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GEOLOGY OF THE KAURO-MERILLE AREA

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

by

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ABSTRACT

The report describes an area of some 3,100 square kilometres (1,200 sq. miles) in north-central Kenya, bounded by parallels 1°00′ and 1°30′N, and meridians 37°30′ and 38°00′E. Approximately one-fifth of the area consists of lavas which were extruded on to a surface of metamorphic rocks, this surface being exposed over much of the remaining area.

The metamorphic rocks, of Precambrian age, comprise mainly metasediments (psammitic, semi-pelitic and calcareous) and migmatites, with some orthogneisses. Rocks intruded into the Precambrian metamorphics include peridotites, dolerites and acid intrusives.

The lavas of late Tertiary and Recent age, are all basic, mainly basalts and basanites. They are locally underlain by Pliocene sandstones. Other deposits are calcareous, ferruginous and siliceous crustal deposits, with marls, pebble sheets and soils.

Detailed accounts are given of the petrography of the rocks, and of the structure and metamorphism of the Precambrian metamorphics. The economic potential and water supplies of the area are discussed.

GEOLOGY OF THE KAURO-MERILLE AREA

I—INTRODUCTION

The tract of country described in this report is approximately 3,100 sq. kilometres (1,200 square miles) in area, situated in north-central Kenya between latitudes 1°00′ and 1°30′N and longitudes 37°30′ and 38°00′E.

This area is part of the semi-arid region of northern Kenya. Rainfall is not recorded anywhere in the area, but is probably in the region of 250 millimetres per year, and comes in the two short rainy periods in April to May and November. The vegetation is chiefly acacia thorn bush, with doum palms, euphorbia and various other species of acacia forming verdant fringes along the larger sand rivers.

The majority of the area falls within the Samburu District of Rift Valley Province. The northern and north-eastern portions of the area are part of Marsabit District of Eastern Province, and a small portion in the east and south-east forms part of Isiolo District, also of Eastern Province.

The Isiolo-Marsabit main road marks the eastern boundary of the Marsabit National Game Reserve, and a Game Ranger post for the Reserve is situated at Lodosoit.

The population of this region is nomadic, the majority belonging to the Samburu tribe whose lands extend westwards into the Mathews Range and beyond. However, small portions of the Kauro-Merille area are occupied by Boran and Rendille tribesmen. The former live in a small area in the Isiolo District in the east, and the latter occupy the land north of the Merille river and extend towards Marsabit.

The Samburu are mainly cattle herdsmen, but also keep sheep and goats, the whole of their territory being heavily overstocked. The Rendille occupy land that becomes progressively more arid northwards from the Merille river, and as a result herd the hardier camel rather than cattle. In those areas the camel also replaces the donkey as a beast of burden.

Access to most parts of this region is relatively easy because of the sparse vegetation and the well drained country with sandy interfluves, which are ideal for motor track alignments. The only major road in the region is the Isiolo-Marsabit road which traverses the west-central part of the sheet.

Apart from this major road there are no maintained roads, the other vehicle routes being rough tracks which provide access to trading centres such as Kauro, Lodosoit, and Koiya.

The old Isiolo-Marsabit safari route, formerly used by ox-wagons, was found to be motorable without too much difficulty northwards from Kauro. The track has a good interfluve alignment from Lenkaya northwards, skirting the volcanic cones at Sasani before crossing the Merille river and continuing to Laisamis. The Inkiposorogi-Lodosoit track continues north-westwards, providing access to the Ndoto mountains region.

Maps.—No large scale maps of this area existed before the present survey, the only useful existing map being the Army 1:250,000 sheet, Maralal N.E., which was consulted regularly but was inadequate for detailed work.

The present map was constructed from aerial photographs, using existing trigonometrical beacons and additional plane table points as ground control, to establish the scale of photographs and finished map. Kodatrace overlays were used for the detailed topographical and geological information. The field strips were prepared on a scale of 1:50,000 and this was reduced photographically to 1:83,333 for final two-thirds mechanical reduction to the printed scale of 1:125,000. The form lines on the map were constructed from the spot heights and form lines on the army map, and further spot heights established during the survey, and must be regarded as approximate only.

II—PREVIOUS GEOLOGICAL WORK

Few early explorers did detailed work in this area, although a number of them crossed it en route for other destinations.

