present area, and that Lotigipi was once part of the same lake.

East and north-east of Muruasigar the Turkana Plain has cut down some 300 to 400 feet below the sub-Miocene surface, but near the lake and Lotigipi the plain now lies above the older surface. End-Tertiary dissection along the foot of the Uganda Escarpment does not appear to have approached planation, and that part of the area is considered to be a pediment with respect to the Turkana Plain. Patches of angular quartz gravel west and north-west of Ngimoruitai appear to have no connexion with either of the erosion surfaces of the area.

IV—SUMMARY OF GEOLOGY

The northern Turkana area consists of a series of elongated ranges of hills with a generally north-south alignment, with intervening areas covered by superficial deposits which obscure the underlying formations.

The succession is as follows:—

8. Recent superficial deposits.
7. Pleistocene to Recent lake beds.
6. Rhyolites, with intercalated andesites in the south-west.
5. Olivine basalts.
4. Phonolites and nephelinites.
3. Augite and analcime basalts.
2. Turkana Grits.
1. Basement System.

In addition there is one major intrusive body, a diorite which is older than any of the volcanic rocks, and two series of minor intrusions, the earlier of which are found cutting only Basement System rocks and are believed to be of pre-metamorphic age, and a later series related to the main volcanism.

The Basement System rocks of the area consist mainly of semi-granitized psammitic sediments, but in the Labur hills semi-pelitic gneisses and crystalline limestones are well developed, with abundant amphibolites and lesser pegmatites. The gneisses occurring along the eastern margins of Labur have been mylonitized.

The Turkana Grits, which unconformably overlie the Basement System rocks, are a succession of sediments which locally exceed 500 feet in thickness. The series is made up of conglomerates, quartzites, sandstones and minor shales, which thin out northwards and westwards from the lake region to where younger lavas directly overlie the Basement System.

The oldest volcanic rocks are a series of generally fine-grained basalts which overlie the Turkana Grits, and like the Grits thin out westwards, overstepping them by only a few miles. These basalts closely resemble, and are probably equivalent to, the Samburu basalts, first described by Shackleton (1946, p. 29) which outcrop widely in and near the central parts of the Kenya Rift Valley.

The age relationship between the next highest volcanic rocks, the phonolitic lavas and the olivine basalts, is not clear. The phonolitic series is seen to overlie the lower basalts north of the Muruangapoi Hills, and plugs of phonolite invade the lower basalts nearby, but are nowhere found in contact with olivine basalts. The olivine basalts are very similar to the Elgeyo basalts, which overlie Samburu basalts in the Eldama Ravine-Kabarnet area of the central Rift Valley (Walsh, 1969).

The highest and youngest of the volcanic rocks are the rhyolites, a series of lavas, tuffs and agglomerates, which extend right across the area mapped. South of the south-west quarter of the area Fairburn and Matheson (report in preparation) were able to sub-divide the rhyolite succession into a lower Muruasigar series separated from the upper Puch Prasir series by an andesite group. Since both rhyolite groups are similar in appearance, both megascopically and microscopically, they could be sub-divided only in the extreme south-west of the present area where they are separated by the andesite series. For this reason the rhyolites have been shown on the map, and are described in this report, as a single series.

Along the shoreline of Lake Rudolf in the Todenyang area a compact, fine-grained buff-coloured rock resembling clay is patchily exposed from beneath Recent shoreline deposits. Microscopic examination of specimen 2/44* reveals, however, a crystalline texture typical of fine-grained ash. The relationship between this rock and other volcanic rocks in the area is not clear but it is possible that the ash originated from the volcanic region on the eastern shores of the lake, easterly prevailing winds inducing deposition around Todenyang.

The Pleistocene to Recent lake beds are developed only near the shores of the present lake, and consist of a series of step-like deposition levels rising over 300 feet above the present lake level. They comprise a series of sands and clays, generally rich in fossils which are locally so abundant as to form thin bands of shelly limestone.

Recent superficial deposits include wide extents of sandy soils, red over Basement System rocks and generally grey, buff or white elsewhere, swamp soils, sands of the present lake shore and small extents of superficial limestone, generally pisolitic and only poorly consolidated.

V—DETAILS OF GEOLOGY

1. The Basement System

The oldest deposits of the area are metamorphosed rocks, mainly sediments, of the Basement System, considered to be Precambrian in age. They outcrop in the west of the area along most of the length of the Uganda Escarpment, in the north-east along the eastern part of the Labur Hills, and in scattered outcrops in the south-centre of the area.

The rocks examined in the western outcrops consist of a monotonous succession of fairly leucocratic coarse-grained migmatitic gneisses, pink, grey or buff in colour and ramified by white or pink veins of quartz-felspar pegmatitic material. A typical specimen, 9/11 from the Uganda border west of Oropoi Police Post, shows in thin section pale green diopside largely altered to deep brown biotite and iron ore, with quartz, oligoclase-andesine and small amounts of microcline. Hornblende and garnet were identified in other similar outcrops in the vicinity. At Oropoi Police Post is an elongated ridge of crystalline limestone. A thin section of this limestone, specimen 9/10, shows, in addition to calcite, forsterite and a trace of quartz.

* Numbers 2/44, etc., refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

Migmatites also constitute the bulk of the Basement System rocks exposed at Labur. In hand specimen they are mottled, often patchily mesocratic rocks. Specimen 2/29 is a typical biotite migmatite exposed in the steep-sided gorge three miles south of Labur Peak. It is an allotriomorphic textured rock composed of a network of microcline replacing quartz and oligoclase. Medium-sized flakes of olive-green biotite are abundantly scattered through the rock. Pale green chlorite may be a replacement of either biotite or original hornblende. Magnetite is a primary constituent occurring in euhedral to subhedral grains. Accessory minerals present are apatite and zircon. In specimen 2/32, from five miles north of Labur Peak, sphene occurs as an accessory mineral, and in 2/51 from the north of the hills, garnet is present.

Coarse-textured massive rocks of psammitic composition tend to form prominent features in the Labur range. They form escarpments and cliff faces, or in the more eroded parts occur as linear heaps of boulders protruding through sands. Specimen 2/45, a typical example of granitoid gneiss from the northern slopes of the range, is a coarse-grained granitic-textured rock composed essentially of quartz, microcline, oligoclase and garnet. The garnet is a pale pink variety of almandine. In some examples of granitoid gneiss such as 2/33 from north Labur microcline exhibits porphyroblastic growth.

About two miles north of the mouth of Lokitaung Gorge a narrow band of crystalline limestone is exposed in a steep hill slope. The limestone occurs within a succession of gneisses and amphibolitic rocks. In hand specimen, 2/22, the marble is a medium-textured whitish to grey rock with few visible impurities. Fine flakes of graphite and small grains of iron ore were identified in a heavy mineral concentrate prepared from crushed samples of the limestone, and the thin section shows a few grains of quartz and phlogopitic mica in addition to calcite.

Basement System rocks exposed along the eastern margin of Labur have been crushed to the extent that their original composition is in most cases obscured. The mylonization occurs within a zone about a quarter of a mile wide, the most extreme crushing being along the eastern edge of the exposed rock. The mylonites are typically pale grey to brownish in colour, and in the most extreme cases of mylonization have a distinctive porcellanous sheen. In less severe brecciation such as is seen in specimens 2/19 and 2/21 fragments of felspar, quartz, pyroxene and iron ore are retained in the fine grained groundmass.

Amphibolites, believed to be the metamorphic derivatives of intrusions into the Basement System sediments, are abundant in the Labur range, occuring mainly in the brecciated zone along the eastern margin. They are typically dark greenish to grey coloured coarse-textured rocks, locally with clearly defined schistosity. In the brecciated zone the amphibolites have a pale greenish slaty appearance. Specimen 2/24 from about three miles south of Labur Peak is a somewhat brecciated example of amphibolite. It is composed of irregular patchy grains of andesine felspar surrounded by trains of finely crushed diopside, green hornblende and epidote. Ilmenite and sphene are accessory minerals.

The scattered Basement System outcrops in the south-centre of the area between Muruasigar and Muruanachok are mainly of coarse granitoid gneiss which tends to form craggy tors. The typical rock type is a leucocratic biotite gneiss cut by white and pink auto-pegmatitic material and with porphyroblastic microcline felspars, which near Muruasigar reach 4cm. in length, but generally average 1cm. White mica locally accompanies the biotite and garnet is also seen in accessory amounts. Along the southern margin of the diorite intrusion at Muruanachok are a few bands up to 200 feet wide of plagioclase amphibolite, all conformable with the enclosing granitoid gneisses. These may represent pre-metamorphic basic intrusions into the original sediments or may be the metamorphic derivatives of calcareous mudstones.

The fault cutting granitoid gneisses at the eastern foot of Muruasigar, which has a downthrow of nearly 3,000 feet, is surprisingly free of brecciation and mylonization. It is locally marked by elongated pods of white quartz up to 100 ft. in width which form hills reaching 40 ft. high. The freedom of the quartz pods from crush effects show them to have been emplaced after movement along the fault had ceased.

The faulted inlier of Basement System rocks to the north of Lodwar again consists mainly of leucocratic granitoid and semi-granitoid rocks, mainly biotitic varieties, but towards the east of the outcrop coarse flaggy quartzo-felspathic gneisses with garnet become the dominant rock type. Near the western margin of the inlier plagioclase amphibolites, conformable with the enclosing biotitic granitoid gneisses, form a significant fraction of the rocks. A thin section of plagioclase amphibolite from near Lotien, specimen 10/21, shows a coarse equigranular aggregate of ragged grains of blue-green hornblende and andesine, much of the latter being untwinned. Sphene and apatite occur in trace amounts, and quartz is not present in the slide.

Several of the faults cutting the gneisses of the same inlier show strong brecciation. A breccia on the first major fault east of Lotien averages 80 ft. in width for a distance of well over a mile, and is so resistant to erosion that it forms the vertical core of a ridge which reaches 300 ft. in height. The rock is off-white in colour with strong red-brown iron staining, and is of a flinty texture. The thin section, 10/22, shows an almost glassy mylonitic groundmass supporting streaks and angular fragments of quartz and amorphous silica with a small percentage of microcline, and patchily distributed translucent iron oxides.

2. Turkana Grits

The term Turkana Grits was originally used by Murray-Hughes (1933) to describe a sedimentary series in north-western Kenya. The term has been accepted by later writers and by members of the Kenya Geological Survey. Arambourg (1935, p 10 *et seq.*) refers to the same series as the "Lubur Series" from their development in the Lubur (Labur) range. The Turkana Grits were deposited on an eroded and locally faulted surface of Basement System rocks. Sediments believed to be contemporaneous with the Turkana Grits have been described from other parts of Kenya, notably the Maralal area (Shackleton, 1946) and in Kavirondo and the central Rift Valley (Murray-Hughes, 1933). Palaeontological evidence, both from vertebrate fossils at Maralal and in Kavirondo and fossil wood of *Dryoxylon* species in Turkana indicates a Miocene age for all these sediments*, and it is likely that the Turkana Grits were laid down during early Miocene sedimentation which occurred over many parts of northern and Western Kenya.

The Turkana Grits were deposited in a lacustrine basin as is shown by such features as current bedding, layers of well-rounded pebbles and the presence of calcareous mudstones, grits and shales found in the present area, and previously described from areas farther south (Joubert, 1966, and Dodson, report in preparation).

Exposures of Turkana Grits are confined to the eastern part of the map area. They outcrop in the Labur range, on both flanks of the Muruangapoi Hills, extending northwards to Muruanachok, and around the Lothidok Hills. They comprise a succession of conglomerates, arkoses, quartzites, sandstones and minor shales and limestones. In the Labur range a few miles south of the peak the sediments attain their maximum exposed thickness in the area, more than 500 feet, and it is probable that they reach a maximum thickness approaching 1,000 feet. North of Labur Peak the series thins out wedge-fashion to a point on the northern slopes of the range where the younger volcanic rocks directly overlie the Basement System. Sedimentary horizons are seldom persistent for more than a few miles. The succession therefore exhibits

* Arambourg (1943, p. 170) does not agree that the presence of *Dryoxylon* necessarily proves a mid-Tertiary age for the Turkana Grits and suggests they may be Eocene or even Cretaceous in age.

variations between adjacent valley exposures. The basal contact of the sediments exposed in the Labur range varies from soft, shaly bands to coarse-textured arkoses and sandstones with seams of pebbles. Thin, discontinuous layers of conglomerate are locally developed against the underlying Basement System gneisses. Massive quartzites and compact sandstones, locally with gritty horizons, comprise the bulk of the succession. A thick band of maroon-coloured arkose is exposed in the middle part of the succession in the two steep-sided gorges just south of Labur peak. This rock, of which specimen 2/23 is an example, is a coarse-grained arkose composed of sub-rounded grains of quartz and felspar cemented in an iron-oxide rich matrix. Higher up in the succession massive quartzites up to 100 ft. thick contain abundant pebble layers. The pebbles are exceptionally well rounded and almost entirely of quartz. They are concentrated in seams sometimes less than an inch thick. Partings of coarse textured conglomerates with pebbles up to three inches in diameter occur within the upper sediments. The conglomerates consist of sub-angular to rounded quartz pebbles set in an iron-oxide stained matrix of chlorite, muscovite, kaolinite, silica and rare pyrite. One such conglomerate lens is exposed in the Lokitaung Gorge about twenty feet below the upper sediment contact.

East of Lokitaung Gorge, close to the lake shore and about 50 ft. above the water level, a low-lying ridge of sediment believed to belong to the Turkana Grit series is exposed in the terrace of a former lake level. It is a greyish coloured compact flaggy rock. In thin section (specimen 2/10) it is seen to be composed of fine grit cemented in a calcareous matrix. The rock is similar to horizons of Turkana Grits immediately underlying the volcanic rocks in the Kamutile Hills in the area south of Lodwar (Dodson, report in preparation). If the calcareous grit does belong to the Turkana Grit series it is likely that its presence close to the lake is due to displacement caused by the north-south faulting along the eastern margins of the Labur range.

Immediately north of the mouth of the Lokitaung Gorge a series of much-weathered stratiform sediments are considered to be reconstituted Turkana Grits.

Nowhere in the map area other than at Labur are the Turkana Grits sufficiently elevated for erosion to have exposed any great thickness of the sediments, except near Muruanachok, where up to 300 ft. of coarse quartzites are exposed in hills, notably Akim (pictured by Fuchs, 1939, Plate 27 fig. 20). The lower-lying exposures in the Muruanachok area are generally of soft off-white grits with only rare thin bands of pebbly quartzite, together with soft sandstones and sandy clays, often of a bright green colour. A typical section exposed on the Lodwar-Lokitaung Road south-east of Lotien shows basalt capping an eroded surface of coarse but soft grit, with no obvious thermal alteration of the grit, which is underlain by a five foot thickness of fine red sandy clay, which overlies 20 ft. (base not seen) of green, sandy clay. In a river exposure two and a half miles farther south-east a similar green sandy clay occurs, three feet thick, but whose base is not seen, capped there by five feet of off-white sandy clay which is in turn capped by coarse off-white friable grit. At Lotien itself coarse yellow grits show intercalations of fine sandstone in which dark red ironcrete bands locally pick out very marked current bedding.

South of the Muruangapoi Hills and underlying the lava hill on which the Government Post of Lodwar is built, Turkana Grits again outcrop, and can be traced southwards in the banks of the Turkwel River. The few feet exposed is of off-white grit with the ubiquitous well-rounded quartz pebbles up to one inch across. North-east of Lodwar on the east flank of the Muruangapoi Hills exposures are generally poor, consisting of pale grey-brown sandy clay capped by pebbly grit. The top few feet of the pebbly grit is locally reworked and recemented with calcareous material.

