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Geological Survey of Kenya

GEOLOGY OF THE LAISAMIS AREA

DEGREE SHEET 28, NE. QUARTER
(with coloured geological map)

by

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CONTENTS									
ABSTRACT									PAGE
I	INTRODUCTION	..	..	..	..	..	..	..	1
II	PREVIOUS GEOLOGICAL WORK	..	..	..	..	..	..	..	2
III	PHYSIOGRAPHY	..	..	..	..	..	..	..	3
IV	SUMMARY OF GEOLOGY	..	..	..	..	..	..	..	6
V	DETAILS OF GEOLOGY	..	..	..	..	..	..	..	7
1.	Basement System	..	..	..	..	..	..	..	7
1.	METAMORPHOSED CALCAREOUS SEDIMENTS	..	..	..	..	..	..	..	8
2.	METAMORPHOSED SEMI-PELITIC SEDIMENTS	..	..	..	..	..	..	..	8
3.	METAMORPHOSED PSAMMITIC SEDIMENTS	..	..	..	..	..	..	..	9
4.	METAMORPHOSED CARBONACEOUS SEDIMENTS	..	..	..	..	..	..	..	10
2.	Intrusives into the Basement System	..	..	..	..	..	..	..	10
3.	Tertiary Sediments	..	..	..	..	..	..	..	13
4.	Pleistocene and Recent Volcanic Rocks	..	..	..	..	..	..	..	13
5.	Superficial Deposits	..	..	..	..	..	..	..	19
VI	METAMORPHISM	..	..	..	..	..	..	..	20
VII	STRUCTURE	..	..	..	..	..	..	..	20
VIII	ECONOMIC GEOLOGY	..	..	..	..	..	..	..	21
IX	REFERENCES	..	..	..	..	..	..	..	23

ILLUSTRATIONS

Fig. 1—	Physiographic map of the Laisamis area	..	..	..	..	..	..	..	4
Fig. 2—	Sketch-map of the volcanic history of the Laisamis area	..	..	..	..	..	..	..	15

MAP

Geological map of the Laisamis area (degree sheet 28, N.E. quarter) scale 1:125,000 .. at end.

ABSTRACT

The report describes an area in northern Kenya, approximately 1,200 square miles in extent, bounded by the meridians 37°30'E and 38°00'E and by latitudes 1°30'N and 2°00'N. Physiographically the area is divided into three units, the lava-capped plateaux; the dissected plain surface; the residual hill masses some of which have levels approximating to the sub-Miocene erosion level.

The rocks of the area include Precambrian gneisses and granulites; premetamorphic basic, ultrabasic and acid intrusions; Tertiary sediments; Pleistocene volcanic rocks; Recent volcanic rocks; superficial deposits of Pleistocene and Recent age. The petrography of the various rock types is described and the structure and metamorphism of the Basement System rocks is discussed. A chapter is devoted to the economic minerals and water supplies of the area.

I—INTRODUCTION

General

The area described in this report is approximately 1,200 square miles in extent and is bounded by latitudes $1^{\circ}30'N$ and $2^{\circ}00'N$, and by meridians $37^{\circ}30'E$ and $38^{\circ}00'E$ (Directorate of Overseas Surveys sheet No. 67). The Laisamis area is part of the Eastern Province of Kenya, with administrative headquarters at Embu, being directly controlled by the District Commissioner, Marsabit.

The geological survey was carried out between November 1962 and February 1963 as part of the reconnaissance mapping programme of Kenya carried out by the Mines and Geological Department.

Communications

The main Isiolo-Marsabit road which runs through the area is kept in a good state of repair. It is, however, a dry-weather road only and movement of vehicles is not permitted during the rainy periods. The other tracks in the area are not maintained but it is possible to motor along them in four-wheel-drive vehicles without any great difficulty. For those portions of the area without tracks the relatively flat nature of the ground and the thinness of the bush cover make movement comparatively easy.

Rainfall and Vegetation

No rainfall records exist for this area, but it is obvious from the barren nature of the terrain that the amount of rain in any one year is very small and is probably in the region of 10 inches or less per year, precipitation occurring in two short periods in November and April.

As a result of the paucity of rain the vegetation is sparse and is composed mainly of stunted thorn trees. Along the banks of the larger sand rivers there is a more prolific growth of acacia and doum palms.

Maps

The only map available at the time of the survey was the 1:250,000 sheet Maralal N.E., E.A.R. No. 1169, compiled by the E.A. Survey Group in 1941 and revised in October 1942, which proved inadequate for the geological survey. The topography of the printed map accompanying this report is based on air photographs at a scale of approximately 1:40,000 taken in 1956 by Hunting Aerosurveys Ltd. A base map was compiled by the author at a scale of 1:83,333 using these photographs controlled by existing trigonometrical stations and secondary points surveyed by plane table. Form lines on the map are based on spot heights taken with an aneroid barometer, the readings being based on the heights of the trigonometrical stations and suitably corrected for diurnal variations, and must be regarded as only approximate. Geological information was plotted in the field directly on to air photographs and transferred to the base map, the final draft of which was reduced mechanically to the printed scale of 1:125,000.

Population

The majority of the population belong to the Rendille tribe who are a nomadic people and whose wanderings are controlled by the location of water for their stock. In the western portion of the area there are a few members of the Samburu tribe.

Both the Rendille and the Samburu have large herds of cattle and goats with a few sheep, and as a result of these herds the available pasture is greatly over grazed. Camels and donkeys are used as beasts of burden but due to the aridity of the land the camel is the more popular.

There are two small trading centres in the area, at Laisamis and at Lokuloko, the shops in both cases being owned by Somalis. At Laisamis there is also a Tribal Police Post.

The Marsabit Game Reserve

That portion of the area to the west of the Isiolo-Marsabit road is part of the Marsabit Game Reserve which extends northwards to Marsabit and southwards to Archer's Post. Grevy's zebra, Grant's gazelle and giraffe are common and several rhino were seen during the course of the survey.

II—PREVIOUS GEOLOGICAL WORK

Prior to this survey practically no geological work had been done on the area and the first accounts were those of the early explorers who passed through the region. On his expedition of 1894-95, A. Donaldson-Smith (1900)* went through the area on his way south and marked Laisamis on his map.

In 1901 Count Wickenberg (1903) on his way to Lamu noticed the lava plateaux between Laisamis and Marsabit.

G.F. Archer (1913) travelled north from the Uaso Nyiro River in 1909 to Marsabit in order to establish a Government Post there. The account of his journey is the most detailed of those of the early travellers. He noted that "Laisamis presents a lonely and arid scene . . ." (p. 423) and that at Laisamis the line of water holes that he had been using on his journey northwards ended. To the east of his route he recorded "... a succession of low plateaux or tablelands which are bounded by abrupt lava scarps. For the most part, the higher ground, some 200 or 300 feet above the surrounding level is very broken and is composed of black cotton soil freely strewn with lava . . .". Of the lower ground Archer said "... the surface is of hard sand, covered with open thorn bush and freely intersected by dry channels, the courses of which are indicated by the lines of flat topped acacia trees ..." Beyond Laisamis, to the west of the track, he noticed Lodermurt (*Halilugum Nder*), which he said "stands . . . towering above the plain like an immense obelisk, 2,000 feet high, and forming an unmistakable land mark, while to the south stands the solid granite mass of Moille, surmounted by a sharp and ragged peak".

J. Parkinson (1920) in a report on the geology and geography of the northern part of the East African Protectorate noted that around Laisamis the greatly eroded surface of the Basement System rocks was overlain by lava, and that examples of *puy*s were conspicuous to the north of Laisamis, and he concluded that the final phase of vulcanicity was of the explosive type. Discussing the drainage in the Kauro-Merille area to the south Parkinson went on to say that "at Laisamis a second large tributary from the west trends eastwards on ridges of felspathic gneiss and presumably goes on to join the Kauro-Merille system". Parkinson noticed that the dominant rock type along the caravan route from Laisamis southwards to Kinya was a compact felspathic biotite gneiss.

In a further paper (1924) Parkinson suggested that the lavas capping the old rocks south of Marsabit were not greatly different in age from those of the Dida Galgalla flows which occur to the north of Marsabit and that these were clearly older than

*References are quoted on p. 23 and 24.

the Marsabit volcano. He regarded the volcano as being "a final effort of the upwelling magma, a piled up series of flows from a single vent, the activity ending with the formation of a noticeable number of parasitic puy; a feebly developed explosive phase".