In 1903, Count Wickenburg (1903)* crossed the north-east corner of the region on his travels southwards to Lamu. He passed through Koiya and mentioned the presence of low plateaux and isolated low cones between Laisamis and Merti.

By far the most detailed early exploration of this region was by G. F. Archer (1913) who started exploration of the area north of the Uaso Ngiro river from an outpost which he had set up on that river. He journeyed northwards from the river towards Marsabit in 1909, passing through Kauro, Kinya and Laisamis. He mentioned the waterholes at Kauro and Kinya before embarking on a more detailed description of the features of the Kauro-Merille drainage system. He noted the perceptible rise over the Uaso Ngiro—Kauro-Merille watershed and the more gradual slope northwards to Marsabit. He believed that the Merille had a semi-circular course bending south-eastwards to join the Uaso Ngiro below Chanler's Falls.

Archer followed what was probably an old caravan route to Marsabit which led from Kauro to Langoia, where he discovered a spring issuing from the north-east corner of a line of granite hills, and hence to the Merille Khor, where he noted that abundant water was available by digging. He also described an alternative route farther east via Kere, Turugong, Kabai and Sirah to reach the Uaso Ngiro some 24 miles downstream from his outpost. East of his route he described "..... a succession of low plateaux, or tablelands, which are bounded by abrupt lava scarps. For the most part the ground, some 200 or 300 feet above the surrounding level, is very broken, and is composed of black cotton soil freely strewn with lava ....." He also described the lower country between the plateaux, "..... in the intervening spaces the surface is of hard sand, covered with open thorn bush and freely intersected by dry channels .....".

In 1911 Captain C. N. French (1913) travelled from Marsabit to the Uaso Ngiro, probably along the same route as that taken by Archer.

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* References are quoted on page 29.

J. Parkinson (1920) in notes on the northern part of the East African Protectorate wrote that the distinction between old lavas capping the scarps and newer rocks on lower levels was easy to make. The latter type is readily distinguished to the south of the Merille where well preserved 'puys' and a thin crust of volcanic ash are to be found. He pointed out that the newer lavas could be of no great age, as indicated by their marked blackness, rougher, more irregular and scoriaceous surfaces, their usual ropey structure and by the fact that they support little or no vegetation. He described the Kauro-Merille system as being one of the three major drainage systems of the Northern Province and refuted an earlier suggestion from A. Donaldson Smith's map (1900) that the Merille flowed into the Uaso Ngiro. Parkinson described the lower course of the Merille as a "..... flat bottomed thalweg with lava-capped cliffs of gneiss, 300 to 600 feet high on either hand ....."

In a further publication Parkinson (1924, p. 102) observed that the thin lavas capping old rocks between Marsabit and the Uaso Ngiro were likely to be similar in age to the Dido Galgallo (Dida Galgalla) flows north of Marsabit. He decided that these flows were clearly older than Marsabit volcano, which is to be regarded as a final effort of the upwelling magma resulting in a pile of flows from a single vent. The activity then ended with the formation of a number of parasitic 'puys', representing a feebly developed explosive phase.

In 1939, Parkinson (p.162) emphasized once more the two phases of vulcanicity; the early extravasation of plateau lavas, succeeded by a volcanic phase of Hawaiian type during which the flat cones such as Marsabit were built. He relates the thin lavas capping crystalline rocks to the east of the old safari route between Laisamis and Larguia to those capping sediments at Merti (to the east of the present area) and conjectured that the lava might be continuous between the two areas.

F. Dixey (1948) referred to the Basement System rocks of this area as being similar to and a possible extension of the rocks of the Turoka Series. He also noted the lava plateaux capping hills of gneiss, or sediments overlying gneiss in this part of northern Kenya. On the plains of older basalt he observed many examples of "..... fresh looking, highly scoriaceous viscous flows forming small tongues and mounds 10-30 feet thick .....". The sediments were described by him as coarse sandstones, often friable and pebbly and yielding indeterminate fossil wood. According to Dixey's description, Merille hills consist of 5 feet of basalt, resting on a few feet of pebbly sandstone and 350 feet of gneiss. The surface preserved by the lava was considered to represent a portion of the former mid-Tertiary peneplain and to be correlatable with the Merti Plateau.