The exposures shown on the map between the Muruangapoi and Lothidok Hills mostly take the form of extensive sheets of the typically well-rounded quartz pebbles derived from the Turkana Grits, with only rare gullies exposing grit and fine green sandy clay *in situ*.

Exposures of Turkana Grits on the south-eastern flanks of the Lothidok Hills are mostly of red and white sandy clays, with only thin layers of true grit. On the southern flanks of the hills coarse grit is again dominant, with bands several feet thick of fine buff, flaggy sandstone with rare discontinuous limestone bands up to an inch in thickness.

The isolated outcrops of Turkana Grits south of the Turkwel River are generally flat-lying exposures, but unlike the sandy soils which surround them are well gullied, and vertical exposures up to 25 feet high can be studied. The succession there is of dark grey, coarse, poorly consolidated grit capping yellowish to greenish soft sandstone. An interesting point is that the grit contains numerous and thick pebble horizons in which, like at a few places in the Labur range, the rounded quartz pebbles greatly exceed the usual one-inch diameter, and often reach four inches across.

A search for fossils in the Turkana Grits proved somewhat unrewarding. Fragments of unidentifiable fossil bone and plant remains occur sparsely in the sediments in the easterly outcrops, mainly in the upper part of the series, but no fossils of any kind were found in the Muruangapoi-Muruanachok exposures. In an earlier paragraph is given the fossil evidence on which a Miocene age has been proposed for the Turkana Grits.

Assays of specimens of conglomerate (2/55 from Lokitaung Gorge) considered likely to contain exogenetic mineralization proved disappointing, the gold content varying from a trace to 0.3 dwt. per ton.

That the Turkana Grits preceded the earliest Tertiary volcanic activity is proved by the absence of any volcanic material in the series. The grits are found nowhere west of Muruanachok. Though there is little doubt they once extended in that direction it seems probable that they feathered out fairly rapidly westwards, and were thin enough to be removed by erosion before being covered and protected by later lava flows. Turkana Grits have not been proved east of Lake Rudolf (the geology of that region is known only in broad outline) and the writers agree with Fuchs (1939, p. 230) that the depression in which the sediments were deposited lay somewhat to the west of the present lake. At Labur the sediments were laid down on a surface of Basement System rocks with a tilt of between one and two degrees to the south. Evidence for the presedimentation tilting is shown by the fact that the grits in contact with Basement System rocks in northern Labur are progressively higher stratigraphically than those at the basal contact in the vicinity of Lokitaung Gorge.

The material of the sediments was derived from the Uganda Escarpment, which marks the western margin of the map area. The predominance of grits and conglomerates and the relative scarcity of clays in the succession proves that the depression did not exist as a permanent lake, but rather as an area of small ephemeral lakes whose shorelines spread and receded with some rapidity, and in which the material of the sediments was deposited as a series of overlying and interfingering and much reworked delta deposits. The occurrence in the sediments of fossil logs of *Dryoxylon*, sometimes many feet in length, also points to deltaic conditions.

3. Tertiary Volcanics

Most of the mountain ranges and groups of hills are composed of a series of lavas and intercalated pyroclastics erupted during a prolonged phase of volcanicity which followed the early Miocene sedimentation, though which in the earliest stages was contemporaneous with sedimentation. The contact between Turkana Grits and the lower basalt is usually disconformable, with a small degree of dissection (up to 15 feet was recorded near Muruanachok) of the grits before the lava was emplaced. Locally deposition of the sediments continued sporadically after the onset of volcanism, and sandstones and sandy clays are intercalated in the lower-most lavas.

(1) *Augite and Analcime Basalts*

Like the Turkana Grits the lower basalts, those with augite and analcime and little or no olivine, are confined to the western half of the map area, and only at the southern end of the Pelekech range do they extend more than a few miles west of the western limit of the sediment outcrops. Unlike the succeeding members of the volcanic series the lower basalts tend to weather fairly rapidly by mechanical breakdown on joints and fractures, which reduce much of the mass of the exposed rock to small boulders and cobbles which in their turn suffer surface weathering and alteration. For this reason the topography of outcrops of the lower basalts is generally a series of low rolling hills, and only in the more elevated exposures, as in the Labur Hills, is erosion sufficiently rapid to exceed the rate of breakdown and weathering of the rock, leading to the development of fairly steep river valleys and gorges which expose relatively unweathered lava.

The augite and analcime basalts in the Labur range are exposed in a continuous section from near the mouth of Lokitaung Gorge to west of the township. The succession is tilted at about 15° to west-south-west and consists of an estimated 6,000 feet of basalts with minor intercalations of pyroclastics near the bottom of the succession. Faulting has undoubtedly caused repetition of strata in this succession, and the true thickness probably lies between 3,000 and 4,000 ft. The lavas of the lower contact, observed at numerous localities in the range, include fine-textured augite basalts, purple to reddish ashes, and at one locality a thin lens of agglomerate. Campbell Smith (1938, p. 525) described the prevalent type of basalt at Labur as a compact rock with occasional microphenocrysts of felspar and augite. Specimen 2/1 from the upper waterhole in Lokitaung Township is typical of the augite basalts, and agrees closely with this description. It is a compact, fine-grained basaltic textured rock composed of augite and plagioclase with microphenocrysts of labradorite (An_{55}). Patches of dark green serpentine may be a replacement of olivine. Analcime occurs in certain basalts within the series such as specimen 2/9 from 12 miles north of Lokitaung. Specimen 2/53 from Lokitaung Gorge shows clear copper-staining. It is a somewhat altered amygdaloidal lava conformable in the sequence, with augite and altered plagioclase tentatively identified as andesine (An_{30}), which would classify it as an andesite rather than a true basalt. This specimen was taken from a thin basalt flow underlying an intercalated layer of sandstone.

Typical of the lower basalts of the Lothidok Hills is specimen 10/9 from Muruarot. It is a fine-grained dark grey lava with rare small phenocrysts, deeply weathered along cracks to a soft red-brown alteration product. In thin section the phenocrysts are seen to be neutral coloured augite in a fine groundmass of augite, andesine-labradorite (An_{50}), magnetite and red-brown secondary iron oxide.

All the specimens examined from the outcrops of the lower basalts east and north-east of Muruanachok showed analcime in the groundmass. A typical specimen from Kanukurdio (10/38) is dark blue-green in colour, of fine grain, with glassy phenocrysts up to 0.4 cm. in length. In the thin section the majority of the phenocrysts are zoned plagioclase felspars, andesine-labradorite (An_{50}) rimmed with andesine (An_{35}). The remaining phenocrysts are enstatite-augite. The groundmass is composed of andesine-labradorite, enstatite-augite and magnetite, with a small amount of interstitial analcime.

The pyroclastics associated with the basalts consist mainly of poorly consolidated ashes with a few layers of agglomerate. The ashes are commonly reddish grey or purple in colour. Fossil plant remains, mainly tree trunks, are fairly common in certain ash horizons in the Labur range. The rather rare agglomerates are typically maroon to purple coloured rocks composed of a compact matrix with angular fragments of scoria and lava. The inclusions of lava prove to be fine-grained basalts.

In certain outcrops thin waterlain sediments occur, usually associated with ash horizons. The most important sediment horizons occur at Muruarot in the southern part of the Lothidok Hills, where they are inter-bedded with layers of purple and red ash. The sediments, while often of a very similar colour to the ashes, in most other respects compare very closely with the Turkana Grits, being mainly of quartzitic material. Only the occasional presence of volcanic material clearly distinguishes them from the true Turkana Grits. The included volcanic material is itself of interest, and in a six-foot-thick boulder bed in the intravolcanic sediments near the eastern end of the Lopi River Pass there are many rounded and semi-rounded boulders, up to six inches across, of nephelinite and nepheline syenite. Syenite and nepheline syenite fragments carried up from depth by erupting lavas are not uncommon in Kenya, having been noted in the area south of Lodwar (Dodson, Report No. 87) and in the central Rift Valley (Thompson and Dodson, 1963, p. 49, and Walsh, 1969). The degree of rounding of the Muruarot boulders points to fairly prolonged exposure to water abrasion. The point of origin of the boulders was not determined. The only other somewhat comparable rocks in the vicinity are the phonolites and nephelinites near Lodwar, which in part at least are demonstrably younger than the basalts at Muruarot.

Other intravolcanic sediments seen at Muruarot are yellow and grey sands, yellow to buff fine sandy clays and a single bed of hard, yellow, sandy limestone just over a foot thick.

During the present survey only a few scraps of mammalian fossils were found in the Muruarot sediments, but Arambourg (1943, pp. 177-180) listed the fossils found there by his expedition as follows:—

Mastodon cf. augustidens Cuv.
Aceratherium sp.
Pliohyrax championi Arambourg.
Brachyodus sp.
Listriodon jeanneli Arambourg.
Dorcatherium chappuisi Arambourg.
Antelope or Cervidae sp.

From this assemblage Arambourg dated the sediments (and therefore the lava) as Lower Miocene (Burdigalian). Deraniyagala (1951) has described a hornless rhinoceros, *Turkanatherium acutirostratus**, from Muruarot, and mentioned the finding of an artiodactyl horn core. Professor Patterson has suggested (verbal communication) that the age of the Muruarot mammalian fauna may be of later rather than earlier Miocene age, approximately comparable in this respect to the Fort Ternan (Kavirondo) fauna. Patterson found a fragment of a bovid horn core at Muruarot. This and Deraniyagala's record are practically diagnostic of an Upper Miocene age. No trace of a horned artiodactyl occurs in the earlier Miocene faunas of Kavirondo at Rusinga, Songhor, etc.

The basalt at Lotien contains several feet of dark purplish red waterlain sediments, the bulk of which is volcanic ash but which also contains semi-rounded quartz gravel with individual fragments up to four inches across, and a one-foot band of fine black shale. North of Lotien, in the banks of the Kalakol River, is a ten-foot layer of greenish-brown sediment which consists of roughly equal amounts of ash and fine quartzose material.

Geodes ranging in size from a fraction of an inch to several feet across are found in the basalts, particularly at lower levels. Such geodes consist of calcite, quartz and semi-crystalline or amorphous silica minerals such as agate and chalcedony. Calcite and silica minerals also occur as nodules and veinlets, and their occurrence, together with the characteristic deep weathering of the basalt, is thought to be due largely to submersion beneath the lake in which the intravolcanic sediments were deposited.

* Arambourg (1959, p. 74) states that *Turkanatherium* appears to be synonymous with *Aceratherium*.

(2) *Phonolites and Nephelinites*

The rocks mapped in this division include phonolites, phonolitic agglomerates, nephelinites, olivine nephelinites and microfoyaites in the form of lava flows or, more rarely, large plugs. A single exposure of tephrite is included in this division since it is considered to be a variant of the phonolitic group rather than of the basalts of the area. Dykes of similar composition are dealt with in a later chapter. In Arambourg's map (1943) the largest area of these rocks, the Muruangapoi Hills, are shown as basalts. It would appear that the discrepancy arises from Arambourg classifying the rocks under the now obsolete term of "nepheline-basalts", as contrasted to "felspar-basalts" which are now known simply as basalts.

The relatively short time available for the survey made it is impossible to cover the outcrops in sufficiently close detail to justify mapping the phonolitic rocks in separate sub-divisions, and thus to draw up an accurate succession. For the same reason it was not always possible to prove the age of the phonolitic rocks in relation to the other volcanics of the area.* The phonolitic lavas of the Muruangapoi Hills are seen to rest directly on Turkana Grits, and at the northern end of the hills overlie the lower basalt series. North of this range plugs of microfoyaite invade the lower basalts, and locally small flows rest on the basalts. However some of the small flows to be described later appear to be considerably younger than the Muruangapoi lavas.

A typical phonolite is specimen 10/5a from the Muruangapoi Hills seven miles north-west of Lodwar. It is medium grey in colour with no visible phenocrysts. In thin section it is seen to contain rare microphenocrysts of nepheline, partly altered to sodalite, and turbid anorthoclase felspar set in a fine-grained groundmass of green aegirine-augite, anorthoclase and nepheline.

South of Muruanachok, resting directly on Turkana Grits, is a sporadically exposed flow of nephelinite. Patches of pebbles derived from the grits in places overlie the lava, but this is probably due to local movement of the pebbles under sheet-wash conditions, and it is unlikely that the lava is intraformational with respect to the grits. In hand specimen (10/29) the nephelinite is of medium grain, with an off-white groundmass supporting spherical clusters 2 to 3 mm. across of greenish grey mafic minerals. In thin section the rock is seen to consist of bright green aegirine, nepheline partly replaced by sodalite, and a small amount of opaque iron ore. Some secondary calcite and an isotropic zeolite are also present.

The lowermost lava seen in the Muruangapoi Hills near Lodwar, specimen 10/30 from the Kauwalathe River, is also a nephelinite. This rock has a dark grey and buff fine-grained groundmass supporting crowded black phenocrysts up to 1 cm. in length but extremely thin in cross section, and spherical white amygdules 0.2 cm. across. The thin section shows the bulk of the phenocrysts to be pale purple-grey enstatite-augite with zoning marked by darker outer margins. Other phenocrysts are of sodalite pseudomorphing nepheline. The groundmass is of nepheline and replacive sodalite, with enstatite-augite and green aegirine-augite and small amounts of sphene and magnetite. The amygdules are of stilbite.

The third rock seen in contact with Turkana Grits is the tephrite on which Lodwar Post is built. Specimen 10/1, which is similar to that described by Mme. Jérémine (in Arambourg, 1935, p. 40) and Campbell Smith (1938, p. 523), has a fairly coarse-grained, medium grey, groundmass with large felspar phenocrysts and smaller black laths. The thin section proves the felspar phenocrysts to be andesine and the smaller phenocrysts to be a deep brown sodic amphibole, which Campbell Smith suggests is kaersutite, largely altered to magnetite, and green aegirine-augite, iron ore and a turbid felspathoid, probably nepheline. Sphene and apatite occur in trace amounts. The rock of Kotieng, west of Lokichogio, also described by Campbell Smith (1938, p. 523), is very similar to the Lodwar rock.

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* K/A dating (see Appendix) suggests that the phonolites are younger than all the basalts of the area.

The main mass of the Muruangapoi Hills appears as a series of ridges and cones, the cones closely simulating recent volcanic features (Plate I (a)). In fact the lavas are a succession of nearly horizontal sheets, deeply eroded, the cone features being formed by protective cappings of more resistant lava (Plate I (b)). The nephelenite capping Lodwar Cone (10/58) is a black coarsely porphyritic rock, which in thin section shows phenocrysts of purple-grey titanaugite with green outer zones in optical continuity with the core, poikilitic phlogopite pleochroic from orange to dark red, sphene and magnetite, in a groundmass rich in euhedral crystals of nepheline with laths and grains of green pyroxene and subhedral magnetite. The whole is stained with red-brown iron oxide. Campbell Smith (1938, p. 534) describes an identical specimen collected from the cone by Champion, and it is apparently Champion's specimen which is figured as a full page illustration in Hatch, Wells and Wells (1949, p. 323). Specimen 10/3, also from the Muruangapoi Hills, from a road cutting 12 miles north-west of Lodwar, is a coarse porphyritic rock with large phenocrysts of augite and olivine, the latter wholly replaced by iddingsite on weathered surfaces.