In a third paper Parkinson (1939) again emphasised the two stages of volcanic activity, first the plateau lavas and second the formation of a Hawaiian type phase which produced Marsabit volcano. He also postulated the northwards continuation of the Merti Plateau to include those plateaux lying to the east of the old route from Laisamis to Langaia. He considered that those puy to the west of Laisamis are distinctly younger than the plateau lavas as they are only very slightly eroded.

H. D. Roberts, in a report of a geological reconnaissance survey of the Merti Plateau (1941), also said that the plateaux to the north of the Merti area have a similar structure to that of the Merti Plateau, i.e. gneiss, overlain by arkosic sediments and capped by lavas, and he thought that these plateaux were at one time probably all continuous.

F. Dixey made a hydrogeological survey of the Northern Province in 1943 (Dixey, 1944), and in 1948 wrote a general report on the geology of this part of Kenya. He commented on the presence of basalt flows capping isolated hills of gneiss, or of sediments resting on gneiss and themselves being capped by basalt and thus being preserved.

As a result of Dixey's hydrogeological report a scheme was instituted in 1950 for the purpose of implementing his recommendations. The results of this scheme are embodied in a report by the consulting engineers to the Kenya Government (Humphries, 1958) and this and the Dixey report will be discussed more fully in the water section of this publication.

III—PHYSIOGRAPHY

The area can be divided into three physiographic units (fig. 1):—

- (a) The lava-capped plateaux which rise from 50 to 200 feet above the plain.
- (b) The dissected plain surface, which slopes downwards in a north-easterly direction.
- (c) The residual hills standing well above the level of the plain, with summit heights ranging from 2,645 feet to 5,746 feet.

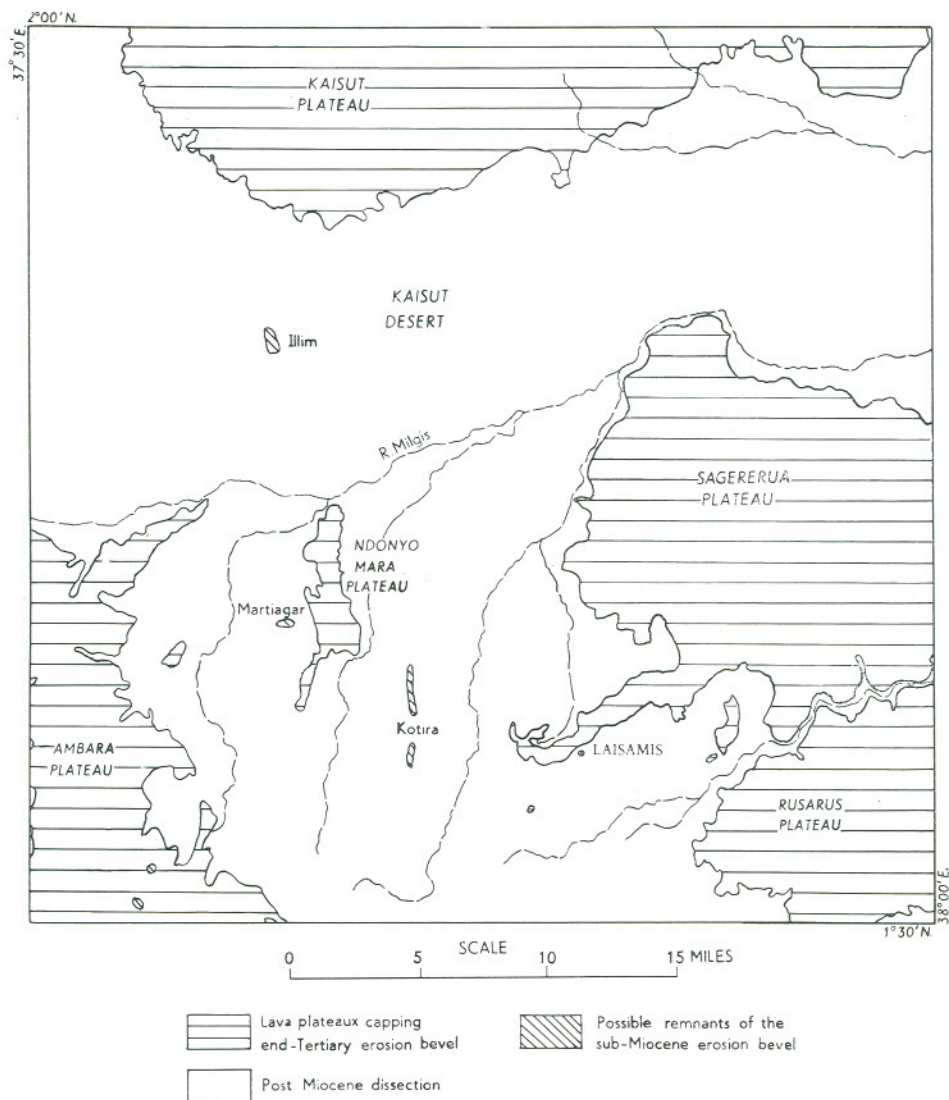


Fig. 1—Physiographic map of the Laisamis Area.

(a) The lava-capped plateaux

These plateaux in general consist of a thin sheet of lava overlying metamorphic rocks. Exceptions to this occur in the south-eastern portion of the area where a sedimentary sequence underlies the lava capping, and in the Kaisut Plateau where there are no indications of either sediments or metamorphic rocks and the lava rests directly on the plain. From ground level these plateaux give the impression of maintaining a fairly constant height, but when viewed from some point above their surface, such as Limirina, it can be seen that the effects of drainage have caused local undulations.

The surface underlying the lava, which has been preserved by the tough, homogeneous nature of the capping basalt, is considered to be remnants of the last erosion bevel in this part of Kenya. The cycle of erosion which led to the formation of this bevel, the end-Tertiary cycle, probably commenced in late Miocene or earliest Pliocene times and had ended by the Middle Pliocene. By placing the end of this erosion cycle in the Middle Pliocene the sediments which occur in the south-eastern portion of the area can be dated as Upper Pliocene and the overlying lava Lower Pleistocene. These plateau lavas are obviously older than the small local flows which in places overlie them and they are also older than the craters and vents of the area, which are well preserved and show little sign of erosion.

In the south-eastern portion of the area the lava caps a sedimentary series on part of the northern and southern margins of the Rusarus Plateau, but along the western portion of this plateau there is no indication of any sediments, the rocks underlying the lava being metamorphic. The sediments also underlie the lava capping of the Tirkamo Plateau, the line joining the sedimentary outcrops at the southern margin of the Rusarus Plateau and those of the Tirkamo Plateau being aligned in a north-north-westerly direction. These sediments have a very local distribution, as Rix (Report No. 92) has noted that in the Kauro-Merille area to the south no sediments are found at Kurato Hill, which lies only two miles south of the Rusarus Plateau, and that there the lava rests on a surface of gneiss.

(b) The dissected plain surface

This surface has resulted from dissection of the end-Tertiary bevel which is now only represented by those remnants which have a lava capping. The lack of protection by a tough homogeneous basaltic lava has led to the erosion of the heterogeneous and often well foliated metamorphic rocks.

The main river in the area is the Milgis which drains eastwards from the Ndoto Mountains. This river is seasonal and contains water only in rainy periods. Over all its length it has a flat profile and nowhere are any solid rocks exposed. Except in the south-eastern and northern portions of the area the drainage all flows northwards to join the Milgis. To a very large extent this northerly direction of the drainage is controlled by the structure of the Basement System rocks, which have a dominantly north-south strike. Eastwards from the northern part of the Ambara Plateau there is no exposure of rock with the exceptions of the northern parts of the lava plateaux of Ndonyo Mara and Sagererua, and the tributary streams flow in a north-easterly direction until they join the Milgis.

In the south-eastern portion of the area the drainage is eastwards. It is clear that at one time the lavas of the Rusarus and Sagererua plateaux formed a continuous sheet, but incision by the Seralatubi River has now separated the two.

It is at Laisamis that the only flowing water in the area occurs, but this extends for a distance of merely 150 yards before disappearing again beneath the sand. The presence of water here is due to the fact that outcrops of Basement System rocks form sub-surface dams across the river. At this point the sand cover above the metamorphic

rocks is thin and the water table sufficiently high that the water rises and flows on the surface until the sand cover is sufficiently thick for it to become sub-surface water again.