H. D. Roberts (1941) in a geological reconnaissance of the Merti Plateau area, referred to the plateaux near Koiya and Laisamis and cited the possibility that they were continuous with Merti. He ascribed an Upper Pleistocene age to these lava plateaux.

III—PHYSIOGRAPHY

This region can be divided into two broad physiographic units (Fig. 1):—

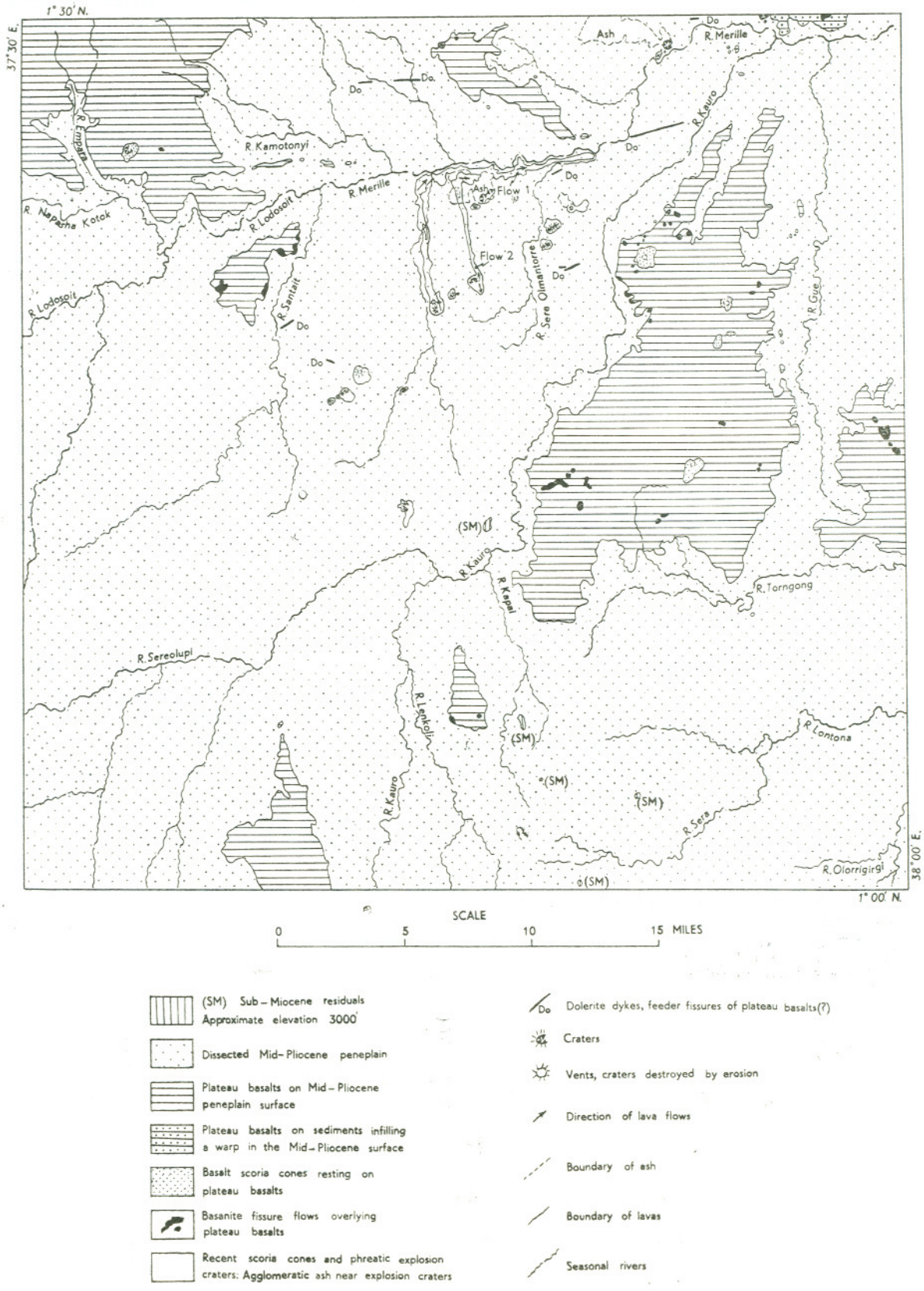


Fig. 1.—Physiography of the Kauro-Merille area.