The phonolite exposed in the south-east of the Mogila Hills is of rather coarse grain, dark purple-grey with grey-green patches, supporting numerous small glassy phenocrysts. In thin section 1/6 the phenocrysts are of anorthoclase and the groundmass contains anorthoclase, aegirine-augite, riebeckite and red-brown iron oxide with a small amount of nepheline and secondary calcite. This phonolite appears to be conformable with the overlying rhyolite, but the relative coarseness of grain indicates that it may be a sill, and might therefore be classified as a microfoyaite or a tinguaite.

The two small isolated exposures of phonolite south of Kakuma and east of Loreng are both probably plugs. The first, specimen 9/7, is a fairly coarse brownish black rock which in thin section shows microphenocrysts of anorthoclase set in a trachytic textured groundmass of anorthoclase, green aegirine, deep purple-brown cossyrite, a yellow-brown iron mineral probably replacing amphibole, and opaque iron ore. Only a very small amount of nepheline is seen in the slide, and if this is typical of the whole rock it could be classified as a phonolitic trachyte rather than a true phonolite. The rock west of Loreng, specimen 9/6, has phenocrysts of anorthoclase in a medium-grained groundmass of anorthoclase, aegirine-augite, nepheline and iron ore. The lava at Lomil, south-west of Muruanachok, is similar but of rather finer grain.

East and north-east of Muruanachok is a series of plugs, locally with minor lava flows, many of which are almost circular in outline, which have been forced upwards through the lower basalts. The basalts at the contacts have been turned upwards by the intrusions and in aerial photographs appear as concentric ridges surrounding the "bullseyes" of the plugs. The rock of the plugs is distinctive in having a much lighter colour than any of the phonolites already described, being of various shades of grey and greenish grey, occasionally buff and light red, the colour varying from place to place in the same outcrop. The rock of Lotien Hill, 10/19, has a trachytic texture and is composed of anorthoclase, aegirine-augite and magnetite with interstitial nepheline and secondary calcite. Specimen 10/49 from a plug near Kanukurdio has rare glassy phenocrysts of anorthoclase in a medium-grained groundmass of anorthoclase, aegirine-augite, riebeckite and cossyrite, again with interstitial nepheline. The relative coarseness of grain of these rocks and their occurrence as plugs would classify them as microfoyaites. Similar microfoyaite plugs have been described by Dodson in the area south of Lodwar (Dodson, Report No. 87) and by Joubert (1966) in the Loperot area of south Turkana. Associated with some of these plugs are thin flows of phonolite often interspersed with light brown or red phonolitic agglomerates. A similar agglomerate occurs near the road just west of Kanukurdio, though in this case no plug is visible nearby. The thin section of this agglomerate, 10/36, shows angular fragments of anorthoclase and a few semi-rounded patches of very fine-grained lava set in a glassy

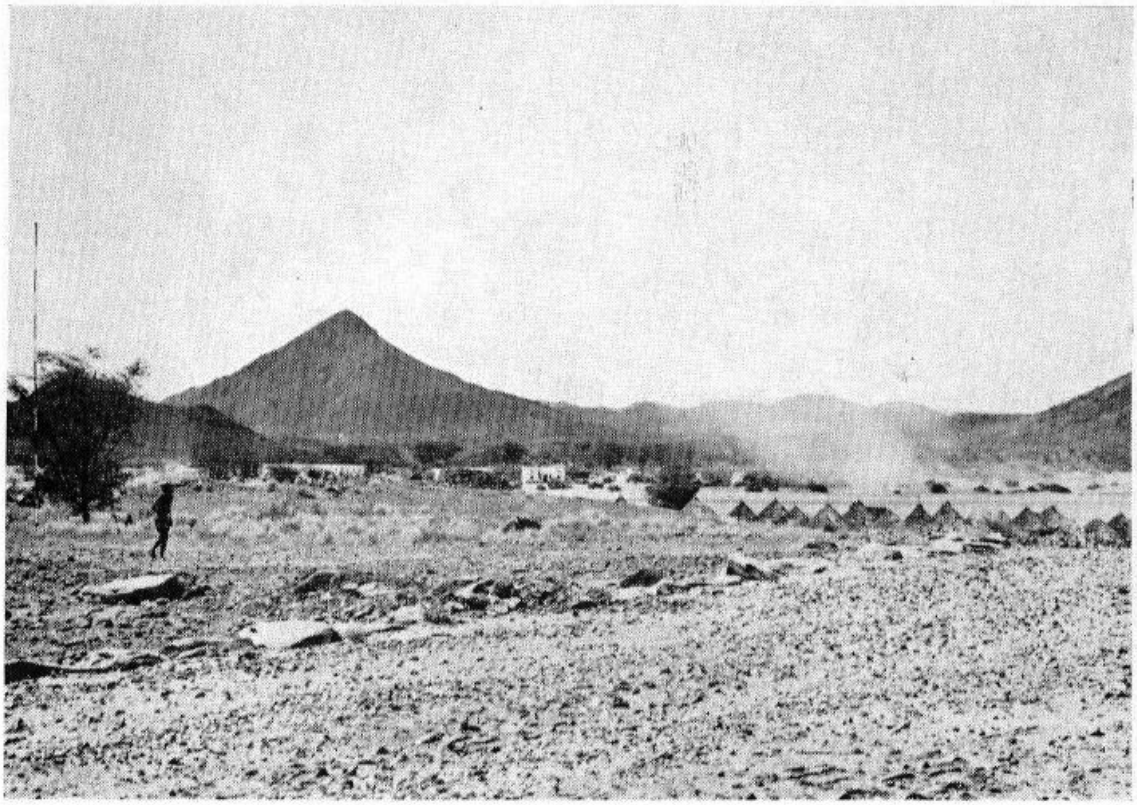


Plate Ia—Lodwar Cone from the township

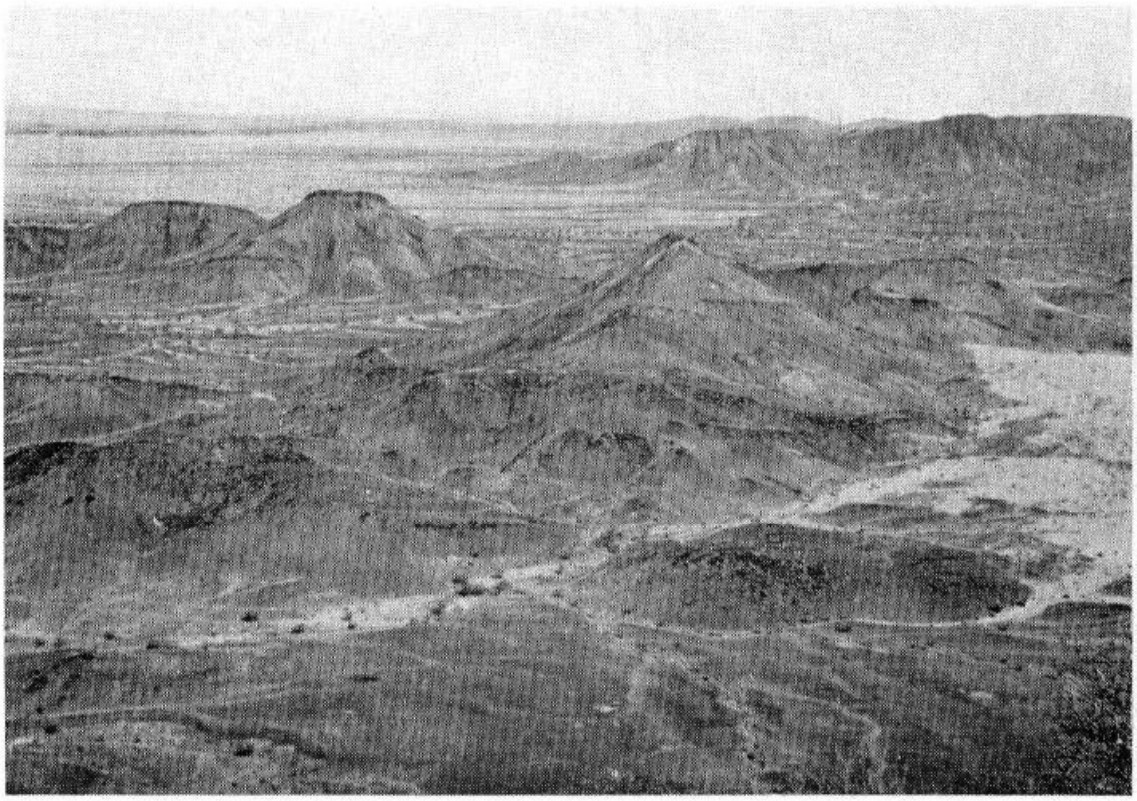


Plate Ib—Muruangapoi Hills looking north-west from Lodwar Cone



Plate IIa—Lake sediments of the 220-foot level exposed in the banks of the Turkwel River at Kangatotha

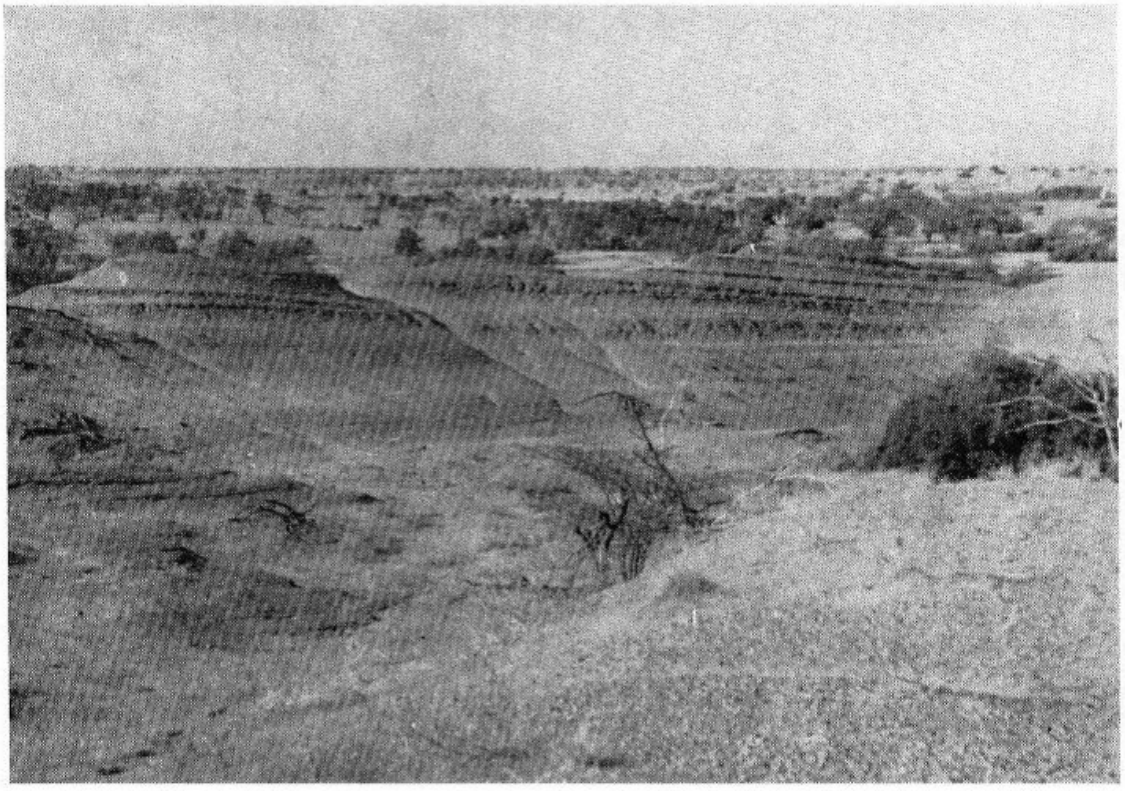


Plate IIb—Lake sediments of the 220-level five miles north of Kangatotha



Plate IVa—Fault breccia in rhyolite north of Lokichogio

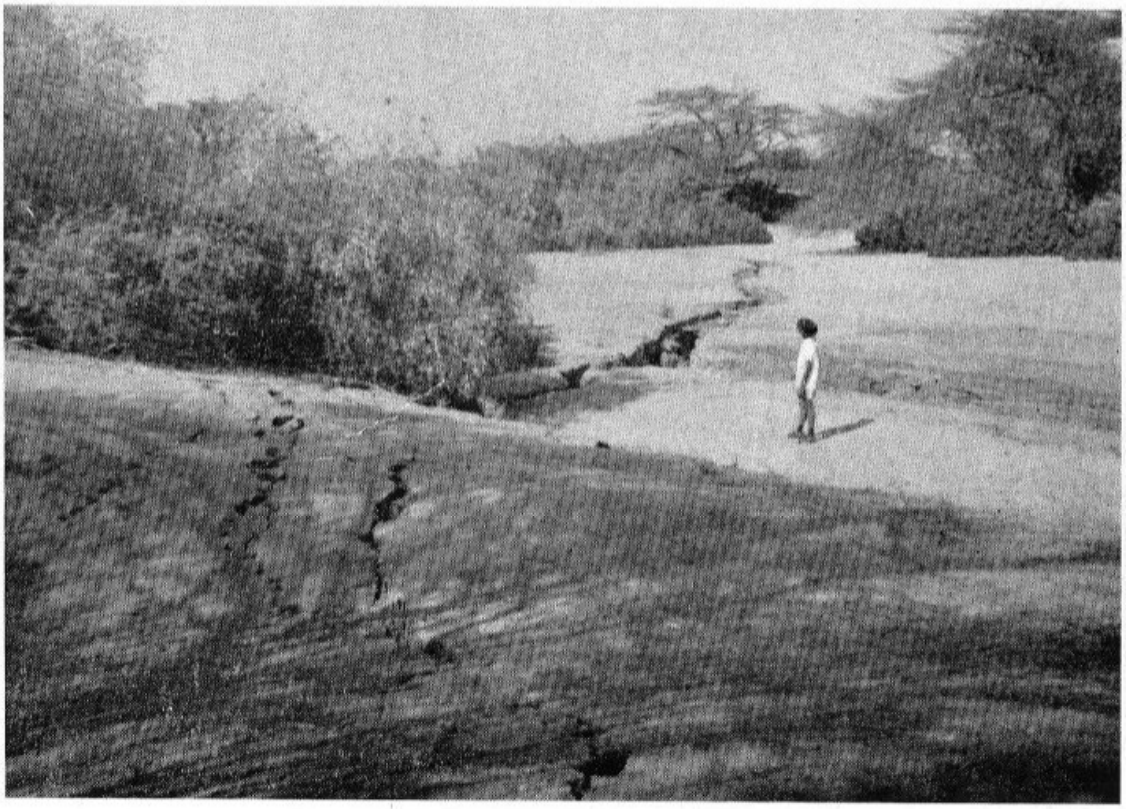


Plate IVb—Fissure caused by earth movements at Kangatotha



Plate IIIa—The landward side of the spit at Ferguson's Gulf, showing wind-blown sand masking old lake beds