In the northern part of the Kaisut Desert streams draining off the lava of the Kaisut Plateau soon disappear beneath the sands. The drainage is more permanent in the north-east where streams coming off the lava run eastwards.

To the south-east of Halisiruwa, along the margin of the lava plateau near the bore-hole, there is an expanse of pale brown alluvium, the remains of an old lake bed formed by the lava damming the original drainage. At the present time this area is still liable to flood and will retain water for some time after the rainy season.

The watershed between the Milgis and Merille drainage systems follows fairly closely the southern boundary of the present area.

(c) The residuals above the plain

All the major hill masses in the area are composed of Basement System rocks, with summit heights ranging from 5,746 feet at Baio down to 2,645 feet at Nalawuru. The hills rise abruptly from the plain and form impressive steep-sided features. The height of the sub-Miocene erosion bevel in the area has been postulated by Pulfrey (1960) at approximately 2,500 feet in the centre of the area, rising to 3,000 feet in the south-west corner. Several features in the area appear to represent remnants of this surface: the ridge immediately north and south of the trigonometrical point of Kotira, at a height of 2,800 feet; a bevel at 2,600 feet on Martiagar (which has a summit height of 2,781 feet); two low hills on the Ambara Plateau whose summits are just below 3,000 feet; the ridge north of the peak of Illim. The remainder of the residual hill masses such as Baio, Illim, Halilugum Nder and Moile perhaps represent eroded remnants of older erosion surfaces.

IV—SUMMARY OF GEOLOGY

The rocks which occur in this area can be classified under five main headings:—

1. Basement System metamorphic rocks of Precambrian age.
2. Basic, ultrabasic and acid igneous rocks intrusive into the Basement System.
3. Tertiary sediments.
4. Volcanic rocks ranging in age from Lower Pleistocene to Recent.
5. Superficial deposits.

The metamorphic rocks of the Basement System can be sub-divided as follows:—

Semi-pelitic	{ A finely banded succession of biotite and hornblende gneisses with calc-silicate lenses.
Semi-pelitic with psammitic horizons	{ Well foliated biotite gneisses and biotite-muscovite gneisses, with bands of hornblende gneiss, crystalline limestone and quartzofelspathic granulites.

The rocks intrusive into the Basement System can be classed under five headings:

Amphibolites
Pyroxenites
Serpentinities
Granites
Quartz veins

Three intrusions of basic and ultrabasic igneous rocks occur in the area. At Halisiruwa in the north-west of the area the dominant rock type is a garnetiferous pyroxenite but other types are also represented. At Chaparkrom in the south-east the intrusive body is an amphibolite which locally contains small amounts of garnet and epidote. The serpentinite at Chaparkrom is younger than the amphibolite intrusion as it has been emplaced in it. On aerial photographs it shows up as a light-coloured patch towards the centre of the amphibolite. Associated with it are veins of magnesite.

Outcrops of granite occur on the eastern side of Baio, but are of limited extent, and there is also a small outcrop to the west of Halisiruwa in the north-west of the area.

Numerous quartz veins of small extent occur in the older rocks of the area.

Tertiary sediments occur in the south-east of the area and extend in a north-westerly direction. It is considered that they are an infilling of a warp in the end-Tertiary erosion bevel and have been preserved by a capping of olivine basalt. Due to their unconsolidated and unsorted state it is thought that they are the products of a rapid mode of deposition.

The volcanic rocks range from Lower Pleistocene to Recent in age. The volcanic history of the area can be divided into three stages:—

- (i) Olivine basalt flows in the Lower Pleistocene forming cappings to the end-Tertiary erosion bevel.
- (ii) A broad flow of olivine-augite basalt in the western part of the Kaisut Plateau, and small flows of analcime basalt on all the olivine basalt plateaux of the area. It is difficult to differentiate between the ages of these two sets of activity but the age range is probably Middle to Upper Pleistocene.
- (iii) The formation of small vents and lava flows of limited extent and the production of explosion craters with widespread emission of ash. From the well-preserved characters of these features it is considered that they are Recent in age.

Large tracts of the area are covered by reddish-brown sandy soils derived from the disintegration of the metamorphic rocks. On close examination fragments of quartz, feldspar and ferromagnesian minerals can be seen. Small patches of secondary (kunkar) limestone occur and ferruginous secondary deposits are present locally, but generally the latter are of too limited extent to be shown on the map. The olivine basalt plateau lavas have a dusty, reddish brown soil cover through which blocks of the lava protrude.

A pale brown alluvium occurs on the south-western edge of the Kaisut Plateau. This is thought to be due to the damming of the drainage by the lava with the production of a lake after periods of heavy rain.

V—DETAILS OF GEOLOGY

1. Basement System

The Basement System rocks of the Laisamis area are considered to be a metasedimentary series and are classified under the following headings:—

- (1) Metamorphosed calcareous sediments
 - (a) Crystalline limestones.
 - (b) Calc-silicate granulites.
- (2) Metamorphosed semi-pelitic sediments
 - (a) Foliated biotite gneisses, biotite-muscovite gneisses and hornblende gneisses.
 - (b) Banded succession of biotite and hornblende gneisses.

- (3) Metamorphosed psammitic sediments.
 - (a) Quartzo-felspathic granulites.
- (4) Metamorphosed carbonaceous sediments.
 - (a) Graphite schists.

(1) METAMORPHOSED CALCAREOUS SEDIMENTS

(a) *Crystalline Limestones*

These form impersistent bands, varying in colour and thickness, in the biotite gneiss and biotite-muscovite gneiss succession. In hand specimen the limestones are typically white or light grey in colour, though one outcrop of pinkish crystalline limestone was also mapped.

Specimen 28/295* from Illim is typical of these crystalline limestones, and in thin section shows a mosaic of calcite crystals with tiny flakes of graphite scattered through the slide. Specimen 28/375 from an outcrop approximately three miles south-west of Kotira is an example of the pink-coloured limestone and in thin section shows calcite with typical rhombohedral cleavage. Also present in the thin section are small flakes of muscovite, small anhedral crystals of quartz, and a crystal of andesine.

(b) *Calc-silicate Granulites*

The term granulite is used in this report in the textural sense only, and has no connexion with the granulitic facies of metamorphism. The calc-silicate gneisses and granulites occur sporadically throughout the area but attain no great size. They are the result of the metamorphism of lime-rich patches of sediments.

In hand specimen the colour of these rocks varies from light green to black, depending on the proportions of the various minerals present. Specimen 28/361 from the slopes of the more northerly of the two hills in the south of the Ambara Plateau is a medium-grained melanocratic rock with patches of light green epidote. Tiny crystals of garnet are also scattered through the rock. In thin section it is seen to contain diopside pleochroic from light green to dark green, prisms of epidote and plagioclase feldspar in the form of oligoclase. Sphene occurs as an accessory mineral in crystals of varying size.

Specimen 28/364 from five and a half miles south of Martiagar is a melanocratic rock with a finely banded appearance. Thin section examination reveals that the dominant mineral is again diopside, with epidote also present. Andesine is the plagioclase feldspar and sphene occurs as an accessory mineral.

Specimen 28/371, from five miles west of Moile, is dark green in colour and granulitic in texture. In thin section it is seen to contain diopside, epidote and andesine with accessory sphene.

(2) METAMORPHOSED SEMI-PELITIC SEDIMENTS

(a) *Foliated Biotite Gneisses, Biotite-muscovite Gneisses and Hornblende Gneisses*

This group of metasediments occur in the eastern and central portion of the area and have a large width of outcrop. Commonly these gneisses form low ground but within the area of their outcrop there are several hills which stand well above the

* Numbers prefixed by 28/ refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

level of the plain. These rocks are the metamorphic equivalents of an original sedimentary sequence. In hand specimen the biotite gneisses are typically leucocratic, semipelitic rocks composed dominantly of quartz and feldspar, but flakes of biotite scattered through the rock impart a well-defined foliation to it. The degree of foliation depends on the amount of biotite present and with higher proportions of this mineral the foliation becomes more marked and the rock has less resistance to erosion and weathering.

In thin section the biotite gneisses are seen to contain biotite which is pleochroic from yellowish brown to dark brown, quartz, microcline and andesine feldspar. Some of the specimens contain small quantities of magnetite. Typical sections showing these assemblages are 28/348 from the eastern slopes of Baio and 28/360 from near the eastern margin of the Ambara Plateau.