1. The plateaux or tablelands, capped by lava, protruding 50-250 feet above the present dissected surface.

2. The present plain surface, dissected by the Kauro-Merille drainage system, and sloping down gently north-eastwards.

The Plateaux.—The plateaux are upstanding areas of metamorphic rocks (sediments in the extreme north-east corner) capped by a thin sheet of lava. The surface of this lava is almost horizontal, with only slight undulations and irregularities due to drainage. This lava is considered to be capping the bevelled surface which the Kauro-Merille drainage system is in the process of destroying, and not the upstanding remnants of some earlier surface. Evidence for this is the presence of plateaux, on the main watershed with the Uaso Ngiro, which are barely etched out above the surrounding areas. Thus, the Merti Kaingos (Marti Nkangos) plateau (Jennings, 1967) protrudes barely 50-80 feet above the dissected plain surface. This plateau is situated near the major watershed where a minimum amount of differential erosion of lava-capped and unprotected areas has taken place.

The surface preserved by the thin lava capping is therefore the latest widespread erosion bevel in this area. It is widely accepted that the last widespread bevel in Kenya was the mid-Pliocene or end-Tertiary surface (Saggerson and Baker, 1965). This places the age of the lavas as Upper Pliocene, an age consistent with the obviously younger age of the cones and flows of the Merille Suite and the Nyambeni Volcanic Series, which often fill valleys in the present dissection (Jennings, 1967; Rix, 1967).

The Basement System residuals under the Merti Plateau (Williams, 1966, Matheson, 1971, Dodson, at the press) appear to approach the elevation of the sub-Miocene bevel at that locality, although the lava capping them is almost certainly part of the same sheet of lava that forms the plateaux in the Merille area. This apparent anomaly is due to the convergence of the two surfaces eastwards across Kenya. Whereas the separation between the two surfaces is 500 feet in the Merille area, it is only about 200 feet near Merti (Williams, op. cit.). This results at Merti in the presence of a thin lava sheet capping sediments that rest on the mid-Pliocene peneplain and are banked against residuals on it, the latter approaching the elevation of the converging sub-Miocene surface. The Merti Plateau is important in relating the lava sheet and erosion bevels at Merti with those of Kauro-Merille.

In the north-eastern corner of the Merille area the lavas are preserving a surface of sediments, and the latter form cliffs 150 to 200 feet high on the north side of the Merille laga (sand river). However, no sediments are present at Kurato hill, two miles south of the sediment cliffs, where the lava rests on a surface of gneiss. Therefore the base of the sediments must dip northwards with a gradient much greater than that to be expected for a slightly dissected mid-Pliocene bevel, such as must have existed in Upper Pliocene times. The course of the Merille north of Kurato is thought to be approximately the southern edge of a warp or embayment in the mid-Pliocene bevel, which was infilled by Upper Pliocene sediments. This warp was a tectonic, not erosional, feature.

The dissected plain surface.—The present dissected plain surface has resulted from the erosion of the bevel now represented by plateau remnants. The lack of a protective cover of lava has resulted in relatively rapid erosion of the heterogeneous, jointed and often foliated metamorphic rocks. The downward slope of both this surface and the bevelled surface is north-eastwards, so that the maximum height of the plateaux tends to be in the north-eastern part of the area rather than in the south, nearer to the watershed with the Uaso Ngiro system.

The Kauro, with the Kapai, Lenkoli and Sereolupi, forms a system draining the plain and inselbergs along the main watershed with the Uaso Ngiro. The Kauro drainage system unites with that of the Merille in the north-east near Kurato hill.

The Merille, formed from the Lodosoit, Napasha Kotok and Santait rivers, flows eastwards across the northern part of the area before uniting with the Kauro. The Lodosoit and Napasha Kotok drain from the Mathews Range farther west and ensure a more consistent supply of water than that obtained from the Kauro catchment. The Merille, as a result, is more important than the Kauro from the point of view of water supply, although a number of places exist on both rivers where permanent water can be obtained by digging in the river sand.

The Torngong and Lontona are the only sizeable lagas which do not join the Kauro-Merille system. These lagas drain eastwards from a north-south watershed near Lontopi. The Gue drains the eastern side of the Marti Serteta plateau, joining the Merille downstream from the Kauro junction.