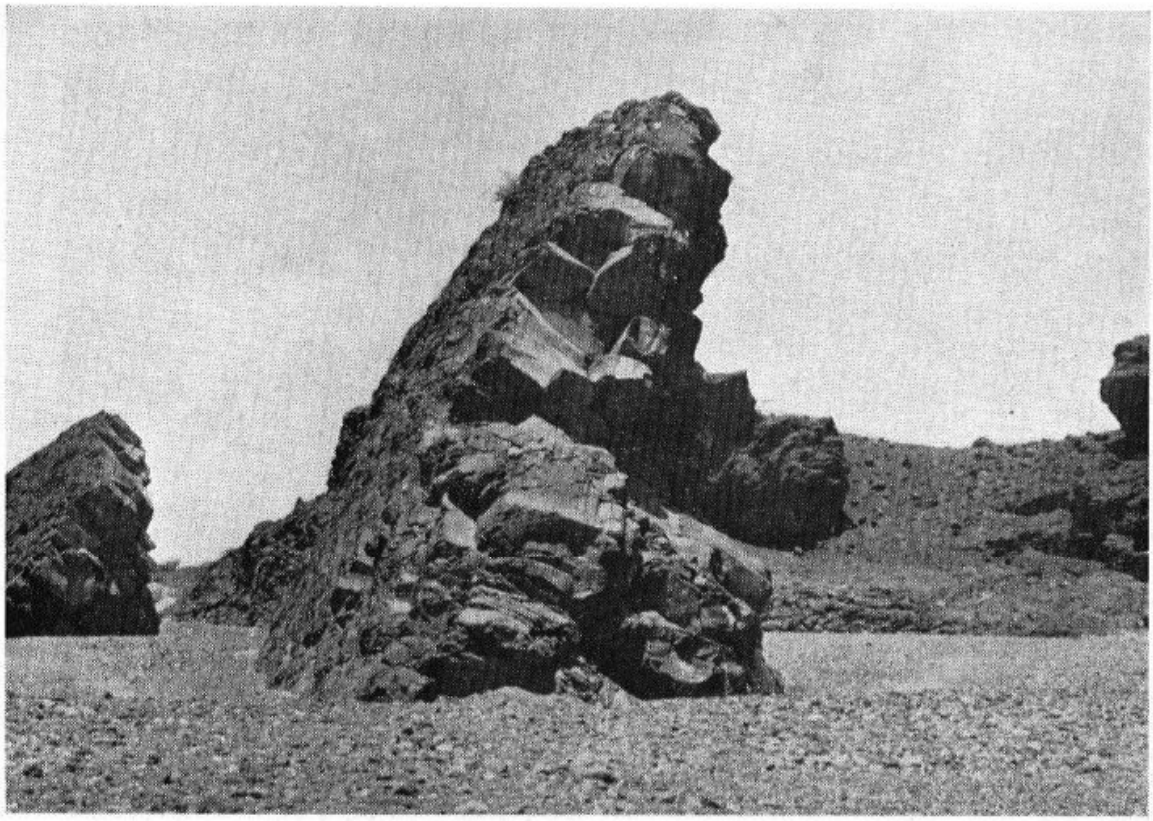


Plate IIIb—Fault blocks of basalt over 50 feet high in the Kalakol River south-west of Ferguson's Gulf

iron-stained matrix. A partial chemical analysis of the rock (Anal. J. Furst, Mines and Geological Dept., Nairobi) showed a silica percentage of 58.5, confirming its phonolitic composition.

The last phonolite to be described occurs as an elongated outcrop oriented north-west to south-east at Muruanachok. It takes the form of a sheet of huge semi-rounded boulders, completely free of vegetation, raised 15 to 20 ft. above the surrounding country. At a few localities along the margin of the outcrop the boulders are seen resting on an eroded surface of rhyolite, and this phonolite was probably extruded from a dyke of Pleistocene or even Recent age. In hand specimen 10/35 the rock is non-porphyritic and of a medium grey colour. The thin section shows a fine-grained equigranular mixture of green aegirine-augite, rare blue-green riebeckite, anorthoclase and nepheline.

(3) *Olivine Basalts*

Widespread in the western part of the area and at intervals in the eastern part are outcrops of olivine basalts, generally coarsely porphyritic. The relatively high resistance to weathering of these rocks, as compared with the older augite and analcime basalts, gives rise to a much more rugged and steep-sided topography. Regular and well-marked jointing is locally a feature of the olivine basalts. In the gorge of the Topernawi River near Lake Rudolf, north of Kalimapus, vertical columnar hexagonal jointing in the rock gives rise to vertical cliffs often exceeding 100 feet in height, individual columns reaching four feet across. Elsewhere in the walls of the gorge the hexagonal columns are disposed horizontally, and at one place are seen radiating outwards and upwards from a solid central core, simulating a child's picture of the rising sun.

The olivine basalt exposed at Muruarot is clearly discordant on the lower basalt, the latter having been eroded and tilted to the west before emplacement of the olivine-bearing lava. Where the olivine basalts are overlain by rhyolites the contact everywhere appears to be conformable.

About four miles north-west of Lokitaung and locally at Katerongoi, east of Lokwanamur, there is some intercalation of thin conformable rhyolite flows in the topmost part of the olivine basalt sequence. However, in the Kangamajoj Hills north of Muruanachok similar conformable intercalations are seen between the rhyolites and the underlying lower basalt sequence, in an area where olivine basalts do not appear. The probable explanation is that the olivine basalts represent a locally developed basic phase occurring towards the end of the extrusion of the older basalt series, and that olivine basalts were locally being extruded on an already eroded surface of the lower basalts (as at Muruarot) whilst elsewhere (as at Kangamajoj) extrusion of the lower basalt lava was still continuing. Thus at the start of rhyolite emplacement both the lower augite basalts and the olivine basalts were being extruded, though at different and widely spaced localities. Nowhere was any evidence seen of augite basalt flows overlying olivine basalts.

The olivine basalts vary little from place to place in the area. They are of medium to coarse texture, dark blue-grey or black in colour, with phenocrysts up to 0.5 cm. across of pyroxene, olivine and plagioclase. Specimen 2/11 from Kalin is typical. In thin section it is seen to be a medium-grained basaltic textured rock composed of a groundmass of plagioclase, augite and iron ore with phenocrysts of augite, euhedral to subhedral olivine, and labradorite (An_{51}). Rare sub-spherical vesicles are infilled with zeolites. Specimens collected in the Lothidok Hills (10/7 and 10/12a) compare very closely with the above, the labradorite in these two specimens

being An_{57} and An_{55} respectively. In the latter specimen much of the olivine shows partial alteration to iddingsite. Mme Jérémine (in Arambourg, 1935, p. 43) gives a chemical analysis of an olivine basalt from the Lothidok Hills, which she classified as an oceanite-ankaramite, as follows:—

	Per cent	*Norm*	
SiO_2	43·26	or	3·34
Al_2O_3	4·55	ab	7·34
Fe_2O_3	5·34	an	6·67
FeO	9·44	di	35·10
MnO	0·19	ol	33·55
MgO	23·58	mt	7·66
CaO	8·18	il	4·26
Na_2O	0·85	ap	0·34
K_2O	0·63		
TiO_2	2·18		
P_2O_5	0·17		
H_2O+	1·75		
H_2O-	0·43		
	100·55		

In the Ngimoruitai Hills in the west of the area the basalt, specimen 9/5, contains phenocrysts of labradorite (An_{60}), olivine, augite (with a large 2V) and enstatite-augite (with a small 2V). Both pyroxenes were also found as phenocrysts in the Mogila Hills in the north-west (specimen 1/7), again with olivine and labradorite. Both pyroxenes in the latter specimen show alteration to green and yellow serpentine, and the groundmass also contains secondary green serpentine and chlorite.

One of the rare exposures of olivine basalt which is locally without visible phenocrysts is that in the gorge of the Topernawi River, mentioned above. Specimen 10/51 from that locality shows in thin section a coarse ophitic groundmass of labradorite (An_{55}), pale purple-grey augite, altered olivine and iron ore, with ragged microphenocrysts of the same minerals. Secondary serpentine minerals also occur in the slide.

Geodes and veins of calcite and quartz which are so common in the lower basalts were found in the olivine basalts only at a few scattered localities near Lokichogio, and where found such specimens are few and small.

Fourteen miles south of Kakuma and five miles south-west of the Kaliou Pass, a river section shows the only known sediment associated with the olivine basalts. Up to seven feet of well-bedded, fine-grained, white and yellow sandstone (specimen 9/4) is seen underlying olivine basalt, with a discontinuous bole layer separating the two. The contact between the sediment and the overlying lava is apparently conformable, but since the base of the sediment is buried by river alluvium it is not certain whether the sediment occurs in the basalt or underlies it. No fossils occur in the exposure.

Similar olivine basalts have been mapped to the south of the present area. Those south of Muruasigar (Fairburn and Matheson, Report No. 85) are demonstrably of the same series, and those in the Kamutile Hills south of the Lothidok range (Dodson, Report No. 87) are considered by the writers to be of the same series.

(4) *Rhyolites*

Rhyolites are found capping all the major mountain ranges of the area with the exception of the south-east corner, where there is no evidence to suggest that they ever occurred.

The acid lavas tend to be more resistant to local conditions of erosion, with the result that they often form protective caps on hills of basalt and pyroclastics. Fault scarps in rhyolitic lavas tend to be vertical or near-vertical due to the breaking away of sheets of rock at strong vertical joint planes.

It has been noted earlier that in the area south of the western half of the map Fairburn and Matheson were able to divide the rhyolites into two separate series, but that in the present map and report they are treated as a single unit.

The rhyolites mapped are mostly sodic varieties, sometimes holocrystalline lavas but more often with a glassy or devitrified groundmass and often of pyroclastic origin, both coarse agglomerates and fine-grained tuffs. Minor intercalations of pantelleritic trachyte occur locally. In hand specimens the rhyolites are always of a light colour, in shades of buff, yellow or pale grey, sometimes stained red-brown by iron oxides.

Alteration of the lavas in the form of iron ore replacement of much or all of the coloured minerals is widespread, but a few of the specimens collected were relatively unaltered. One such, No. 1/1, from the west side of Songot (Zingout) has a pale grey groundmass with numerous white phenocrysts averaging 0.3 cm. in length. Microscopic examination shows the phenocrysts to be sanidine, though unusually cloudy, with lesser ragged phenocrysts of kataphorite, pleochroic from green to mauvish brown. The groundmass is of sanidine, quartz, kataphorite and a small amount of deep brown cossyrite. The precise classification of this rock would therefore be pantellerite.

Specimen 9/9 from a small outlier south-east of Oropoi Police Post is a pale grey comendite, with phenocrysts of glassy sanidine in a groundmass of sanidine, quartz and riebeckite, the latter pleochroic in shades of green and blue. A pale purple-red lava from below the peak of Muruasigar (10/25) is very similar in thin section except that the coloured minerals of the groundmass are completely altered to a black or dark chocolate brown iron mineral in mossy aggregates. Campbell Smith (1938, p. 516) concludes that the iron ore was originally riebeckite, and therefore this rock, too, could be classed as an altered comendite. Lavas from the Kakuma area (9/1) and west of the Moruerith Hills (2/15) are very similar to the Muruasigar lava except that in both euhedral and subhedral quartz phenocrysts are common.

Several of the specimens collected appear in hand specimen to be similar to the iron-stained lavas just described, but when examined under the microscope the apparent phenocrysts of sanidine are seen to be only rarely euhedral, being usually fragments of larger crystals, set in an iron-stained matrix of such fine grain that individual minerals can seldom be recognized. Such rocks were collected from Kolopusia north of Kakuma (9/3), and from the Moruerith Hills (2/35). Fairburn and Matheson (Report No. 85) suggest that such rocks are not true lava flows, and can best be explained as being emplaced by ignimbrites or *nuées ardentes*, clouds of intensely hot, discrete fragments of viscous magma in which each fragment rapidly and continuously emits gases. The gases cushion the fragments so that the clouds can move rapidly outwards in the absence of any friction effects between individual particles. Such flows, which may cover large areas as flat-topped deposits, can become compacted both by welding initiated by their own high temperature after the release of the bulk of their gas, and by compaction by overlying deposits. Grange (1934) quotes rhyolite sheets of similar origin which cover many tens of square miles in New Zealand.

All of the rhyolitic lavas were seen locally to include bedded pyroclastic horizons, often tens of feet thick, composed of angular fragments of pumiceous tuff and (more seldom) rhyolitic lava cemented in a hard, extremely fine-grained matrix. The angular fragments of the agglomerates generally average 0.5 to 1.0 cm. across, though in specimen 1/2 from west Songot such fragments sometimes exceed 3.0 cm. Similar but much coarser rocks were proved to be fault breccias, and are described later.

Several such agglomerates whose identity could not be determined with certainty under the microscope were partially analysed for their silica content, and thus proved to be rhyolitic. These specimens were:—

No.	*Locality*	SiO_2 *Per Cent*
1/2	West Songot	67.8
9/8	South of Kakuma	68.7
10/32	Muruanachok	71.7
10/45	Nakalale	73.6
10/46	Pelekech	74.4

Anal. J. Furst

Campbell Smith (1938, pp. 518-519) lists several localities in northern Turkana from which Champion collected pantelleritic trachytes associated with rhyolitic rocks. These rocks are generally similar in appearance to the rhyolites, and only to be distinguished from them in thin section. In the present survey only one specimen taken from the rhyolite group proved to be a pantelleritic trachyte, No. 10/47 from Pelekech. In hand specimen it is of pale grey colour with scattered off-white phenocrysts. The phenocrysts are ragged grains of cloudy anorthoclase set in an altered trachytic groundmass of anorthoclase and iron ore which has replaced the original coloured minerals. Quartz occurs only in trace amounts. Campbell Smith records aegirine and sodic amphiboles (kataphorite and a member of the riebeckite-arfvedsonite series) in Champion's specimens.

Nowhere in the area is there any sign of craters from which the rhyolites were extruded, though Fairburn and Matheson record two possible rhyolite craters to the south-west of Muruasigar: Kalolokwel and Moruangiliop. The bulk of the rhyolites appear to have been extruded from fissures, now seen as dykes.

At Kaimothia in the Sudan north of the Lokwanamur Hills a forest of fossil trees was reported by Champion (1937, p. 114). The trees were rooted in a red tuff, part of the same rhyolite series already described, and were overwhelmed by a later lava flow. Fuchs (1939, p. 241) reported quantities of fossil wood in the rhyolites of the Lorienatom range east of Kaimothia. These trees, like those in the Turkana Grits already described, proved to be *Dryoxylon* sp., and it therefore seems likely that the rhyolitic succession is also of Miocene age, or Lower Pliocene.

(5) *Andesites*

The major outcrops of andesites in the south-west of the map area are all clearly of one age, being intercalated in the rhyolites, but the ages of the few small andesite outcrops elsewhere in the area are doubtful, and are discussed later.

The andesites of the south-west are the thinned-out remnants of a major group centred to the south, described at length by Fairburn and Matheson (Report No. 85). In hand specimen they are indistinguishable from the bulk of the porphyritic olivine basalts which underlie the rhyolites, and distinction between the two groups can be made only from thin sections. Insufficient specimens were collected during the present survey to ensure completely accurate demarcation of the two types, and some errors may be present on the map in the south-west. The andesites there are all porphyritic pyroxene andesites, melanocratic fine-grained rocks with black or green phenocrysts up to 1.0 cm. long. In thin section the phenocrysts are of very pale purple-brown, rarely pale green, augite, with a few phenocrysts of brown hornblende and even fewer of andesine. In the area to the south Fairburn and Matheson record lava flows in the same group in which andesine phenocrysts greatly exceed pyroxene in number. The groundmass of the andesites is usually of very fine grain, but where distinguishable

the only primary minerals present are plagioclase varying in composition from oligoclase to andesine, almost colourless augite, and iron ore. Secondary minerals present are serpentine and chlorite, which locally appear to have replaced olivine, calcite and rare zeolites. Fairburn and Matheson also record minor intercalations of trachyandesite and trachyte in the upper part of the group.