Included in the pelitic metasediments are the biotite-muscovite gneisses which form bands in the biotite gneiss succession but are not of sufficient size to be delineated separately on the map. In both hand specimen and thin section (e.g. specimen 28/365 from south of Martiagar) they are very similar to the biotite gneisses in that they are composed of quartz, feldspar and biotite, but in addition flakes of muscovite occur.

Hornblende gneisses occur as discrete bands in the biotite gneiss and biotite-muscovite gneiss succession. In hand specimen they are generally leucocratic rocks with alternating bands of hornblende and quartz and feldspar. The colour of the hornblende varies from black to dark green and occasionally this mineral occurs in clots. A good example of this is specimen 28/337 from a point about two and a half miles north-east of Nalawuru. In thin section the minerals present are seen to be hornblende, pleochroic from light green to dark green, quartz, microcline, andesine and magnetite.

(b) Banded Succession of Biotite and Hornblende Gneisses

In many cases these gneisses are similar to the foliated biotite gneisses which have been described in the previous section. They occur in the west central portion of the area and have been mapped as an alternating series of biotite and hornblende gneisses. Except where it has been necessary to show the structure these rocks have not been differentiated as the change from one rock type to another is very rapid. The hornblende gneisses in this succession are similar petrologically to those already described as occurring as discrete bands in the biotite gneiss and biotite-muscovite gneiss succession.

(3) METAMORPHOSED PSAMMITIC SEDIMENTS

(a) Quartzo-feldspathic Granulites

The quartzo-feldspathic granulites are thought to be the end product of the metamorphism of arkosic horizons in the original sedimentary series. In the field they form features which are resistant to weathering due to the fact that they are largely composed of quartz and feldspar and have only minor amounts of mica. Outcrops are massive, occasionally with jointing at right angles to their strike, and are relatively short and narrow, suggesting that they were derived from impersistent bands of arkosic sediments.

In hand specimen the granulites are unfoliated, leucocratic, holocrystalline rocks and vary in colour from white to buff. The dominant minerals are quartz and feldspar, but small flakes of biotite and crystals of magnetite can be seen to be scattered through the rock in random orientation. In thin section there is a general uniformity of mineral composition and very little variation from one specimen to another. A typical example of these granulites is 28/312, from the Isiolo-Marsabit road five miles north of Laisamis, which shows a mosaic of quartz, microcline and andesine crystals with biotite flakes in random orientation. Magnetite crystals are also present in small amounts scattered through the slide. Sphene is present as an accessory mineral in some of the specimens,

notably 28/336 from two miles north-west of Chaparkrom. This specimen does not contain biotite in the thin section, but otherwise the minerals present are the same as in 28/312. Epidote is present as a band approximately one millimetre thick in 28/338 from the western flank of Losai. Also present are quartz, microcline and andesine with a few flakes of biotite.

(4) METAMORPHOSED CARBONACEOUS SEDIMENTS

(a) *Graphite Schists*

One band of graphite schist was mapped on the eastern slopes of Baio. Specimen 28/347 is an example of this rock which in hand specimen is seen to contain flakes of biotite and graphite. In thin section a certain amount of parallel orientation of the graphite and biotite flakes can be seen, with the spaces between these two minerals filled by quartz. The graphite amounts to about one per cent by volume of the rock.

2. Intrusives into the Basement System

(1) *Pre-metamorphic Intrusives*

Five major intrusions were found in the area, a pyroxenite body at Halisiruwa in the north-west, the Chaparkrom-Soito Narok amphibolite in the south-east, a serpentine lens intrusive into the Chaparkrom body, and two granitic intrusions, one in the north-west and the second to the east of Baio.

(a) *The Halisiruwa Pyroxenite*

Several rock types make up this body which consists of Halisiruwa Hill, the two hills immediately to the south and the low ridge to the west. The dominant rock is a garnetiferous pyroxenite but the north-west face of the most southerly hill from Halisiruwa is composed of garnetiferous diorite. Diffuse lenses of quartz and quartz-felspar pegmatite occur but are rare. At the top of Halisiruwa Hill there is an actinolite schist and a quartz-epidote rock with crystals of epidote up to three centimetres in length. On the ridge to the west of Halisiruwa laminated garnetiferous hornblende gneisses are present in the lower part and pass upwards into a garnetiferous pyroxenite with epidiorite patches and lenses. On the eastern side of the ridge there is much quartz float from quartz veins and small exposures of finely laminated hornblende gneiss with an equigranular texture. The lamination appears to be due to original compositional variations. There are also some exposures of coarse gneissose hornblende granite traversed by plagioclase amphibolite sills.

(i) *Garnetiferous Pyroxenites*

These form the dominant rock type of the intrusion. In hand specimen they are melanocratic holocrystalline rocks with abundant garnets scattered through them. In some specimens the garnets make up as much as 30 per cent of the rock by volume. Specimen 28/289, a typical example of these pyroxenites, shows in thin section a mosaic of garnet, diopside and hornblende with very small quantities of plagioclase felspar (labradorite). The hornblende was probably formed by the breaking down of diopside. Specimen 28/307 is very similar to 28/289 and comes from a three-foot lens in the garnetiferous diorite of the most southerly of the three hills. The main difference in thin section is that this specimen contains no felspar and that hypersthene is also present in large crystals.

(ii) *Garnetiferous Diorites*

The whole of the north-west face of the most southerly of the three hills is composed of a garnetiferous diorite, with diffuse bands varying from granitic to gabbroic in composition. Quartz lenses and quartz-felspar pegmatites occur but are rare. This garnetiferous diorite has not been differentiated on the map as it is not possible to show it on the scale used. A typical specimen, 28/306, is a leucocratic holocrystalline rock with quartz, andesine felspar, garnet and hornblende.

(iii) *Actinolite Schists and Quartz-epidote Rocks*

Both these rocks occur at the top of Halisiruwa Hill but do not form outcrops of any appreciable size, covering an area of only approximately 50 sq. feet. The actinolite schist, 28/287, is green in colour and shows a network of fibrous crystals of actinolite. Thin sections show fibrous actinolite and large actinolite crystals with a sub-parallel alignment. No other minerals are present. It is likely that the actinolite has been derived from the metamorphism of original pyroxenes. The quartz-epidote rock, 28/288, shows crystals of green epidote up to three centimetres in length together with small quantities of crystalline quartz.

(iv) *The Origin of the Halisiruwa Intrusion*

There are two possible hypotheses as to the origin of this pyroxenite. The first is that the body was emplaced as an eclogite and suffered retrogressive metamorphism to form a pyroxenite. Eclogites are rocks of high specific gravity composed of omphacite and garnet. Omphacite differs from the pyroxenes of normal igneous rocks in that it has a high content of Na_2O and Al_2O_3 and negligible amounts of TiO_2 . The garnets characteristic of this rock are lime-bearing almandine-pyropes. In chemical composition eclogite is equivalent to an olivine gabbro. The origin of eclogites is still a matter of dispute, but it is generally considered that they are products of high-grade regional metamorphism and have been formed at depth at high temperatures and pressures.

If then the Halisiruwa pyroxenite body were derived from an eclogite, it would seem probable that it was emplaced prior to the deposition of the sediments that now make up the Basement System rocks of the area, and is the product of a much earlier metamorphism which was of the eclogite facies and of which now the only remnants are at Halisiruwa. With the onset of the metamorphism of lower grade that succeeded the deposition of the sediments which now form the gneisses and granulites of the area the eclogite body suffered retrogressive metamorphism. Eclogites are very susceptible to diaphthoresis and the omphacite crystals break down in the initial stages to diopside and plagioclase feldspar, and finally go to hornblende. The garnets change to hornblende and epidote. In the thin sections of the rocks collected from the Halisiruwa pyroxenite it is seen that both diopside and garnet are present but feldspar is present only in very small quantities in one specimen. Epidote occurs as large crystals on the top of Halisiruwa Hill, as does an actinolite schist.

The second hypothesis is that the body was emplaced as a pyroxenite prior to or during the first stages of the metamorphism of the sediments and that this metamorphism caused the breakdown of the pyroxenes to hornblende, the garnets being formed at the same time. The presence of the granitizing fluids associated with the metamorphism led to the formation of the quartz and pegmatite veins and to the production of the garnetiferous diorite.