At the Gue junction the Merille has traversed on to sediments and has become aggraded. It has a flat bottomed profile with wide spreads of alluvium and tapering tributary streams. To the east it runs between lava-capped cliffs of sediments and becomes a braided, tapering stream until it is absorbed in the semi-desert region some distance north-east of the present area.

The majority of the rivers show a fair degree of structural control. The Kauro and Lodosoit rivers are good examples, following variations in rock type and structure in the metamorphic rocks, and also being controlled by the edges of basalt lava sheets. An instance of more recent control is the slight diversion of the Merille by the lava flows from Olmbaa Lesuguroi. These lavas flowed northwards down the slope of the Merille dissection and thence along the valley eastwards. The Merille was diverted slightly northwards, the river being obliged to find a new course along the edge of the lava flow. The river valley was not completely blocked because no lake beds exist upstream of the lava. However, widespread alluvium is present west of the point where the lava entered the valley and the writer considers that during the annual flood periods a temporary lake formed due to the lava forming a slight bottleneck. Widespread deposition of silt occurred but the river later cut into these deposits, leaving a few alluvial terraces. Even at the present time alluvium is widespread west of the lava and flooding occurs for a short time during rainy periods.

Alluvial deposits have built up south of the flow as a result of the inability of small tributary streams to reach the Merille. This is particularly noticeable between the two parallel flows down the valley side from Olmbaa where streams were effectively contained on three sides by lava. The build-up of alluvium has resulted in the scarp on the south side of the flows being almost imperceptible, and during rainy periods flood water probably escapes over the lava into the main river. A beneficial result of the diversion by lava has been the relative abundance of water in the seven mile stretch of river along the lava flow. The water sometimes forms a steadily flowing trickle on the surface for some miles. The direct cause of the presence of the water is the lack of a deep sand bed above bedrock, resulting in a rise of the water table along this section of the river. This factor in turn is due to the filling of the former sand channel by lava, and consequent diversion of the river.

Residuals.—There are five hills in this region which attain an elevation close to or exceeding 3,000 feet above sea level. These are Lenkaya (3,170 ft), Lontopi (3,016 and 2,992 ft), Sera (3,009 ft) and Naingamengama on the southern boundary. This elevation is close to that postulated for the sub-Miocene bevel in this area (Pulfrey, 1960) and the hills are regarded as degraded remnants of the bevel. They rise some 300 to 500 feet above the lava plateaux, which is consistent with the postulated separation of the sub-Miocene and mid-Pliocene bevels in this area (Saggerson and Baker, 1965).

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL HISTORY

The rocks of the Kauro-Merille area comprise four main groups:—

4. Upper Pliocene sediments and Quaternary superficial deposits.
3. Upper Pliocene to Recent volcanic rocks.
2. Intrusive rocks.
1. Basement System metamorphic rocks of Precambrian age.

Basement System metamorphic rocks.—The stratigraphical succession of metamorphic rocks in this area is as follows (thicknesses are approximate):—

Migmatitic	(iii) Biotite-hornblende migmatites	2,000 feet
Semi-pelitic	(ii) Finely banded succession of biotite and hornblende-rich gneisses and granulites	5,000 feet
Predominantly semi-pelitic with calcareous, semi-calcareous and psammitic horizons	(i) Foliated biotite gneisses and biotite-muscovite gneisses with quartz-sillimanite gneisses; bands of hornblende gneisses, granulites and quartz-felspar gneisses	9,000 feet

An impersistent orthogneiss member, the Soito Narok amphibolite, also occurs in this area. Apart from orthogneiss the Precambrian succession is predominantly a metasedimentary sequence of semi-pelitic origin, with a migmatitic sequence.

Intrusive rocks.—Two types of rocks are intrusive into the metamorphic sequence. An intrusion of serpentinised peridotite, forming Kisepetai hill, distinctly shows the displacement of the metamorphic rocks by the emplacement of the boss or plug of peridotite. It is therefore post-Basement System in age, possibly Precambrian. The intrusion is 2,500 feet in diameter at the surface. Three intrusions of biotite granite were also mapped, two dykes and a small boss. The largest of these, the Lerekere dyke, is traceable for six miles. Intrusive pegmatites also occur, the veins being persistently concordant with the strike of the metamorphic rocks. These are also considered to be of Precambrian age.