The occurrence of andesite which is clearly a local variation of the augite basalt series in Lokitaung Gorge has already been mentioned (p. 15). Other andesitic lavas from the lower basalt series were collected at Muruarot in the Lothidok Hills (10/12) and Lotien, north of Muruangapoi (10/20). The exposure of andesite shown on the map in the Labur Hills eight miles north of Lokitaung, specimen 2/31, is very different in appearance from the lower basalts near by, being of coarse grain, of medium grey colour with small white and black phenocrysts. In thin section the phenocrysts are seen to be ragged grains of cloudy andesine (An_{38}) and augite, pale brown with a darkening of colour outward from the centre. The groundmass has a coarse grained sub-ophitic interlocking texture, and consists of augite, andesine and iron ore, with a good deal of secondary chlorite. The coarseness of grain suggests that this rock may be a sill, and therefore younger than both the underlying lower basalt and the overlying rhyolite.

The origin of the andesite (2/12) exposed at Kalin, north-west of Lokitaung, is again not evident. The rock is a compact, dark blue-grey lava with small glassy phenocrysts of andesine (An_{45}) locally altered to a calcite aggregate, and smaller phenocrysts of magnetite set in a fine-grained micro-trachytic groundmass of plagioclase and opaque iron ore, with secondary calcite and yellow iron oxide.

4. Major Intrusions

Only one major intrusion is exposed in the northern Turkana area, at Nakwazuro in the north of the Muruanachok Hills. It is seen as a single faulted exposure four miles by three miles in area, cutting Basement System rocks and overlain by Tertiary volcanics. Its age therefore lies anywhere between Precambrian and Miocene, though a degree of granitization of the rock suggests an age nearer the former. In hand specimen 10/37 the rock is coarsely crystalline, speckled white and grey-green, with a Shand colour index of 50. In thin section the coloured mineral is seen to be pale blue-green hornblende in ophitic relationship to coarsely perthitic andesine (An_{45}) which is locally altered to microcline with trace amounts of quartz. The rock can thus be classified as a diorite which has undergone some degree of granitization.

5. Minor Intrusions

The area includes numerous minor intrusions. Many are obviously related to lava bodies as feeder dykes, but some may be older than the volcanic rocks of the area, and a few are clearly younger than the main volcanic phase. Dyke swarms tend to follow an approximate north-south alignment following the predominant structural trend.

Pegmatites.—Stringers of auto-pegmatite are ubiquitous in the Basement System rocks, and are particularly strongly developed in the more acid gneisses. A typical specimen, 2/28 from Labur, shows a coarse aggregate of white quartz and pink and white felspar with occasional streaks of small flakes of black mica. Elsewhere muscovite was found, never more than a few millimetres across, and more rarely garnet. The thin section of the Labur specimen shows the felspars to be oligoclase and microcline, the latter somewhat sericitized, and the mica to be a chloritized biotite.

Basaltic Dykes.—In the northern part of the Labur range a swarm of teschenite dykes with a north-north-easterly orientation form a series of narrow ridges rising above the somewhat weathered Basement System rocks of that region. The dyke rocks are dark grey and of medium to coarse texture. Specimen 2/50, a typical

example, has an interlocking xenomorphic texture comprising laths of labradorite with olivine, partly replaced by serpentine, magnetite and rare analcime. Apatite is an accessory. Another example of teschenite occurs north of the Lokitaung Gorge two miles west of the township. This rock, specimen 2/64, shows phenocrysts of augite, biotite and brown hornblende, the latter surrounded by a reaction rim, in a sub-ophitic groundmass of andesine and analcime with specks of pyroxene, olivine and reddish brown biotite, plus a high proportion of opaque iron ore grains. This rock compares very closely with that from the mouth of the gorge described by Campbell Smith (1938, p. 512).

All of the specimens of dyke rocks taken from the Lokitaung Gorge, cutting both Turkana Grits and the lower basalt series, proved to be of andesitic composition. Specimen 2/3 is typical, a compact bluish grey rock of medium to coarse ophitic texture, with andesine (An_{40}), iron ore and augite. Most of the ferromagnesian minerals are highly altered, and the rock shows abundant evidence of secondary calcification. Specimen 2/54 is very similar, but in addition shows secondary greenish chlorite and a small degree of copper staining.

On the south-western slopes of Lokwanamur a narrow basaltic dyke is believed to be contemporaneous with the younger olivine basalts. This specimen, 2/49, is a porphyritic basaltic-textured rock composed of a fine-grained matrix of plagioclase, olivine, augite and ilmenite with phenocrysts of idiomorphic olivine and subhedral labradorite.

Phonolitic and Nephelinitic Dykes.—The major dyke swarm at Muruanachok, which consists of many more dykes than it was possible to show on the map, appears to be wholly of phonolitic rocks. Specimen 10/24, which is typical of the porphyritic variety, contains phenocrysts of anorthoclase and deep brown hornblende in a fairly coarse groundmass of anorthoclase, green aegirine-augite and nepheline. Equally abundant are dykes of very fine grained non-porphyritic rock, as specimen 10/23, which under the microscope shows only anorthoclase and iron ore which has wholly replaced the original ferromagnesians, and a small amount of interstitial nepheline. Mme. Jérémine (in Arambourg, 1935, pp. 25 and 33) described a dyke from the southern end of this swarm which is composed of microlites of felspar and ragged aggregates of aegirine with rare grains of arfvedsonite and cossyrite. Disseminated prismatic crystals of nepheline enclose other minerals of the rock and are therefore of later formation. The chemical composition of this rock is given as:—

	Per cent		*Norm*
SiO_2	60·16	or	27·80
Al_2O_3	15·46	ab	43·60
Fe_2O_3	5·78	ne	5·61
FeO	2·08	ae	14·78
MnO	0·22	di	4·68
MgO	0·07	ol	0·78
CaO	1·06	mt	0·93
Na_2O	8·34	il	0·46
K_2O	4·68		
TiO_2	0·22		
P_2O_5	Tr.		
H_2O+	1·37		
H_2O-	0·33		
Cl	0·08		
SO_3	0·07		
	99·92		

Mme. Jérémine also records solvsbergites, microsyenites and phonolitic trachytes from Muruanachok.

Two ring-dykes of phonolite occur close to Muruanachok. That to the south-east, which cuts and encloses Turkana Grits, is some 5,000 ft. across at its widest part, and is a fairly coarse-grained, brownish grey, non-porphyritic rock. The dyke rock occurs as walls of tumbled boulders which rise as much as 50 ft. above the grits, but nowhere could the true thickness of the dyke nor its inclination be determined. The thin section of this phonolite, 10/27, shows a pale green pyroxene, probably aegirine-augite, anorthoclase, iron ore and interstitial nepheline.

The ring-dyke at Nakalale north-east of Muruanachok is surrounded by Recent sandy soils, though occasional rounded pebbles in the soil suggest that the bedrock is again Turkana Grit. The centre of the ring is of a pale buff and red agglomerate (specimen 10/45) with a silica content of 73.16 per cent—comparable with the rhyolitic agglomerates and tuffs mentioned earlier. Since straight, thin dykes and stringers of the wall rock invade the agglomerate it appears that the ring dyke is younger than the main volcanic succession. This ring is about 3,000 ft. across at its widest part, and locally the thickness of the main dyke is seen to exceed 200 ft. but the contacts were nowhere sufficiently clear to enable accurate measurements to be taken. The dyke rock, specimen 10/44, is of fairly coarse grain, off-white in colour, with dendritic clusters of greenish grey mafic minerals. The thin section shows microphenocrysts of anorthoclase and altered nepheline in a felted groundmass of anorthoclase with mossy aggregates of aegirine-augite, riebeckite and cossyrite, and interstitial nepheline and analcime.

The dyke seven miles north-east of Lodwar outcrops as scattered boulders and cobbles capping a gentle ridge in sandy soil. The bedrock is not exposed but is probably of the Turkana Grit series. The rock of the dyke (10/5b) is a porphyritic, fairly coarse-grained grey-green nephelinite. In thin section the phenocrysts are recognizable as nepheline, partly altered to sodalite and calcite, and green aegirine-augite, in a granular groundmass of aegirine-augite and idiomorphic nepheline, with rare magnetite. A few wisps of phlogopite appear to be of secondary origin, as is the green chlorite which is scattered throughout the slide.

Other phonolite dykes were recorded south of Lokitaung (cutting basalt), at the eastern foot of Muruasigar (cutting rhyolite) and in the Lokwanamur Hills (also cutting rhyolite). The last two are therefore younger than the phonolitic lavas of the area.

Rhyolitic Dykes.—A major swarm of rhyolite dykes invades olivine basalt 16 miles south-south-west of Lokitaung. The rhyolite of the dykes bears close resemblance to the rhyolite of the flows making up the greater part of the nearby Moruerith Hills, but the dyke rock is deeply weathered and a typical thin section, 2/41, shows only altered felspar phenocrysts in a fine-felted groundmass of felspar, quartz and iron ore, with a good deal of secondary calcite. Two smaller rhyolitic dyke swarms in the north-east, south-east of Katerongoi and north of Kakelai, are very similar in appearance, and again probably mark feeders of the nearby rhyolite flows. The only other rhyolite dyke found during the survey crosses the main road to Kakuma where it passes north-west of Muruanachok. The dyke averages 250 ft. in width. The altered rock is again recognizable only by its resemblance in hand specimen to the rhyolite lavas.

Limestone.—Three occurrences of limestone which have the form and appearance of dykes are included here for convenience. The first two, 14 miles south of Lokichogio (specimen 1/4) and three miles west of Lokichogio (specimen 1/5) are both exposed as dykes two to three feet in width and several hundreds of feet long, occasionally branching, cutting olivine basalts. They are coarsely crystalline, individual crystals sometimes exceeding 1.0 cm. across, and in hand specimen are indistinguishable from the crystalline limestones of the Basement System. In thin section they are seen to consist mainly of coarsely crystalline calcite, with only minor amounts of amorphous

carbonate which occurs as streaks and veinlets. Quartz and red-brown iron oxide both occur in trace amounts. A volcanic origin (carbonatite) was at first suspected, but no trace of radioactivity could be found, and it is considered that they were formed from local concentrations of calcium carbonate in or developed from the enclosing basalt which was subjected to later pressure and probably heat to give them their coarsely crystalline texture.

The third occurrence is west of Muruarot in the Lothidok Hills, and forms a ridge about 40 ft. high of very fine-grained white limestone with no trace of fossils. The thin section 10/10 shows only a very fine-grained microspherulitic aggregate of carbonate. Fuchs (1939, p. 272) tested specimens from this outcrop and obtained a considerable precipitate of magnesium oxalate crystals. Staining tests showed a few calcite crystals set in the dolomitic matrix. Fuchs concluded (and the present authors agree) that the limestone is a calc-tufa precipitated from thermal waters associated with the earth movements and vulcanicity of the area.

6. Pleistocene to Recent Lake Sediments

Sediments of the Lake Rudolf basin have been described by Arambourg (1933, 1935, 1943 and 1947), Fuchs (1939) and more recently by Dodson (1963, pp. 36 to 39). They comprise a series of lacustrine deposits dating from the Pleistocene and continuing into the Recent period, and occur as platforms stepping up from the present-day lake shoreline at 1,230 ft. to deposits at altitudes in excess of 300 feet above the shoreline. In the area between the Labur Hills and the lake, platform-like terraces were recognized at the following altitudes: 1,240 ft. 1,280 ft., 1,300 ft., 1,330 ft., 1,350 ft., 1,370 ft., 1,410 ft., 1,450 ft., 1,530 ft., 1,560 ft., and (possibly) 1,700 ft. Near the mouth of the Topernawi River the old lake beds are first met, traversing eastwards. at 1,450 ft., and thence fall gradually, without recognizable steps, to 1,310 ft. where they are overlain by modern sandy alluvium and dunes. A few miles farther south, on the eastern flank of Kalimapus, the lowest level at which the older lake beds are recognizable is 1,390 ft., and the surface rises in less than three-quarters of a mile to its highest point at 1,530 ft. At Kabua, in the Kalokol River, bedded lake sediments dipping at 1° to the east occur between 1,330 and 1,370 ft. South of that point bedded lake sediments are found only between 1,425 and 1,460 ft. (with the exception of the spit at Ferguson's Gulf, to be discussed later) and all are apparently of the 1,450 ft. (+220 ft.) level.

Theoretically the upper lake levels are likely to be the oldest sediments, pre-existing deposits laid down during earlier water-level flunctuations having been removed during the advance of the lake to maximum height. Actually there is a strong possibility that most of the lower beds identified may be older than the uppermost sediments, their continuing presence being due to the protection and resistance afforded by dense rocky shoreline deposits.

The following is a generalized description of the sediments exposed east of Labur Mountain. The sediments along the lakeshore include sands, littoral gravels and locally compact buff-coloured clays. The 10-foot level (i.e. at 1,240 ft., 10 feet above the present lake level) is of Recent age, and probably represents a beach level only tens of years old. The sediments consist of coarse- and fine-textured grey sands with abundant fish, reptile and less common mammal remains.

At certain localities of the next higher terrace, the 50-foot level, flaggy calcareous grits of the Turkana Grits series are preserved, lake sediments having been deposited around and over the older sediments. The predominant sediment of the level is a pale mauve clay, weathering to yellow. A few fragments of fossil bone and somewhat indurated mollusc shells have been preserved. Large nodular growths of secondary limestone resembling cauliflower heads are patchily developed, sometimes in fairly dense accumulations. A single fragment of meerschaum (specimen 2/66) was

discovered on the upper surface of these sediments a few hundred yards north of the Lokitaung-Lake Rudolf track. It appears to be of good quality but is less than two inches long. A cursory search for other pieces of meerschaum was unsuccessful, but detailed prospecting may reveal workable quantities of the material.

The 70-foot level sediments consist of alternating layers of coarse-textured black sands, pale-coloured clays and fine buff-coloured sands. Fossil remains are rare.

The overlying sediments form a distinct terrace at approximately 1,350 ft., 120 feet above the present level of the lake. A less obvious terrace at the 110-foot level is considered to be the result of a minor recession of the lake. The 120-foot level sediments consist of diatomaceous clays and fine powdery silts; nodular limestones are developed in the silts. Fossils are fairly abundant in these sediments, the most common types being fish vertebrae of *Lates* sp. (Nile Perch) and *Clarias* sp. (Catfish), and molluscs such as *Melanoidia tuberculata*. In an eroded depression due east of Lokitaung Gorge boulders of fossiliferous secondary limestone were found in similar diatomaceous clays. The fossils contained in the limestone were identified by G. Isaac of the National Museum, Nairobi, as the remains of turtles, crocodiles and mammals. Slabs of selenite are scattered about the surface and occur in the upper part of the 120-foot level deposits.

The 140-foot level sediments consist mainly of fine-textured sands and gravels with rare diatomaceous partings.

The most highly fossilliferous sediments of the series are those at the 180-foot and 220-foot levels. Like the lacustrine sediments of other levels the 180-foot level sediments exhibit lateral lithological variations between different exposures. They consist mainly of fine-textured sands and diatomaceous clays, and locally include horizons of shelly limestone. The 180-foot level sediments are well exposed at the base of Labur Mountain west of Todenyang Police Post. At this locality they are tilted gently to the east-north-east as a result of rejuvenation along the pre-existing north-south fault lines. The exposed section at that point consists of fine-textured grey sands with two shelly limestone horizons approximately six inches thick. The limestones are comprised of fossils of *Melania tuberculata, Corbicula fluminalis* and *Parreysia bakeri*. In the sands *Mutela truncata* is abundant. The freshwater oyster *Aetheria elliptica* occurs in the upper part of the deposits.