(b) *The Chaparkrom-Soito Narok Amphibolite*

This intrusion has an arcuate form and extends into the area to the south. It is concordant with the Basement System rocks of the south-eastern part of the area and has been folded with them. The intrusion varies in width from about 1,200 feet in the south to about 6,500 feet at Chaparkrom. At Soito Narok the low hill forming the outcrop is practically bare rock and the amphibolite appears as a black rock with glistening prisms of amphiboles. In places this intrusion bears a resemblance to the Halisiruwa body in that garnet and epidote are present locally, but the former never reaches the proportions in which it is present at Halisiruwa.

The thin section of one of the specimens collected from Chaparkrom, 28/325, shows hornblende, pleochroic from bright green to dark green, with quartz and epidote. Feldspar is rather rare but is present in this section as labradorite, and pyroxene relics are also present. This section shows a roughly developed alignment of the hornblende

prisms. From the outcrop at Soito Narok, specimen 28/327 shows feldspar present in greater proportions, and in this specimen is andesine. Hornblende, epidote and quartz are again present as are relics of pyroxenes. Specimen 28/332 is a green holocrystalline rock composed of hornblende with needles of epidote.

From the evidence of relics of pyroxenes which are present in some slides it is likely that this intrusion was emplaced as a gabbro. During the metamorphism and folding of the Basement System the pyroxenes were changed to amphiboles and a crude foliation was impressed on the rock by the parallel or sub-parallel alignment of the amphibole prisms.

(c) *Serpentinite*

This forms a lens-like body within the amphibolites of Chaparkrom aligned parallel to the length of the intrusion and hence parallel to the regional strike, which at this point is east-west. In length the lens reaches nearly three-quarters of a mile, with an outcrop width of about 200 yards. Along the contact between the serpentinite and the amphibolite there is no indication of any metamorphic effects and it is assumed that the serpentinite was intruded at a temperature which was low enough not to produce any contact phenomena. In hand specimen (28/333) it is dark green in colour, homogeneous and unfoliated, and thin section examination shows olivine crystals surrounded by fibrous antigorite and accessory magnetite. This body is cut by veins of magnesite seldom more than three or four inches thick, which have a random orientation.

(d) *Granites.*

Two occurrences of granite were mapped in the area. The first is in the north-west of the area, to the west of Halisiruwa at the southern end of a short river exposure. It is a faintly gneissose porphyritic granite with offshoots which penetrate the surrounding hornblende rocks. In hand specimen (28/309) it is a mesocratic holocrystalline rock, the thin section showing quartz, andesine feldspar, biotite and small quantities of muscovite.

The second exposure of granite is on the plain below the eastern slopes of Baio. Several small outcrops are exposed there and form impressive features which rise abruptly from the plain and present a bare rock surface with little or no vegetation. They have the form of exfoliation domes, being elliptical or round in plan and possessing a crude concentric foliation, probably due to temperature variations.

In hand specimen this rock is leucocratic and holocrystalline with visible quartz, feldspar and abundant biotite. Specimen 28/352, a typical example, in thin section is seen to be composed of quartz, albite feldspar, biotite and small quantities of hornblende. There is no indication of any contact metamorphic phenomena between the granite and the country rock, but it has been noted that at Rosguill, Co. Donegal, Ireland (Knill, 1961), that the emplacement of a granodiorite into regionally metamorphosed sediments has only produced porphyroblastic biotite and small quantities of cordierite and muscovite in the contact aureole.

(e) *Pegmatites*

Pegmatites are common in the Basement System rocks of the area, and vary in size from a few inches up to six feet in width. The majority of the larger pegmatites are concordant with the strike of the Basement System rocks, but the smaller ones tend to cross-cut. All are leucocratic, coarse-grained rocks consisting dominantly of quartz and microcline feldspar. Small amounts of other minerals are present in some, notably muscovite and magnetite, but neither occurs in economic concentrations.

(2) QUARTZ VEINS

These are numerous in the metamorphic rocks of the area but never attain a large size and none have well-formed crystals of quartz. In only one case is there any mineralisation associated with them, in the outcrop to the east of Halisiruwa Hill, where there are needles of tourmaline.

3. Tertiary Sediments

These occur in the south-eastern portion of the area and extend in a north-westerly direction. They underlie the Tirkamo Plateau and the eastern side of the Rusarus Plateau. A vertical section at the northern end of the Rusarus Plateau shows the following succession:—

	<i>approx. thickness (feet)</i>
9. Olivine basalt	(25)
8. Brown sand with quartz grains	20
7. Red and green sand with quartz pebbles	12
6. White sand with quartz pebbles	6
5. Local wedges of quartz conglomerate and sand	1.5
4. Red and green sand with quartz and felspar	8
3. Brown sand with quartz and quartzo-felspathic pebbles	12
2. Reddish sand and quartz grains	9
1. Red and green sand with quartz, felspar and asbestos fibres	9
	77.5

The mineral assemblages and fragments of rocks present indicate derivation from Basement System rocks. There is no sorting in the individual units of the sediments and the pebbles and sand grains are intimately mixed. The sand is poorly washed and unconsolidated, and in attitude the sediments are horizontal to sub-horizontal.

The succession of the sediments is much thicker at the southern end of the Rusarus Plateau than at the northern end, and is also thicker under the olivine basalt of the Tirkamo Plateau than at the latter locality. These sediments are probably equivalent to the Merti Beds of the Chanler's Falls area (Williams, 1966, p. 36), and the sediments underlying the Barchuma Plateau of the Barchuma-Kom area (Dodson, Report No. 93, in preparation). The sediments of both these areas are similar lithologically to the sediments of the present area. The sediments were deposited in a trough in the end-Tertiary erosion surface and it is likely that this trough was produced by local down-warping of the surface, so that the sediments are probably late Tertiary in age. Since the sediments are ungraded and unsorted a rapid mode of deposition is indicated. It is probable that the material of the sediments was transported by water, possibly during periods of heavy rain, and swept into the trough from the surrounding higher ground. The angularity of the fragments precludes their having been transported over great distances. No traces of organic remains were found in the sediments.

4. Pleistocene and Recent Volcanic Rocks

The lack of fossils in the sediments underlying the Rusarus and Tirkamo plateaux makes it difficult to date the overlying volcanics with any degree of certainty. The age range is probably from Pleistocene to Recent, although the lower age limit of the olivine basalt plateau lavas could possibly be put in the late Tertiary since they preserve the sediments which accumulated during the end-Tertiary cycle of peneplanation.

For the purpose of petrographic description the volcanic rocks of the area are described as follows:—

- (1) Olivine basalt plateau lavas.
- (2) Olivine-augite basalts of the Kaisut Plateau.
- (3) Analcime basalts.
- (4) Vents and associated olivine basalt lavas.
- (4) Tuffs and agglomerates.
- (6) Explosion craters.

Figure 2 shows the distribution of the volcanic rocks in the area and it can be seen that the last three groups are concentrated in the eastern part of the area. The explosion craters are particularly well preserved, as are the volcanic vents north-west of Laisamis.