Upper Pliocene to Recent volcanic rocks.—There are four types of extrusive phenomena in this area, each being of a different age. These are:—

(iv) Recent spatter-cones, lava flows and explosion craters of the Merille region. The lava type is predominantly olivine melanephelinite.

(iii) Pleistocene spatter-cones of olivine basalt overlying plateau basalts. These cones are much eroded.

(ii) Pleistocene (?) fissure flows of very limited extent forming tongues and mounds of basanite lava overlying plateau basalts.

(i) Upper Pliocene olivine basalt sheet flows forming plateau cappings.

A few dolerite dykes, possibly marking feeder fissures, are also present.

Upper Pliocene sediments and Quaternary superficial deposits.—Unfossiliferous, arkosic sandstones of Upper Pliocene age occur in the north-east, having been preserved by a capping of olivine basalt. They contain rounded pebbles, show no traces of bedding, and are considered to have been formed in a shallow water or swampy environment.

Superficial deposits include a small area of lacustrine marls, concretionary deposits of calcareous, ferruginous and siliceous composition, and pebble sheets. Narrow strips of alluvium are present along the larger river courses and some alluvial terraces were mapped in the Merille.

The ubiquitous red sandy soil, formed from the breakdown of the metamorphic rocks, covers most of the area but white sandy soil has developed in the north-east on the friable Upper Pliocene sandstones. Black cotton soil has formed in badly drained depressions in the west.

The following table gives a brief indication of the geological history:

Time	*Geological events*	*Earth Movements and erosional phases*
RECENT	Merille cones, explosion craters and lava flows form on dissected bevel.	Erosion producing the present dissected land surface.
PLEISTOCENE	Superficial deposits forming during this period. Basalt spatter cones and basanite fissure flows on plateau basalts.	
UPPER PLIOCENE	Extrusion of sheets of olivine basalt lava. Deposition of arkosic sandstones on the bevelled surface.	Erosion of end-Tertiary bevel begins.
		Tilting.
NEOGENE	Maturation of end-Tertiary bevel.	
		Erosion of sub-Miocene bevel.
		Tilting.
	Maturation of sub-Miocene bevel.	
PALAEOGENE to CAMBRIAN		A number of cycles of uplift, denudation and peneplanation during this period.
PRECAMBRIAN	Intrusion of peridotite and granite. Major folding and metamorphism of sediments. Contemporaneous intrusion of pyroxenite and pegmatite. Migmatites formed. Deposition of sediments in Mozambiquian geosyncline.	Prolonged erosion begins. Major orogenic period.

V—DETAILS OF GEOLOGY

1. Basement System

The Basement System rocks in the Kauro-Merille area are chiefly metasedimentary in origin, although migmatites and orthogneisses also occur. The metasedimentary rock types encountered are typical of large areas of the Basement System in Kenya and have been described in many earlier reports. The most interesting of the metasediments are the calc-silicate rocks which, however, typically occur as small bands and segregations only. Limestone bands are important as marker horizons for structural mapping.

(i) Psammitic Metasediments

(a) *Quartz-felspar gneisses and granulites*

These rocks are considered to be the metamorphosed equivalents of former arkosic sandstone horizons in the geosynclinal sequence. They have a wide distribution in the Kauro-Merille area but are not extensively developed at any one locality. They form impersistent bands and lenses in a generally semi-pelitic and semi-calcareous succession.

Prolonged erosion of the metamorphic rock surface has resulted in the psammitic bands forming upstanding features due to their relative resistance to erosion. These features are usually elongated ridges of no great length or breadth. Most of the smaller upstanding masses consist of this rock type but the largest residual, Lenkaya, is lithologically heterogeneous. These rocks are typically traversed by vertical joints, usually at right angles to the strike direction.

Lithologically, the psammitic rock types vary from quartz-felspar gneisses and granulites to massive leucocratic biotite gneisses. Biotite is ubiquitous throughout the succession in this area, and even in the psammitic types a biotite-free metamorphosed arkose is uncommon.