The 220-foot level sediments form the most distinctive and widespread terrace of the lake beds. They are characterized by an abundance of the oyster *Aetheria elliptica* which locally are concentrated in beds exceeding a foot thick. The presence of abundant oyster shells is characteristic of the 220-foot level in other parts of Turkana (Dodson, 1963, p. 37). The beds of this level near Labur consist of a succession of shelly limestones, yellow to buff clays and sandstones with narrow diatomaceous partings.

The 300-foot and 330-foot beds are composed mainly of coarse sands and consolidated pebble beds, locally with fine-textured sands. The pebbles are nearly all of lava, and vary from sub-rounded to well-rounded forms, suggesting a littoral environment. About five miles south of the mouth of Lokitaung Gorge deposits of the 300-foot level include a horizon of shelly limestone about three feet thick. The limestone is composed almost entirely of *Melania tuberculata*.

At approximately 470 feet above the present lake level the presence of concordant platforms and a slight linear discoloration of the Basement System rocks in the Labur area, very distinctive when seen from an aircraft, suggest an advance of the lake to that altitude. Within the Labur Mountains, however, the rugged topography would discourage the preservation of sediments which might have been deposited at that altitude. The existence of former lake level deposits at altitudes of this magnitude were noted in the area south of Lodwar by Dodson (Report No. 87). Fuchs (1939,

p. 247 and fig. 24) noted beaches at the foot of the Lodwar Hills which he ascribed to the 330-foot level. The location of Fuchs' fig. 24 was found two miles north-east of Lodwar Post, and by the writer's calculations the altitude of the beach-like feature is 1,700 ft. O.D., i.e. the 470-foot level. Deposits once left by the ancient lake at this place have been largely removed, and the flat surfaces seen consist of the top two or three feet of the exposed Turkana Grits reworked and recemented with calcareous material, with the inclusion of pebbles from the nearby lavas. No fossils were found either in the grits *in situ* or in the reworked surface.

In the south-east of the map area the only true lake sediments recognizable are those of the 220-foot level. Higher than this level, between the Lothidok Hills and the Lodwar-Ferguson's Gulf road, a series of bouldery clays and hill-wash, with some red, sandy sediments with lava pebbles plus rare soft, sandy limestones, is believed to represent outwash material deposited at the margins of the old lake, most of it sub-aerially. These deposits dip eastwards at one to two degrees, in good accord with the depositional dip of the true lake sediments. They are seen to abut against and overlie Turkana Grits and lower basalts on their western margins, and are obscured by Recent sands and soils in the east. Just south of the peak of Lothidok they rise from 1,540 ft. to 1,700 ft., i.e. from 310 and 470 feet above the present lake level, and most probably are contemporaneous with the 330-foot and 470-foot levels east of Labur. However, unlike the Labur exposures, there is no evidence of platforms in these deposits, and fossils, which are found locally in the 330-foot level at Labur, are completely lacking at Lothidok. The fault which marks the western boundary of these deposits at Lothidok peak has given rise to slickensiding in the deposits, showing very late renewal of the fault, with a downthrow of a few feet to the east.

The true lake sediments of the 220-foot level are very well exposed in an almost vertical section in the banks of the Turkwel River at Kangatotha (Plate IIa), dipping at just under one degree to the east. The succession there is—

± 5 ft. of fine sand with occasional clay layers, with pottery fragments (pot-sand);

55 ft. of dark grey-brown to black sandy clay, with rare layers of silversand one to two feet thick;

35 ft. of pale buff sand, poorly consolidated. Base not seen.

An expedition from the Harvard Museum of Comparative Zoology led by Prof. Bryan Patterson showed the senior author a fossil skull of *Homo sapiens* which the expedition found in the upper few feet of the sandy clay near the junction with the pot-sand. At the time of writing no definite age has been assigned to the skull* but Glynn Isaac of the National Museum, Nairobi, tentatively identified pottery fragments found just beneath the skull as of Magosian age, i.e. dated 8,000 to 4,000 years B.C. In this part of the area the pot-sand is found capping the 220-foot level sediments in many localities, and is apparently contemporaneous with the lake deposits, so the 220-foot level must be regarded as of Epi-Pleistocene (Recent) age. A careful examination of the deposit was made to determine that the skull was *in situ* in the sediment, and had not been interred. A few years ago a well-fossilized skull was found farther north at Muruarot with clear evidence of interment (Dr. L. S. B. Leakey, personal communication). In 1965 an anthropological expedition from the University of California, Berkeley, began a detailed study of Kangatotha and neighbouring areas.

Fossils collected at Kangatotha in the course of the survey (specimens 10/15-16) were identified as *Cleopatra johnstoni. Parreysia bakeri, P. chefneuxi, Melanoidia tuberculata, Viviparus unicolor, Corbicula radiata, C. fluminalis, Aetheria elliptica, Clarias* sp., *Crocodilus* sp. and fragments of turtles and mammals. K. S. Thomson of the

* Carbon-14 dating by Yale University of oyster shells (*Aetheria elliptica*) collected a foot below the skull gave an age of 4,880 ± 100 years.

Harvard expedition has listed fish fossils from the same lake sediments as follows (Thomson, 1966): *Bagrus* cf. *B. bayad, Barbus* cf. *B. bynni, Clarias* sp., *Clarias* cf. *C. lazera, Lates* cf. *L. niloticus, Synodontis* sp., *Synodontis* cf. *S. schall* and *Tilapia* sp.

Northwards from Kangatotha the 220-foot level is remarkably even and, except at its eastern margin, free of gullying, so that a Land-Rover can be driven at speed along it. About five miles north of Kangatotha deep gullies from the east show a good cross-section of the upper clay stratum. At this point the dip is 2° to the east, and it can be seen (Plate IIb) that the dip is depositional and caused by the wedging out eastwards of sand intercalations, suggesting some fluctuation of lake level to allow the deposition of deltaic sands during times of low water levels. Further evidence of such fluctuations is given by the existence of channels with shallow beds of small rounded quartz pebbles. The channels had been cut down into the clay and been infilled by later deposits of the same clay material.

Continuing northwards to Eliye Point the same beds are seen with an upper surface at 1,435 ft. O.D., 205 feet above the present water level. The pot-sand still caps the clay, which dips 1° east-north-east. To the east of the point a spur of the lake beds encloses a depression which, with the rise of only a few feet in the lake level, becomes a gulf, as it was when visited in September 1963. On the spur the lake beds dip eastwards at up to 15°, and the clay beds reach down to the water's edge. This appears to be due to the undercutting of the lower sandy strata by wave action and the consequent slumping of the higher clay beds. In and on the lake beds here were found (specimen 10/57) *Melania tuberculata, Corbicula radiata,* part of the jaw and a tooth of an antelope, a few chert artefacts and fragments of decorated pottery.

Moving northwards again, what are clearly the same lake beds are found in the vicinity of Ferguson's Gulf to lie at between 1,330 and 1,360 ft., that is between 100 and 130 feet above present lake level. The same fossiliferous clay beds capped by pot-sand are seen, and it would seem that there has been local downwarping on a roughly east-west axis through the gulf, with an average downward slope between Eliye Point and Ferguson's Gulf of ten feet per mile. The outer spit at the Gulf (Plate IIIa) appears at first sight to be an elongated sand ridge 100 feet high, but at a few places on the steep slopes of the ridge were found many of the fossils characteristic of the clay strata of the 220-foot level, such as *Lates niloticus, Clarias* sp., *Parreysia* sp., fragments of turtle shell and chert artefacts and decorated pottery (specimen 10/55). The spit proves to be a spur of the lake beds with a veneer of wind-blown sand.

At Kalimapus, ten miles north-east of Ferguson's Gulf, the lake beds outcrop from 1,390 ft. up to 1,530 ft. O.D., 160 to 300 feet above the present lake. Again the uppermost part is clearly the level which generally lies at + 220 feet, dark fossiliferous clay capped by pot-sand, and it appears that the earth movement which led to the depression at the gulf has there raised the sediments. Six miles farther north, south of the Topernawi River, the 220-foot level is found at its correct altitude abutting old islands of olivine basalt. Fossils collected from the last-mentioned locality (specimen 10/50) include *Melania tuberculata, Mutela truncata, Viviparus unicolor, Corbicula fluminalis, C. radiata* and *Parreysia* sp.

In a lengthy discussion on the true age of these lake beds Arambourg (1943, pp. 186-207) divided them into an older, Lower Pleistocene series (the Omo beds) and a newer Middle to Upper Pleistocene series. At many localities in the Omo Valley in Ethiopia, north-east of the present area, Arambourg proved unconformity between the lower tilted Omo beds and the overlying virtually horizontal Middle and Upper Pleistocene beds. His map shows the Omo beds to extend into the present area along the lakeshore to a few miles south of Todenyang. Referring to the newer Pleistocene beds, Arambourg pointed out their typical occurrence as raised terraces, and the

occurrence of fossil forms which are identical to those of the present day. However, the only mollusc found living in Lake Rudolf during the present survey was a gasteropod of *Gulella* (*Paucidentina*) sp. (identified by Dr. W. J. Clench of Harvard Museum of Comparative Zoology), which appears to be the only mollusc able to survive the increasingly alkaline condition of the water. *Gulella* was not recognized in fossil form in the lake beds. Arambourg also recorded artefacts which are probably of Chelles-Acheul culture, of the Middle Pleistocene. For various reasons already given in this report it is clear that part of the lake sediments are of Recent age.

7. Recent Superficial Deposits

Superficial Limestones.—At various localities flanking the Muruangapoi Hills and on the Lodwar-Lokitaung road north of Kanukurdio are broad flat expanses of nodular pea-sized kunkar limestone of varying shades of off-white and pink, sometimes with a heavy admixture of soil and sand (as north-east of Lodwar) but more often virtually pure limestone. In the exposure north of Kanukurdio the limestone is locally compact and flaggy. In all the exposures fragments of lava are present. The limestones are a very recent feature, and a clear indication of their origin is seen at Lodwar Cone, the slopes of which, as far as the summit, are strewn with such pea-sized nodules which have formed from the lava by surface weathering and have accumulated at the eastern foot of the cone by downwash.

At intervals along the eastern foot of the Songot Hills are alkaline springs, first recorded by Champion (1937, p. 116), which occur as a series of shallow but permanent water pans. For an area of several hundreds of feet around each pan is a veneer of off-white porous limestone riddled with solution cavities and tubes up to half an inch across. A thin section of the limestone, 9/12, shows it to consist of very fine-grained, sometimes amorphous, calcite or aragonite, with rare angular fragments of quartz. A few poorly preserved gasteropod fossils were found in the limestone and tentatively identified as *Viviparus* sp.

Sandy Soils.—These deposits are divisible into two main groups, deep red, often well compacted, sandy soils derived wholly from Basement System rocks, and generally buff to grey, occasionally light red, fine-textured and powdery sandy soils derived mainly from lavas. The red Basement System soils are well developed only along the western margin of the map below the Uganda Escarpment. Washed samples of the soil show mainly angular fragments of quartz, often with deep-red, iron-oxide staining but little or no magnetite or ilmenite, and lesser amounts of felspar and mica. The red soils support a scattered cover of large thorn bushes and trees and grass, their growth encouraged by the rather higher rainfall in that part of the map area and the exclusion of domestic stock from the border strip. Where gullying occurs the compact nature of the soil leads to deep steep-sided gullies.

The lighter sandy soils elsewhere are again mainly quartzose, but in them the quartz displays a high degree of rounding due to wind action. Where vegetation cover is slight or absent sand-dunes tend to form, particularly in areas exposed to the strong daily winds blowing over the lake. Barchan dunes are common in the south-east corner of the area, being particularly well developed around the swamp area of Aiyangiyang. In 1963 most of the dunes in that region were relatively stable due to a thin vegetation cover, but a year or more of drought conditions would undoubtedly lead to movement and formation of new dunes.

Patchily distributed over both types of soil are deposits of angular gravel, mainly quartz, but occasionally felspar and more rarely fragments of gneiss or lava. Individual fragments range from pea size up to three inches across, and occasional gullies show the thickness of the gravels to average two to three feet.

The swamp soils of Lotigipi are generally dark grey in colour, rarely black or light red, of extremely fine texture and thus liable to wind deflation when dry. The composition of the soils varies somewhat from place to place, but quartz predominates over material derived from the basic lavas. Iron minerals in the soils generally occur in a reduced form though sometimes, notably at the southern end of Lotigipi near Kakuma, they are oxidized and locally give rise to extensive flats of reddish alluvium. Similar swamp deposits occur in closed drainage basins south and east of the Lothidok Hills and between the Labur range and Todenyang.

Recent Lake Deposits.—The youngest deposits of the area are those around the lakeshore, chiefly sandy beaches with rare shingle and occasional pale yellow to buff clay deposits. The latter contain present-day fish and reptile remains. These deposits, like the fine soils already described, are liable to blow into dunes or to mask underlying Pleistocene beach deposits, as at Ferguson's Gulf and Eliye Point. At the southern end of Ferguson's Gulf barchan sand dunes are common, reaching 50 feet from horn to horn and up to six feet high. The rate of forward progress of the dunes was not established, but in even light winds sand can be seen moving up the windward side and falling to lee. A forward movement of several feet per month is not unlikely. The ease of movement of these shore deposits, both by wind and wave action, leads to fairly rapid changes in the lake shoreline. In 1958 westward-pointing sand spits at the tip of the main spit of Ferguson's Gulf had closed the opening of the gulf to under half a mile, but in 1963 most of these secondary spits were gone. Aerial photographs of the Turkwel delta taken in 1957 show the main river course to be that arm running south and south-east into the lake, and the direct easterly arm to be overgrown with grass and reeds. But in July 1963 the easterly arm was clear of vegetation and the southern arm could only be distinguished with difficulty. At the same time the lake had flooded southwards at Eliye Point and formed a shallow gulf over a mile long.

VI.—METAMORPHISM AND GRANITIZATION

The Basement System rocks of the area fall within the almandine-amphibolite metamorphic facies of Fyfe, Turner and Verhoogen (1958, p. 228). The typical assemblage of pelitic rocks is biotite-microcline-oligoclase-almandine (plus diopside, hornblende and chlorite), and in the plagioclase amphibolites diopside-hornblende-andesine-epidote. The occurrence of epidote suggests the staurolite-quartz sub-facies, whereas the presence of diopside and microcline in the more acid rocks suggests the higher sillimanite-almandine sub-facies. Sillimanite was not seen in any of the thin sections examined, and its lack is perhaps due to a paucity of alumina in the original sediments. The mineral was recorded in both areas to the south of the present map (Fairburn and Matheson, Report No. 85, and Dodson, Report No. 87). It is probable that the metamorphic grade of the area falls between the two sub-facies. Such a grade results from regional metamorphism with fairly high temperatures and pressures. Prolongation of such temperatures and pressures has led to the widespread development of migmatites, and influx of potassic material has led to widespread granitization, with replacement of much of the original plagioclase by microcline, and the alteration of diopside and hornblende to biotite. The local occurrence of chlorite suggests a degree of retrograde metamorphism, probably due to relief of pressures on removal of the overlying rock sheets by erosion, combined with a degree of hydration.