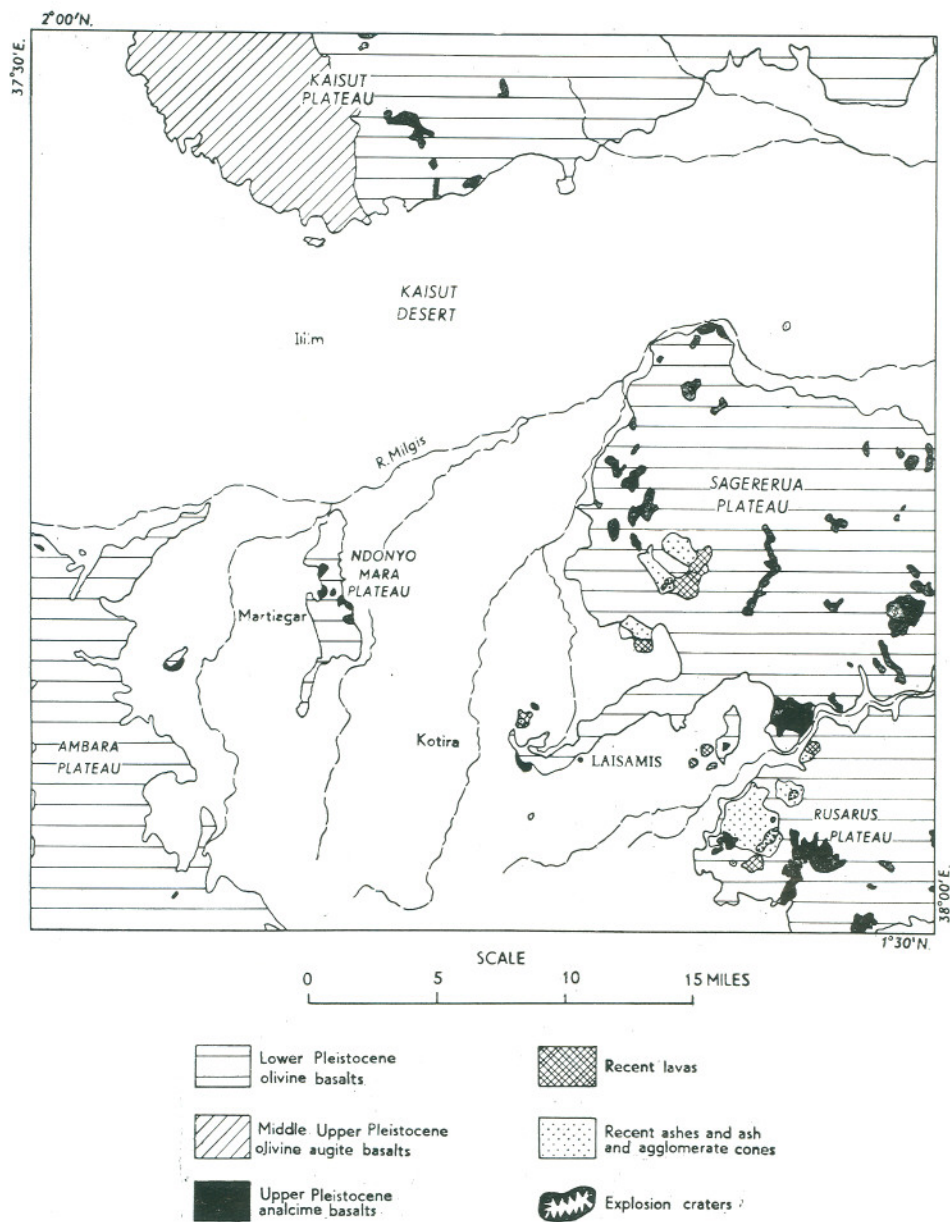


Fig. 2—Sketch-map of the volcanic history of the Laisamis area.

(1) OLIVINE BASALT PLATEAU LAVAS

These lavas are widespread in the area and form cappings, varying in thickness from 10 to 20 feet, on remnants of the end-Tertiary erosion bevel. In hand specimen they are melanocratic, aphanitic rocks with phenocrysts of olivine present in some and sparse microphenocrysts of feldspar in one specimen. In most cases the lavas are massive, but some specimens are scoriaceous while others show a tendency to vesicularity.

In thin section these lavas are seen to have a uniform mineral composition. Specimen 28/300 from the Sagererua Plateau is a typical example and shows olivine phenocrysts marginally altered to iddingsite. The groundmass consists of augite, laths of labradorite feldspar and magnetite. Calcite is present as an infilling in the vesicles. Similar specimens are 28/310 from the Kaisut Plateau, 28/340 from the small outlier by the Isiolo-Marsabit road three miles south-west of Laisamis and 28/368 from the Ambara Plateau. Slight variations in these specimens consist of differences in the iddingsite alteration of the olivine phenocrysts; in some thin sections crystals of olivine have undergone complete alteration while in others there is very little change. The groundmass also shows textural variations, that of 28/368 being very much coarser than any of the others.

The olivine basalt lavas of these plateaux originated from fissures, though none were seen, and are probably penecontemporaneous with the earliest Marsabit vulcanicity (Parkinson 1924, p. 102). In a later paper Parkinson (1939, p. 165) postulated the original northward continuation of the Merti Plateau to include those plateaux which lie to the east of the old road from Laisamis to Langaia. The lava-capped Merti Plateau lies nearly 40 miles south-east of the nearest plateau of the present group, a distance which would appear to be too great for there to be any direct connexion between the two, and it seems that these lava plateaux had their origins in a series of separate fissure eruptions. It is more than likely however, that the Rusarus and Sagererua plateaux were at one time a single plateau and that subsequent dissection by the Seralatubi River led to their present separation. None of the remaining plateaux in the area have any apparent connexion with each other.

(2) OLIVINE-AUGITE BASALTS OF THE KAISUT PLATEAU

The olivine-augite basalts show up very distinctly on aerial photographs, and are clearly separate from the olivine basalts of the Kaisut Plateau which they overlie in the western part. The lava is devoid of vegetation of any kind but has a thin covering of soil. Since this lava is younger than the olivine basalt plateau lava its age is probably Middle to Upper Pleistocene.

The plateau formed by the lava rises 10 to 15 feet above the surrounding country. The flow shows a crudely developed form of columnar jointing, being composed of large polygonal blocks with vertical long axes and generally flat tops. The columns dip inwards at the sides of the plateau and the flattish upper surfaces define the marginal top of the flow which slopes down at the plateau margins at angles of 15 to 20 degrees, but locally reaches 45 degrees. Well-developed radial and marginal fissures up to 10 feet deep occur at the plateau margins. The fissures from which this lava was erupted are not seen.

In hand specimen the lava is a melanocratic holocrystalline basalt with olivine microphenocrysts, and is highly vesicular. A secondary calcite infilling of the vesicles is occasionally present. In thin section the three specimens collected, 28/303, 28/304 and 28/305, show a uniform mineral composition with olivine and augite being the major components. Some of the olivine crystals have alteration rims of iddingsite. The plagioclase feldspar is labradorite and small quantities of magnetite are also present.

(3) ANALCIME BASALTS

On all the olivine basalt plateaux a series of younger fissure flows are present. Vegetation, apart from an occasional tree growing from soil trapped in crevices, is absent as there is no surface soil cover present as there is on the olivine-augite basalts of the Kaisut Plateau. These lavas rise up to 50 feet above the level of the olivine basalt plateau and vary greatly in extent. Some of the flows consist of merely small isolated ridges a quarter of a mile long while others cover quite appreciable areas. These flows are probably Middle to Upper Pleistocene in age.

On the Ambara Plateau in the west of the area these lavas are comparatively rare, but there is a gradual increase in the frequency of their occurrence towards the east and it is in that part of the area, in the southern portions of the Rusarus and Sagererua plateaux, that they have their maximum development. In outcrop these lavas, particularly the smaller flows, consist of piles of angular blocks and it is only towards the centre of the larger flows that there is any indication of columnar jointing, but this is only very crudely developed.

In hand specimen these rocks are melanocratic holocrystalline basalts with olivine microphenocrysts and all are slightly vesicular, with the vesicles of some specimens lined with secondary calcite. Specimen 28/297 from the northern part of the Sagererua Plateau is a typical example, and shows olivine phenocrysts, many of them with iddingsite alterations, with augite, labradorite, magnetite and analcime in the groundmass. Not all the specimens collected contain analcime but from their similarity both in hand specimen and in outcrop all have been classified under the one heading.

(4) VENTS AND ASSOCIATED OLIVINE BASALT LAVAS

Three well-preserved vents lie to the north-west of Laisamis and are considered to be of Recent age. The tuffs and agglomerates and explosion craters which will be described in the two subsequent sections are also thought to be Recent. The two northern vents have not produced large quantities of lava, the flows being sufficient only to build up the cones, but the southern one has produced flows from two vents, of which now only one remains, on the south-eastern side of the cone. The summit is composed of ash and agglomerate and the vent which produced the flows around the northern and eastern sides of this volcano was presumably sited on the eastern flank. The vents are comparatively shallow features and access to them is easy.

Other lavas of Recent age are present around the feet of cones, such as Sengerarua, on the eastern side of the explosion crater to the south of Sengerarua, and around the foot of the cone on the south-eastern margin of the Sagererua Plateau. The trigonometrical point of Limirina on the Rusarus Plateau is entirely composed of Recent lava.