In hand specimen the rocks have an appearance that is typical of psammitic rocks from all parts of Kenya. They are massive, holocrystalline, leucocratic rocks with a variable biotite content, though never enough to produce a marked foliation. The rocks weather to a white, pink or buff colour. In thin section they show a monotonous similarity. Typically, the fabric of the rocks consists of a mosaic of quartz, microcline and plagioclase (oligoclase-andesine). Accessories may be crystals of magnetite with small sphenes on occasion. Biotite is nearly always present, although in some of the quartz-felspar gneisses it is present only as very small interstitial flakes.

Specimens of psammitic rock types which show these features are 28/70*, a quartz-felspar gneiss from two miles east of AD 65 survey point and 28/74, a quartz-felspar gneiss from one mile south-west of Kinya. Perthitic felspars are common, the usual form being microcline perthite. Sections showing perthitic felspars are 28/75 from one mile south of Lerekere and 28/143 from four miles north-east of Kinya. 28/245 from the Santait river, one mile south of the Lodosoit track, exhibits albitisation, untwinned plagioclase crystals showing albite edging, where they abut against microcline crystals. Sericitized felspars are also present, as in a number of these psammitic rocks.

Magnetite is an accessory mineral in 28/145, a large crystal being evident in the thin section. 28/229, a quartz-felspar gneiss from two miles north of Olmbaa, contains sphene and diopside as accessory constituents. Specimen 28/202 from three miles south of Lenkaya Wells, 28/85 from one mile east of Kinya plateau and 28/80 from the south end of the Kinya plateau, are examples of quartz-felspar granulites. In mineral composition these rocks are similar to the gneiss examples quoted above, but the texture is equigranular. The quartz and felspar grains are near equidimensional and form virtually the whole rock but shreds of biotite and muscovite are also present, with magnetite as an accessory mineral.

(b) *Massive leucocratic biotite gneisses*

The field occurrence of these rocks and appearance in hand specimen are very similar to the quartz-felspar rocks, the difference being the presence of rather larger and more abundant crystals of biotite. Specimen 28/158, a quartz-felspar biotite gneiss from four miles north-west of Olmpos, and 28/102 from two miles north-west of Lontona, are good examples of the leucocratic type of biotite-bearing gneisses.

Samples 28/196 from half a mile east of Soito Narok and 28/212 from near Ndonyuo, are leucocratic hornblende gneisses in which biotite is subordinate. The band near Ndonyuo is very prominent both on the ground and on aerial photographs and hence useful for structural mapping.

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* Numbers 28/70 etc. refer to specimens in the regional collection of Mines and Geological Department, Nairobi.

(ii) Semi-pelitic Metasediments

(a) Foliated biotite, biotite-muscovite and quartz-sillimanite gneisses

Foliated biotite gneisses occur in the extreme eastern part of the area and also form the predominant rock type in the central zone. They form low ground for the most part, a notable exception being portions of the hill Lenkaya. These rocks are considered to be the metamorphosed representatives of original semi-pelitic sediments. Having a high content of biotite, these rocks have a well developed foliation and are sometimes quite friable. Why they should form a marked feature at Lenkaya hill is a little puzzling. However, this hill is situated where a number of pegmatite veins occur in the Basement System rocks, and it is thought that these have contributed to the resistance of the gneisses to erosion. The biotite gneisses on Lenkaya are also rather more leucocratic than elsewhere.

In hand specimen these rocks are seen to be quartzo-felspathic in composition but numerous flakes of biotite, which impart a foliation, are present. Thin sections typical of the foliated biotite gneisses are 28/92 from four miles north-west of Lontopi, 28/115 from three miles south-east of Lenkaya and 28/270 from one and half miles east of Lodosoit trading centre. In all these examples biotite is an abundant mineral.

Some of the foliated rocks have a considerable muscovite content, but biotite-muscovite gneisses have not been differentiated as such on the map. In hand specimen this type is similar to the biotite gneisses except that flakes of muscovite are discernible. In thin section biotite and muscovite can be readily seen, in addition to the common leucocratic minerals, quartz, microcline and plagioclase. Examples of this rock type are 28/60 from one mile west of Nkangos plateau and 28/124 from one mile north-west of Sera. Specimen 28/179 is from a muscovite-rich lens in the Nolwao pegmatite. The thin section shows large crystals of muscovite exhibiting good cleavage, together with smaller pleochroic crystals of hornblende. Sample 28/154 from three miles north of Olmpas is a quartz-sillimanite "faserkiesel" from quartz-sillimanite gneisses. Only one band of rock containing sillimanite was mapped in the area.