VII—STRUCTURE

The structure of the area is shown in Fig. 2. Insufficient data was obtained during the survey to elucidate fully the structure of the Basement System rocks, but the rocks generally strike north-south, with both easterly and westerly dips, and lineations show marked plunges both to north and south. Such a structure is consistent with

a series of folds on roughly north-south axes, such as is common over much of Kenya. The folding of the Basement System rocks was probably contemporaneous with their metamorphism, and therefore of Precambrian or early Palaeozoic age.

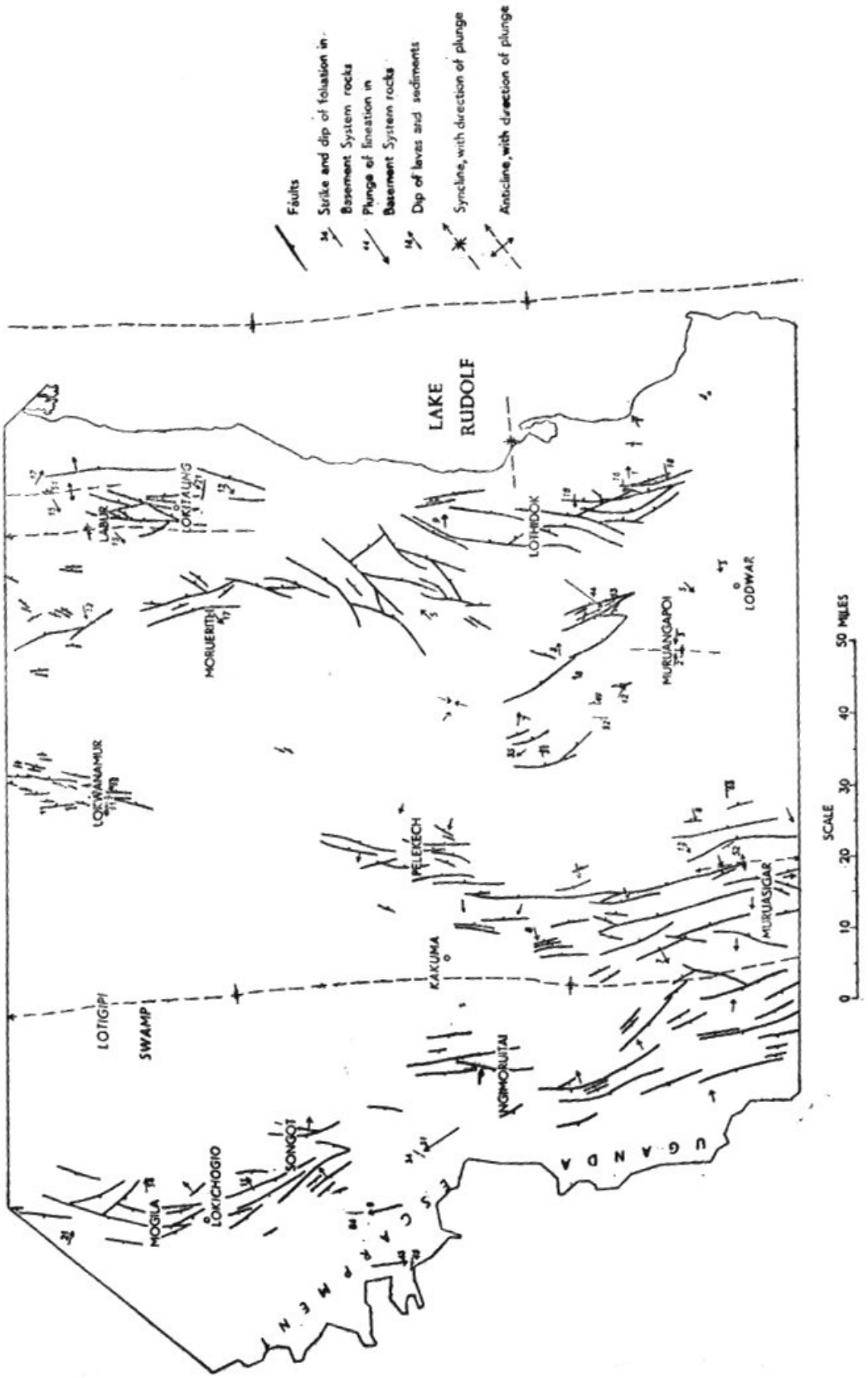


Fig. 2—Structural map of northern Turkana

There is no evidence as to the history of the area between the folding of the Basement System rocks and the Tertiary period and it must be assumed that the area was undergoing denudation throughout this long period. Earth movements during this period would certainly have led to the deposition locally of terrestrial sediments similar to the Turkana Grits, but which, unlike the Turkana Grits, were not protected by overlying volcanics, and have now been completely removed by erosion. The history of the area since mid-Tertiary times is summarized in a later chapter. Briefly, warping of the sub-Miocene peneplain in late Oligocene or early Miocene times was followed by deposition of Turkana Grits and lavas, which in early Pliocene times were faulted and tilted to roughly their present-day attitudes. Continuing erosion and a minor renewal of faulting in lower Pleistocene times evolved the topography as it is seen today.

Champion (1937, p. 104) and Fuchs (1939, p. 264) considered the Uganda Escarpment to have been initiated by major faulting accompanying the downwarping of the sub-Miocene peneplain. Dixey (1948, p. 28) did not agree that the escarpment is a fault- or fault-line scarp, nor do the present writers. The escarpment is too irregular and too deeply embayed to have resulted from a major fault or faults, and no such fault was seen during the present survey. Basement System rocks are locally exposed for more than ten miles eastward from the foot of the escarpment, as near Oropoi, and if major faulting were present it is unlikely to have been missed either in traverses over the area or in studies of air photographs. It is therefore concluded that the Uganda Escarpment was formed by erosion cutting back westwards from the downwarped area to the east.

Evidence that the lowest point of the basin in which the Turkana Grits were deposited lay just west of the present lake has already been given.

Disconformities, generally fairly small, between the Turkana Grits and the succeeding volcanic series, as well as unconformities between individual members of the volcanic series, show that minor tilting took place at intervals throughout the Miocene period, and at the close of volcanicity, probably in early Pliocene times, extensive faulting on roughly north-south lines with consequent tilting affected the whole succession. The overall effect of the faulting was the production of three major upstanding blocks on north-south axes, bounded on the east by fault-scarps and tilted westwards. These blocks, from east to west, are Labur-Lothidok, Moruerith (with a southerly extension to Muruangapoi) and Lokwanamur-Pelekech-Muruasigar. All these three blocks are continued northwards into the Sudan. An indication of the magnitude of faulting is given on the eastern flank of Muruasigar, where the Basement/lava contact has been downthrown over 2,800 feet to the east.

The westernmost block in the area is bounded on its western side by north-south faulting downthrowing west, through Mogila, Songot and Ngimoruitai, with eastward tilting of that side of the block, and the production of a major syncline plunging northwards. This syncline, the Lotigipi Syncline of Fuchs (1939, p. 265) initiated a drainage pattern which diverted all the run-off from the western part of the area to the northward, and the detritus carried by the rivers and streams of that part of the area has accumulated in the northern part of the syncline and now forms the Lotigipi Swamp.

The second major syncline marked on Fig. 2, that lying in Lake Rudolf, and the smaller folds at Muruasigar and Labur, are evidenced by the attitude of the sub-Miocene bevel as shown in Fig. 1. From the same evidence an anticline may be present in the Lokwanamur Hills. The minor syncline at Muruangapoi can be clearly seen looking south along the Lodwar-Lokitaung road to the north of the hills. Evidence for the shallow east-west syncline to the east of Lothidok, downwarping the Pleistocene to Recent lake beds, has already been given. Dodson (1963, p. 48) described similar east-west folding, which he dated at late Upper Pleistocene, at the southern end of Lake Rudolf.

All the faults of the area appear to be normal faults with the possible exception of that along the eastern margin of the Labur Hills. The *a*-lineations measured in the brecciated Basement System rocks in that region, particularly in the gorges south of Labur peak, suggest that the fault is a low-angle thrust, pitching southwards at 20 to 25 degrees. The most pronounced tilting of fault blocks is seen at the mouth of the Kalokol River near Ferguson's Gulf, where fault blocks of lower basalt over 50 feet high are tilted to the north-west at angles exceeding 50 degrees (Plate IIIb).

Surprisingly few of the faults cutting lavas show pronounced brecciation. The best example seen is in the Mogila Hills a few miles north of Lokichogio, where a north-south fault in rhyolite is marked by a very coarse angular breccia exceeding 50 feet in width (Plate IVa).

Arambourg (1943, p. 205) gave evidence of renewal of faulting in Lower Pleistocene times which affected the lower members of the Pleistocene lake beds (Arambourg's Omo series). There is evidence of only small earth movements since the Lower Pleistocene, as evidenced by the east-west syncline mentioned above and very minor faulting seen in the later lake beds east of Labur and Lothidok. West of Todenyang the 180-foot level lake deposits are gently tilted to east-north-east as a result of rejuvenation along existing north-south faults. A fault cutting the 220-foot level sediments south-east of Lothidok is seen in a gully to have a downthrow to the west of 15 feet. On the same 220-foot level at Kangatotha, some 15 miles farther south, in June 1963 the writers saw and photographed (Plate IVb) a fissure caused by earth movements. The fissure, some 300 yards long, cut the western flank of the raised lake deposits and continued across the dry river bed on a bearing of approximately 210°. The average width of the crevice was five inches, though it appears much wider on the photograph due to the caving-in of unconsolidated river sands. That the movement was caused by mere slumping was discounted by the fact that the fissure cut the raised flank of the lake deposits at an acute angle, and that the cliff face of the same deposits in the bank of the Turkwel River (Plate IIa) is more than half a mile away to the south, and slumping in the beds is not seen more than a hundred feet from the river cliff.

The tectonic history of the Northern Turkana area, folding in late Oligocene or early Miocene times, followed by major faulting early in the Pliocene and renewals in the Pleistocene, thus closely follows the history of other parts of the Rift Valley in Kenya, e.g. in the Eldama Ravine-Kabarnet area (Walsh, Report No. 83) and in the Thomson's Falls-Nakuru-Lake Hannington area (McCall, 1967, pp. 93-102). Pleistocene faulting at the southern end of Lake Rudolf (Dodson, 1963, p. 48) led to the formation of a true rift valley in the Suguta Valley and the southern extremity of the lake, but Dodson points out that this narrow rift system cuts obliquely across the lake in a north-north-easterly direction, and agrees with Fuchs (1939, p. 266) that most of the Lake Rudolf basin does not lie within the Suguta Valley rift system. The present survey bears out Fuchs' contention that the Lake Rudolf basin, while an integral part of the Gregory Rift Valley, owes its present form to downwarping rather than to true rift faulting.

VIII—THE GEOLOGICAL HISTORY OF LAKE RUDOLF

That a lake or lakes existed near the site of the present Lake Rudolf in early Miocene times is evidenced by the lacustrine facies of the Turkana Grits. Intravolcanic waterlain sediments near the base of the lower basalts in the Lothidok and Labur hills show that the lake persisted for a short time after the onset of volcanicity, but the steady build-up of the lava succession swamped the whole area, and the present-day lake had its origin in the major earth movements in early Pliocene times which rejuvenated the earlier north-south depression at the same time as the major mountain

ranges were formed. The earliest records of the renewed lake are the Omo beds in Ethiopia, which Arambourg (1943, p. 190) dated as Lower Pleistocene and the Gaza beds from the east side of the lake which Fuchs (1939, pp. 248-250) considered to be of similar age or slightly older. It seems probable that sedimentation of the renewed lake commenced in the Pliocene, but any older beds are concealed beneath the lake or the younger deposits.

It is clear that the lake once extended far beyond its present borders, and the writers agree with Arambourg (1943, p. 187) that the lake must have extended north of the Labur Hills and filled part at least of the tectonic depression to the west. From the air it appears very likely that the Lotigipi Swamp was once part of the lake, though during the present survey it was possible to penetrate only a few miles into the swamp, and no fossiliferous beds were found there. It is likely that if such beds do occur they are hidden under recent detritus. That part of the Sudan immediately north of the border, the Ilemi Triangle, is administered by Kenya, and a large area is policed by the Kenya Police, but unfortunately the writers were not allowed to cross the inter-territorial boundary, and were unable to trace the possible extent of the early lake. Topographic maps of the area are too poor to be of use in this respect. However, Inspector M. Holloway, a pilot of the Kenya Police Air Wing, showed the authors fossil molluscs which strew the airstrip at Kibish, 50 miles north of Todenyang, and the faunal assemblage there appears identical with that of the 220-foot level.

Both the recent and fossil fauna of the lake have strong affinities with that of the Nile Basin, though Arambourg and Fuchs differ as to the date at which a connexion was established, somewhere north of Lotigipi, by which the lake drained north-westward into the Nile. Arambourg (1943, p. 209) distinguished Nilotic types in the fossils of the earliest Omo beds, at the beginning of the Pleistocene, but Fuchs (1939, p. 249) considered that the connexion was not established until the Middle Pleistocene. Whether the later closing of the lake basin was due to the formation of a barrier across the original Nile outlet or to shrinkage of the lake under increasingly dry conditions is not known. The waters of the lake are becoming increasingly alkaline (some water analyses are quoted on a later page) but the rate of increase has not been measured and it is not possible to calculate by chemical means the approximate date of the establishment of the closed basin.

The increasing alkalinity of the lake waters tends to complicate the faunal picture, and Mr. R. McConnel, the Fisheries Officer at Ferguson's Gulf, told the senior author that fish in the less alkaline water of three small lakes on Central Island, a few miles west of the gulf, and stated by Fuchs to be of Recent volcanic origin, show marked differences to fish of similar species in the open waters of the lake.

Fuchs (1939, p. 251) attempted a correlation of the varying levels of the lake with Pleistocene pluvials recognized elsewhere in East Africa. While he gave recognition to the effects of earth movements on the lake levels the authors feel that as yet too little is known of the dates and magnitudes of such movements to evaluate their effects as compared with the climatic changes. It will be seen from Fuchs' graph that he dated the 220-foot level as Upper Pleistocene (Gamblian), whereas present evidence points to a much later date.

In the present century the waters of Lake Rudolf have shown a steady fall, despite temporary rises of the level in unusually wet years. Fuchs (1935, p. 116) recorded a drop of four feet between 1931 and 1935, and Champion (1937, p. 106) instanced the complete drying up of Sanderson's Gulf, west and north-west of Todenyang, since 1917, estimating a drop of 25 feet in 25 years.

Calculations made from the recent maps of the Survey of Kenya, drawn from air photographs taken between 1957 and 1959, show the area of the lake to be 2,810 square miles, with a maximum length of 156 miles and a maximum width of 30 miles. No complete bathymetric survey has been made of the lake, and the maximum depth so far recorded is 240 feet.