All the Recent olivine basalt lavas show a marked similarity in hand specimen and in thin section. All are melanocratic, holocrystalline, fine grained rocks with olivine microphenocrysts. Specimen 28/314, from the middle vent of the group to the north-west of Laisamis, also has phenocrysts of feldspar, but in thin section this rock is seen to be a contaminated lava. It contains olivine and andesine feldspar, and quartz and microcline. The two latter have been derived from fragments of Basement System gneisses caught up and partially assimilated by the lava. The groundmass, like that of all these lavas, is fine-grained and heavily impregnated with magnetite.

Specimen 28/302 from the lava on the eastern side of the craters south of Sengerarua contains olivine phenocrysts, some of which have iddingsite alterations. The fine-grained groundmass consists of augite, andesine feldspar and magnetite, with secondary calcite.

The lava flow at the foot of Sengerarua from which specimen 28/301 was taken shows phenocrysts of olivine and augite. The groundmass is extremely fine-grained, almost glassy.

Specimen 28/319 from the western foot of Limirina has phenocrysts of olivine extensively altered to iddingsite, augite, and leucoxene probably derived from titaniferous magnetite. Only magnetite and small crystals of augite are recognizable in the very fine-grained groundmass.

(5) TUFFS AND AGGLOMERATES

These occur mainly on the eastern side of the area, particularly on the Sagererua and Rusarus plateaux, but there is also a small hill of tuff in the north-central portion of the Kaisut Plateau. The highest hill in the east, Sengerarua which is 2,360 feet high, is conical with steep sides composed of ash and agglomerate which make climbing difficult. The tuffs are generally weathered and unconsolidated. In the case of Sengerarua and the hill three and a half miles to the south-south-west, the emission of the tuffs and agglomerates was preceded by lava flows which covered only small areas around the feet of the cones, and which have been described in the preceding section.

On the Rusarus Plateau there are several small hills composed of tuffs and basaltic agglomerates which have not been preceded by lava flows.

(6) EXPLOSION CRATERS

These are spectacular phenomena and occur only on the eastern plateaux. The main centre of their occurrence is on the Rusarus Plateau but two small craters are also present on the Sagererua Plateau. These two craters, one mile south-south-west of Sengerarua, are interconnected.

A total of seven craters are present on the Rusarus Plateau but from none of these was there emission of lava prior to the formation of the craters. Of the seven craters present on this plateau, four are interconnected to form one large one which is elliptical in shape. The remaining three craters, the last two of which are also interconnected, lie to the north of this along a line trending north-north-east. The significance of this line will be discussed later.

All the craters show a close similarity in form, the rims being composed of bedded tuffs which dip outwards from the craters at angles varying from 18° to 26°, and all have steep inner walls, making a descent to the bottom virtually impossible. The highest points of all the craters are on the western sides, and tails of tuff extend in a north-westerly direction, indicating that the prevailing wind at that time was from the south-east.

Contained in the tuffs which fringe the craters are blocks of basalt and crystals of olivine. Specimen 28/321 from the western rim of the largest crater immediately to the north of Limirina is a cluster of pale green olivine crystals with small magnetite crystals. No traces of metamorphic rocks were found around the rims of the craters but the thin section of a secondarily compacted tuff, 28/324 from a stream bed to the west of Rusarus Plateau, shows quartz and microcline accompanying augite, olivine and labradorite, indicating that Basement System rocks were involved in the explosions.

With regard to the origin of these craters there are two possible explanations. The first, which applies particularly to those craters on the Sagererua Plateau, surmises that after the emission of the lava which flowed northwards the vent became blocked by the cooling lava, leading to a building-up of pressure in the magma chamber. This pressure when sufficiently high overcame the blockage and removed the top of the volcano in the ensuing explosion, scattering showers of ash and basaltic fragments over the adjacent area. The second theory is that in the initial stages the magma was emitted not as lava but as tuff, and a cone was built up. The discharge of the magma created a void in the magma chamber into which the cone collapsed.

The alignment in a north-north-easterly direction of the craters on the Rusarus Plateau has already been noted. This line can be extended southwards to include the cone of Limirina. The same alignment is seen in the craters on the Sagererua Plateau. Extension of this line to the north brings in the cone of Sengerarua, and an extension in a southerly direction shows that the volcanic vents lying to the north-west of Laisamis also lie along this line. It is obvious that these two north-north-easterly trending lines have a structural significance and have to a great extent determined the situation of the craters and volcanic vents. It is also significant that the large crater on the Rusarus Plateau is sited on the intersection of one of these north-north-easterly trending lines and the continuation of a fault which runs in a south-easterly direction and which downthrows to the south-west. The intersection of this fault with the line joining Sengerarua and the volcanic vents to the north-west of Laisamis does not produce any phenomenon at that point.

5. Superficial Deposits

(1) CALCAREOUS CRUSTAL DEPOSITS

Small patches of secondary limestone (kunkar) occur in various parts of the area. The largest outcrop is on the eastern side of the Manderay River, to the south-east of the Ndonyo Mara Plateau, which apparently overlies crystalline limestone. In hand specimen 28/359 this buff-coloured limestone shows quartz inclusions, and thin section examination reveals the presence of quartz and amphiboles set in a fine-grained calcareous matrix with patches of crystalline calcite. Another occurrence of secondary limestone is present to the north of Laisamis, on the eastern side of the Marsabit Road, where the limestone is present only as small fragments scattered about the surface. This deposit, like other small deposits throughout the area, is too small to be shown on the map.

Kunkar limestone is characteristic of areas with limited rainfall and hence is useful as a climatic indicator. It owes its origin to capillary action which draws lime-rich water to the surface, where by evaporation a calcareous deposit is formed.

(2) FERRUGINOUS CRUSTAL DEPOSITS

These occur to a limited extent in the area mapped, but none attain a large size and most are too small to be shown on the map. One outcrop exists on the southern side of the Illaut-Laisamis track east of Losai. In outcrop the deposit is unconsolidated and brown in colour and contains fragments of metamorphic rocks. A similar but much smaller deposit exists about a mile west of Moile.

The origin of these ferruginous deposits is similar to that of the calcareous deposits, i.e. capillary action which drew iron-rich water to the surface where it evaporated.

(3) PEBBLE SHEETS

These were encountered only in one locality, close to the amphibolitic intrusion of Chaparkrom. The pebbles are of angular quartz, derived from quartz veins on the hill east of Chaparkrom.

(4) RECENT SANDS AND ALLUVIUM

Reddish brown sands are extremely common and form a blanket over much of the region to the south of the Kaisut Plateau, a cover broken only by inselbergs such as Illim and Baio. Examination of these sands shows that they contain fragments of quartz, feldspar, hornblende and biotite and hence are derived entirely from metamorphic rocks.

Pale brown alluvium is present along the south-western portion of the Kaisut Plateau, marking the site of a small lake. Alluvium is also present along stretches of the Milgis River.

VI—METAMORPHISM

The metamorphic rocks of the area have been derived from sediments which are thought to have been deposited in the Mozambique geosyncline (Holmes, 1951). The period of sedimentation was followed by down-warping of the crust accompanied by folding and regional metamorphism whereby the original arenaceous, argillaceous and calcareous sediments were converted into psammitic, semi-pelitic and calcareous metamorphic rocks.

It is probable that in the late stages of orogenesis the metamorphic rocks were subjected to metasomatism, a process which in this case involved the introduction of alkalis. Metasomatism has been defined by Goldschmidt (1922, pp. 105-123) as "a process of alteration which involves enrichment of the rock by new substances brought in from outside" and this enrichment occurs "by definite chemical reactions between the original minerals and the enriching substance". The degree of metasomatism therefore is largely controlled by the original composition of the host rock and by textural and structural details, as joint planes for example greatly facilitate the movement of the metasomatic agents. Rocks of calcareous and quartzitic composition are little susceptible to metasomatic processes and often provide barriers to the passage of the agents of metasomatism.

In the Laisamis area the ancient rocks have been subjected to potash metasomatism leading to the formation of the potash feldspar microcline, which is greatly in evidence in the gneisses. The degree of metamorphism attained by the Basement System rocks is indicated by a comparison of the mineral assemblages present with the idealised assemblages present in regionally metamorphosed rock as described by Turner (Fyfe, Turner and Verhoogen, 1958, pp. 215-239). In this area typical mineral assemblages are:—

Semi-pelitic and quartzo-feldspathic assemblages:—

- (a) Quartz-microcline-plagioclase-biotite.
- (b) Quartz-microcline-plagioclase-muscovite.

Calc-silicate assemblages:—

- (a) Garnet-epidote-plagioclase-diopside.

Basic assemblages:—

- (a) Hornblende-plagioclase.
- (b) Garnet-diopside-hornblende.

These assemblages show that the metamorphic grade of the rocks corresponds to a sub-facies of the almandine-amphibolite facies of metamorphism, either the kyanite-almandine or the sillimanite-almandine sub-facies, although neither kyanite nor sillimanite were seen during the survey. The non-development of these minerals is probably due to an insufficient quantity of alumina in the original sediments. A single occurrence of sillimanite was found in the Kauro-Merille area (Rix, Report No. 92) some eight miles south of Soito Narok.

VII—STRUCTURE

Over the major part of the area the structure is straightforward and shows a series of folds with dominantly north-south axes. Several of these folds are overturned to the west. Foliation in the area is best developed in the biotite gneiss succession, and to a lesser degree the hornblende prisms of the hornblende gneisses cause a crude foliation to be developed. The intrusion at Chaparkrom, being dominantly composed of hornblende, has a weakly developed foliation.

Lineations are useful in the elucidation of the structure of an area because they reflect the direction and magnitude of the plunge of a fold axis. They occur in the Laisamis area as alignments of biotite flakes, or more often as alignments of quartz crystals on the foliation planes of the rocks of the Basement System. Measured lineations plunge gently to the north over most of the area, but in the south-eastern portion there is a steepening of the angle of plunge.

The Basement System rocks in the south-eastern portion of the area show a divergence from the north-south trend of the rest of the area, there the alignment being in a north-westerly direction. As Laisamis is approached the rocks revert to the normal north-south trend. At first sight it would seem that cross-folding had taken place as at the extreme limit the trend is east-west. The lineation plunges are steeper here than elsewhere in the area. This area of disturbance can be traced into the Kauro-Merille area to the south, and to interpret the structure it is best to consider the north-eastern part of the Kauro-Merille area and the south-eastern part of the Laisamis area as one unit. In that part of the Kauro-Merille area (Rix, Report No. 92) the foliations indicate that some closures which are difficult to interpret are in fact overturned folds. The lineations indicate that no second folding is involved and that the axes have a persistent north-south trend. A stereogram of foliations and lineations plotted by Rix shows the lineations plunging both north and south. In the Laisamis area the overturning is not so acute as in the Kauro-Merille area and the dip of foliations varies between east-south-east and north. The lineations also plunge to the north, at steep angles in the south-east but becoming less steep closer to Laisamis. It therefore appears that the local overturning of folds was a direct result of the main episode of folding.

Only one visible fault was mapped during the survey although it is possible that other faults exist beneath the widespread cover of superficial deposits. The fault mapped is a post-Pleistocene feature as it cuts the olivine basalt lava of the Sagererua Plateau. It trends in a south-south-easterly direction, downthrowing to the south-west with a maximum throw of 50 feet. It continues across the south-west corner of the Tirkamo Plateau, but there is no indication of it on the Rusarus Plateau.

Mention has already been made of the two north-north-easterly trending lines linking the explosion craters on the Rusarus Plateau and the craters and cones on the Sagererua Plateau and the vents to the north-west of Laisamis. These lines appear to be due to structural weakness in the underlying Basement System rocks as the lines of features on the Rusarus Plateau can be traced into the area to the south. It has also been noted that the craters on both the Sagererua and Rusarus plateaux are situated on or close to the intersection of these lines with the south-easterly trending fault line, and probably owe their positions to this cause.

VIII—ECONOMIC GEOLOGY

Local concentrations of economic minerals were found during the survey of the area, but in none of the occurrences were the minerals present in sufficient quantities to warrant exploitation. The nearest railhead is Nanyuki, some 160 miles to the south, and unless a low-price mineral is present in sufficiently large amounts it will prove uneconomic to exploit the deposit due to the high costs of transportation.

Mica.—Mica was found associated with pegmatites in the area, but none of the books were bigger than two inches long and one inch thick.

Magnetite.—This was found in small quantities on the western slopes of Halilugum Nder as float from a pegmatitic vein.

Magnesite.—Associated with the serpentinite intrusion on Chaparkrom are randomly oriented veins of magnesite generally not more than a few inches in width. The total tonnage available is too small to warrant exploitation.

Garnet.—Quantities of almandine garnet are present in the intrusive body at Halisiruwa. Soils around the base of the intrusion contain eroded garnets, but these are of limited extent and the garnets themselves are flawed.

Tourmaline.—Prisms of black tourmaline are developed in quartz to the east of Halisiruwa.

Graphite.—A graphite schist was mapped on the eastern slopes of Baio. The outcrop is only of limited extent and the graphite content does not exceed one per cent.

River Sands.—Ample supplies of clean quartz sand are available from the sand rivers for use as building material. There is however no foreseeable demand in the area for this material.

Road Stone.—Should the need arise for material for roads in the area there are supplies of volcanic rock which could easily be broken up and used for this purpose. The present Isiolo-Marsabit road can be used only in dry weather but it is unlikely that a tarmac road will be constructed for many years.

Radioactive Minerals.—Radiometric monitoring was carried out in conjunction with the daily work of the survey, but no anomalies were found.

Water.—By far the most precious commodity in the area is water, and its presence or absence is one of the controlling factors in the movements of the people who live there. Dr. F. Dixey (1944) made a hydrographical survey of the Northern Province in 1943 and noted that at that time there was no permanent water in the Kaisut region as the borehole at Lokuloko which had been drilled by army engineers in the early part of the war had ceased to operate and had been filled with stones. He recommended that this borehole should be reopened or a new one put down close by, and suggested that drilling in the stream courses to the south of Lokuloko would offer a good chance of success. As a result of this survey a firm of consulting engineers, Howard Humphries and Sons, was appointed in 1950 to put into effect Dr. Dixey's recommendations in the Northern Province and Samburu Region.

In the present area the only flowing water occurs at Laisamis. This is due to the presence of Basement System rocks which form a natural sub-surface dam across the river. Quantities of water can be held by the sand of river beds throughout the year, and where the sand cover above the metamorphic rocks is thin the water table may rise and water flow on the surface until the sand cover is sufficiently thick for it to become sub-surface water again. At Laisamis the water flows on the surface for about 150 yards and the amount is sufficient to serve the needs of the people and their animals. For this purpose a concrete well and drinking trough have been installed.

Elsewhere in the area water can be obtained by digging in some of the sand rivers.

Boreholes have been drilled at two places in the north of the area, at the trading centre of Lokuloko and to the south-east of Halisiruwa. At the latter locality a large shallow lake forms after rains and water is available there for short periods. The borehole, drilled at the edge of the lava flow, was completed by the Ministry of Works in August 1960.

The log of this borehole is as follows:—

Halisiruwa—C. 3056.

<i>Feet</i>			
0-10	Ferruginous sand.	130-150	Quartz and felspar sand.
10-32	Coarse sand of lava.	150-170	Sandy deposit.
32-70	Dark brown lava.	170-252	Sandy clay.
70-130	Brown sandy clay.	252-330	Basement System rocks.

Total depth of borehole—330 feet.
 Water struck at 252 to 297 feet and at 320 feet.
 Water rest level—218 feet.
 Estimated yield—400 to 800 gallons per hour.

The borehole at Lokuloko, as already mentioned, was drilled to a depth of 244 feet, with the water rest level at 209 feet, but had been filled in with stones prior to 1943. It was cleaned out and extended to a depth of 280 feet by Howard Humphries and Sons and equipped with a mechanical pump.

The log of the borehole is as follows:—

Lokuloko—C. 1758.

<i>Feet</i>		<i>Feet</i>	
0-3	Red soil.	183-187	Decomposed lava.
3-38	Boulders.	187-216	Old land surface.
38-40	Clay.	216-236	Decomposed lava.
40-68	Lava.	236-245	Lava.
68-95	Clay and sand.	245-268	Old land surface.
95-183	Lava.	268-280	Solid rock.

Total depth of borehole—280 feet.
 Water struck at 229 feet.
 Water rest level—215 feet.
 Estimated yield—1,750 gallons per hour.

In their recommendations for further supplies of water the consulting engineers suggest (Humphries, 1958) that boreholes should be drilled between Baio and Halilugum Nder, and in the vicinity of the old airstrip to the west of the Isiolo-Marsabit road and just to the north of the Sagererua Plateau, where they say that water is fairly sure to be struck at a depth of about 300 feet.

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