IX—ECONOMIC GEOLOGY

Minerals

The area proved disappointing in that no deposits of economic minerals were found in quantities likely to be workable in such a remote area, where transport costs are likely to be prohibitive on all but high-grade deposits. Among minerals found are *gold,* an assay of samples of banket-like agglomerate from the Turkana Grits at Labur showing a maximum of 0.3 dwt. per ton. Most of the larger rivers of the area were sampled and panned, but none showed gold. Cryptocrystalline silica minerals are common locally in veins and pockets in the lower basalts, notably in the Lothidok and Labur hills. Among those recognized are dark green *prase,* sometimes speckled with red (*heliotrope*), and banded *agate,* usually in shades of grey and white, more rarely buff. All of these might be cut for semi-precious gemstones. Associated with these silica minerals are *quartz,* often glass-clear in well-formed crystals in geodes, and *calcite,* in geodes and veins, occasionally sufficiently clear to form *iceland spar.* In the Pleistocene and Recent lake beds some of the clay bands contain crystals and platy aggregates of *selenite,* the crystal form of *gypsum,* but in too small amounts to be workable. A single small fragment of *meerschaum* was found in the same lake beds near Labur. Diatomaceous beds are common, but no pure *diatomite* deposits were found. *Limestone* occurs as marble in Basement System rocks at Labur and Oropoi, as a fine-grained tufa near the road south of Lothidok, in thin bands in the Turkana Grits and Pleistocene to Recent lake beds, and as superficial deposits near the Muruanachok and Muruangapoi hills and west of Songot. Heavy *copper* staining was seen in Lokitaung Gorge in amygdaloidal basalt close to the contact with the underlying Turkana Grits.

The Basement System rocks of the western border of the map area were not closely traversed, but it seems doubtful that any important mineralization occurs in the monotonous series of granitoid gneisses. Some of the auto-pegmatites bear tiny books, only a few millimetres across, of *muscovite,* and *garnets* are not uncommon both in the gneisses and in the auto-pegmatites. Small, scattered flakes of *graphite* were seen in some of the marbles of Labur. No signs of economic mineralization were found associated with the diorite intrusion north of Muruanachok.

Water Supplies

The water supplies of the area though small (apart from Lake Rudolf) are generally ample for the needs of the small nomadic population and their stock, the latter being necessarily limited in numbers by the poor grazing available. Springs occur on most of the larger hill masses, notably at Lokitaung and elsewhere in the Labur and northern Lothidok hills, on the slopes of Muruasigar, in the Mogila Hills, and west of Songot. The Songot springs are saline, and said to be used only rarely for watering stock. In most of the larger sand-rivers water can be obtained from shallow wells dug in the river beds. In dry seasons the water-level in such wells sinks rapidly, sometimes to more than 30 feet below the surface, and in prolonged droughts water can only be obtained from selected sites, such as upstream from concealed rock-bars which dam up the sub-surface water.

The water of Lake Rudolf, while unpleasant to the taste and very high in fluorine, is nevertheless used for human and animal consumption. The accompanying table lists analyses of samples of water taken from various localities in the lake:—

COMPOSITION OF LAKE RUDOLF WATERS

(parts per 100,000)

	1	2	3	4	5	6	7	8
ALKALINITY (as $CaCO_3$)—								
Carbonate	30·8	nil	32	60	50	13	24·8	50
Bicarbonate	82·3	15·6	76·5	45·8	59·9	37·6	91·2	82
AMMONIA—								
Saline	n.d.	n.d.	n.d.	n.d.	0·048	0·016	0·032	0·05
Albuminoid	n.d.	n.d.	n.d.	n.d.	0·08	0·012	0·072	0·036
Chlorides (as Cl) ..	44	2·8	41·2	40·3	43·1	19·3	42·8	52
Sulphates (as SO_4) ..	4	trace	2·4	3·2	2·1	trace	1·5	5
Nitrites (as NO_2) ..	n.s.	n.s.	trace	n.s.	n.s.	present	n.s.	present
Nitrates (as NO_3)	n.s.	n.s.	n.s.	n.s.	n.s.	present	n.s.	present
Calcium (as Ca)	0·5	1·1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Magnesium (as Mg) ..	0·79	0·66	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Iron (as Fe)	n.d.	n.d.	n.d.	n.d.	0·014	0·03	0·14	0·07
Silica (as SiO_2)	n.d.	n.d.	n.d.	n.d.	trace	6·3	0·7	0·3
Total hardness	4·0	5·0	3·5	3	3	2	2	2
Total solids	n.d.	n.d.	n.d.	n.d.	199	103·5	203	230
Fluorides (parts per million)	12·5	1·0	17·2	11·3	9·3	3·87	9·2	8·6
pH	10·3	7·6	10·6	n.s.	10·4	8·7	8·5	8·5

n.d.=not determined.
n.s.=not stated.

1. Lake Rudolf, Todenyang.
2. Omo River, northern end of Lake Rudolf.
3. Lake Rudolf.
4. Lake Rudolf near Lokitaung.
5. Lake Rudolf.
6. Lake Rudolf.
7. Illeret, eastern shores of Lake Rudolf.
8. Ferguson's Gulf, Lake Rudolf.

The sodium content was not determined, but nearly all of the carbonate and bicarbonate is thought to occur as sodium salts. Dried up creeks and inlets around Ferguson's Gulf were seen with incrustations of sodium carbonate, and the waters of the gulf, which to some extent acts as an evaporating pan, are so charged with soda as to feel soapy to the touch.

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APPENDIX

AGE AND POLARITY OF THE TURKANA LAVAS, NORTH-WEST KENYA

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The extension of the Trap Series of Ethiopia into north-west Kenya has previously been suggested on stratigraphical and petrological grounds.[1] This area has recently been mapped on the basis of a reconnaissance[2], and the following succession suggested:

Rhyolites and andesites	Tvr, Tvd
Olivine basalts	Tvb_2
Phonolites and nephelinites	Tvp
Augite and analcime basalts	Tvb_1
Turkana grits	Tm

The age of the lavas has hitherto been based on a sparse mammalian fauna found in grits intercalated in basalts (Tvb_1?) at Lothidok, 25 km. north-east of Lodwar. Initially thought Burdigalian[3], recent work[4] has suggested that it is younger (Up.-Miocene) in age. Some fossil wood found in the rhyolites 60 km. north of Lokitaung (*Dryoxylon* sp.) hints at a Mio-Pliocene age.

Four lavas have been dated (R.L.G.) at the University of Cambridge; Table 1 gives the results obtained on whole rock samples.

TABLE 1

Sites	K_2O (per cent)	Vol. of $^{40}Ar/g$ (mm^3)	Atmos. contam. (per cent)	Age (m.yr)	Polarity
260/1	1·31	$1·406\times10^{-3}$	38·9	32·2±0·5	R
(Tvb_1)		$1·375\times10^{-3}$	36·7	31·5±0·7	
264/5	0·61	$4·210\times10^{-4}$	48·2	20·7±0·4	R
(Tvb_1)		$4·686\times10^{-4}$	46·4	23·0±0·7	
293/4	0·90	$7·04\times10^{-4}$	78·0	23·5±1·1	R
(Tvb_2)		$6·99\times10^{-4}$	51·7	23·3±0·2	
243/50	3·84	$1·90\times10^{-3}$	54·3	14·9±0·5	N
(Tvp)		$1·56\times10^{-3}$	66·5	12·5±0·3	

Field mapping showed that the basalts and rhyolites interdigitated in two localities, but neither was observed to overlie phonolites or nephelinites. The *Tvp* group is thus younger than both basalts (but could be older than the rhyolites), and comparable in age with the Lothidok grits and the Kapitian phonolites. The basalts (Tvb_1?) at Lothidok are unconformably overlain by basalts which are considered, on petrological grounds, to be equivalent to the Tvb_2 basalts in the north. However, palaeontological evidence indicates that the Lothidok basalts are much younger, and this discrepancy remains to be resolved.

The disagreement between samples 260/1 and the apparently underlying sample 264/5 might be due to loss of argon in sample 264/5, which shows a high chlorite content, or to local repetition of the succession by faulting: a similar wide scatter has been observed in five dates[6] (30-69 m.yr.) for the Abbai basalts of Ethiopia. The age and character of the Turkana basalts are comparable with those of the (Upper) Magdala Group of the Ethiopian trap series (25 and 33 m.yr.).

The lava succession is best seen in the Lokitaung Gorge, where 5,000 ft. of lavas, pyroclastics and sediments are exposed. The complex faulting in the vicinity of Lokitaung has also complicated the sequence of magnetic polarities previously described in the Lokitaung section[8]. The samples of the dated lavas appear to be magnetically stable. The results of thermal and alternating-field cleaning were found to agree closely (Fig. 1), and the shapes of the alternating-field demagnetization curves of the saturation remanence and of the natural remanence were similar (Fig. 2). High-field heating showed only single curie points—a value of 450°-500° C. for the basalts, and 150°-300° C. for the phonolites and nephelinites (*Tvp*). The last-mentioned, on heating, developed a new, strongly magnetic component with a curie point of about 500°-550° C. Preliminary examinations of the opaque minerals showed a low state of oxidation, with some maghemitization.

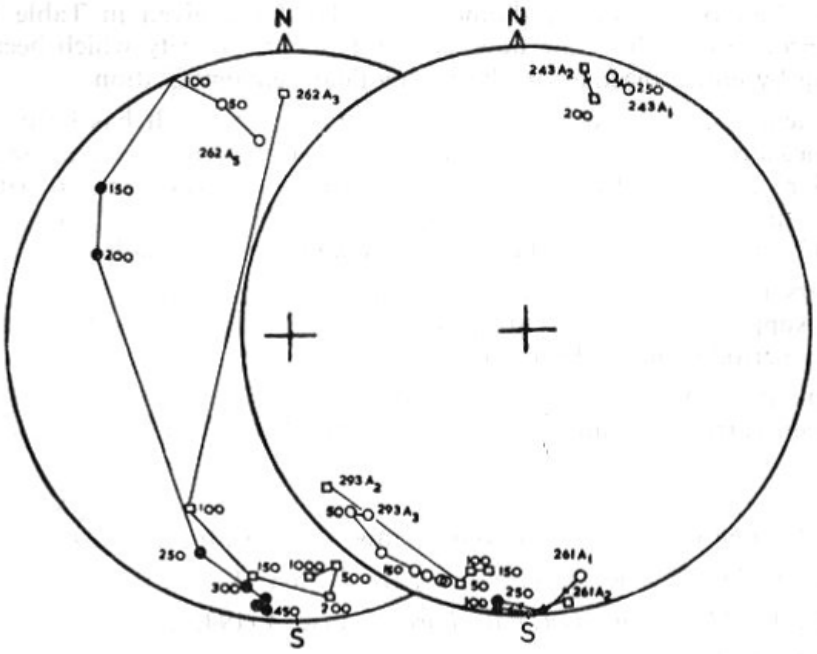


Fig. 1—Polar projection of typical changes of direction during demagnetization. ●, Dips down; ○, dips up: thermal demagnetization—numbers indicate temperatures in °C. ■, Dips down: □, dips up: alternating field demagnetization—numbers indicate peak field in oersteds

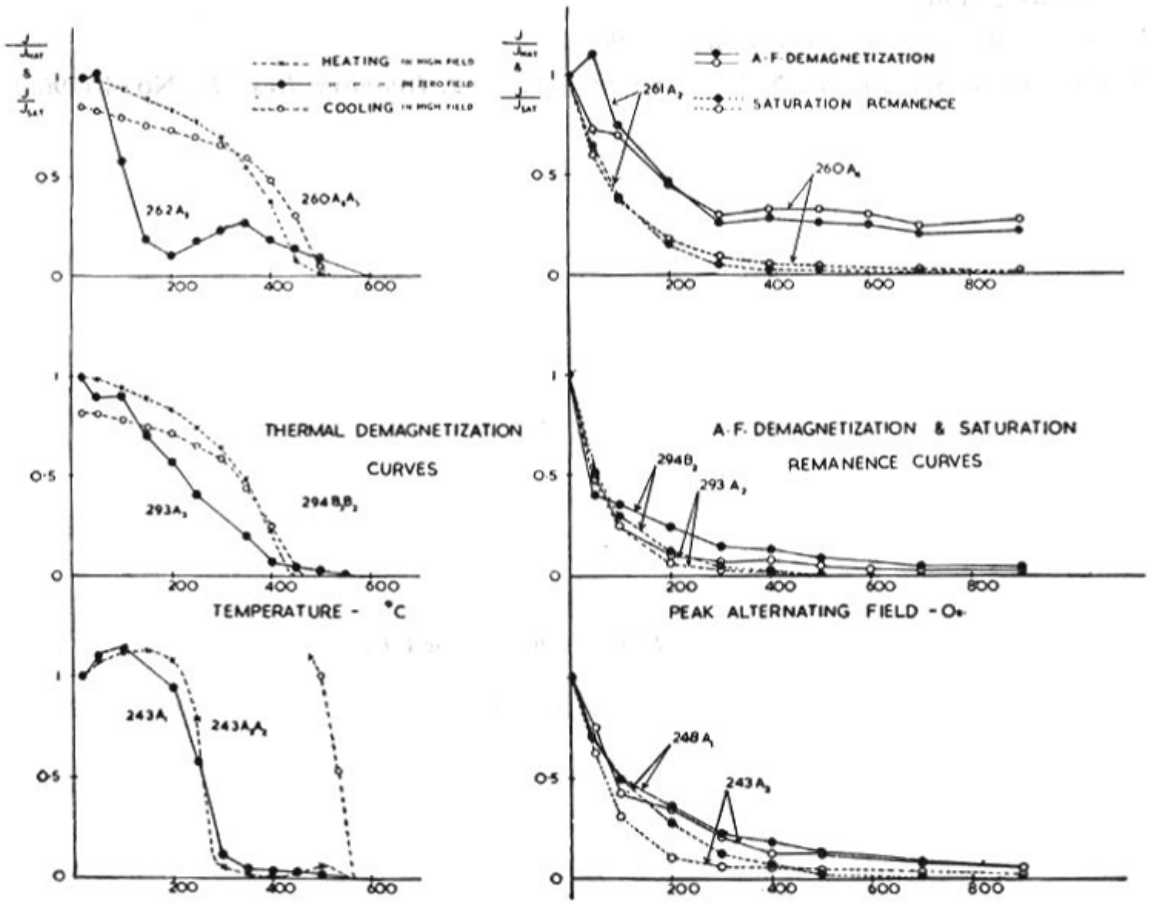


Fig. 2—Behaviour typical of dated sites during thermal and alternating-field demagnetization of natural remanent magnetism, alternating-field demagnetization of saturation remanence and high-field heating and cooling curves

The polarities of the sites radiometrically dated are given in Table 1. A further site, 262/3, probably in the same flow as 260/1, had a polarity which became reversed after cleaning by either thermal or alternating-field demagnetization.

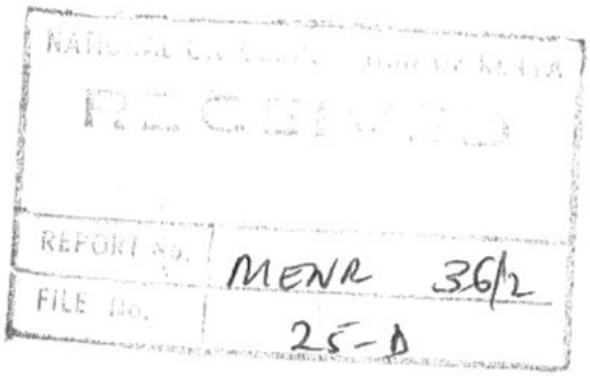
The existence of both polarities above the Lokitaung fault has been confirmed by 150 block measurements made in the field (1965) using an astatic magnetometer. No reversed polarities were observed below the fault. The reversed polarities occur in many rock types, an agglomerate horizon having a consistently reversed polarity, whereas highly mineralized fault breccias are magnetized normally.

Self-reversal and tectonic repetition are probably both present, but the foregoing observations support the previous suggestion of a field reversal in the Upper Oligocene preceded by a period of normal polarity.

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GPK 2934—1m—10/69