(b) Finely banded succession of biotite and hornblende-rich gneisses and granulites

An extensive area in the western part of the Kauro-Merille region and a less extensive strip of country in the east are composed of a finely banded succession of semi-pelitic gneisses. Variations within the rocks are so rapid and on such a small scale that differentiation of the bands on the present scale of mapping is impossible.

This succession is essentially one of foliated biotite gneisses, such as have already been described, alternating with bands of biotite-hornblende gneiss and hornblende gneiss. There are also small lenses and bands of calc-silicate rocks within this predominantly semi-pelitic succession.

The lithologies of these rock types, with the exception of the biotite-hornblende gneisses, are described in other parts of this section, and it is not proposed therefore to duplicate the descriptions under this head.

Most of the specimens collected from this succession were hornblende gneisses and foliated biotite gneisses. A few specimens of biotite-hornblende gneiss were collected, such as 28/95 from Lontopi. In thin section it is seen to be a coarse grained rock consisting of quartz, plagioclase (oligoclase), large crystals of biotite and hornblende and some accessory sphene.

(iii) Calcareous and Semi-Calcareous Metasediments

(a) Crystalline limestones

Crystalline limestones are abundant in the central part of the area, where they form impersistent bands, varying greatly in thickness, and occur among the succession of finely banded semi-pelitic and semi-calcareous rocks. These bands are useful as marker bands of structures in the folded metasediments.

The limestones are typically white rocks with a bluish sheen, although pink and grey varieties were discovered. In hand specimen they appear to contain few accessory minerals. In thin section the rocks typically exhibit large crystals of calcite forming a homogeneous mosaic.

Specimen 28/91 from four miles north of Lontopi, shows large rhombohedral crystals of calcite. Crystals of muscovite and a fibrous mineral (possibly wollastonite) are present. A good specimen of a pure crystalline limestone is 28/114 from two miles south-east of GT18 survey beacon. 28/156 from three miles north-east of Nolwao, contains fibrous crystals of tremolite, and 28/171 from two miles south-west of Kurato, contains the same mineral infilling cavities in the calcite. Rhombohedra of calcite also occur in these cavities. Xenoblastic aggregates of quartz crystals are other constituents of these limestones.

(b) Calc-silicate gneisses and granulites

Gneisses consisting chiefly of calcium-rich minerals form small bands and lenses in the semi-pelitic and semi-calcareous succession. The larger lenses and bands of rock having this composition have been indicated on the map.

These rocks vary in appearance from dark green to black, with light green and light brown varieties, the colour depending on the identity of the calc-silicate minerals contained within the rock. The calc-silicate rocks are chiefly gneisses, with a few granulites in which the uniformity of grain size can be quite striking.

Specimen 28/61 from two miles west of Nkangos plateau contains quartz, plagioclase (labradorite) and small irregular crystals of microcline; hornblende, sphene, apatite and garnet are the calcium-rich minerals. The rock from Kurato hill, 28/138, contains diopside, epidote and some large crystals of turbid felspar. In hand specimen it is light green in colour flecked with dark green crystalline areas and contains large pink felspar crystals, probably orthoclase.

Sample 28/248 from four and a half miles south-west of Kisepetai, contains large crystals of colourless diopside, small prismatic crystals of sphene, some microcline, calcite and calcic plagioclase. A mineral showing deep blue anomalous polarisation colours also occurs; the interference figure is poor and the mineral could be idocrase or zoisite. 28/276 from three miles east of AD62 survey point, also displays colourless diopside, pink-brown idocrase and zoisite showing striking deep blue, anomalous polarisation colours. Scapolite is a minor constituent.

The rock from three miles north-west of Kamotonyi, 28/280, is a diopside gneiss with subsidiary quantities of other calc-silicate minerals. Large crystals of diopside are prominent with calcic plagioclase, zoisite showing anomalous polarisation colours, large crystals of quartz and accessory sphene crystals.

A number of the calcareous metasediments show a striking equigranular texture and qualify for the designation of granulites. Specimen 28/65 from four miles north of AD65, is a good example of this type. It consists of an equigranular mosaic of yellow epidote crystals with larger crystals of green diopside, often pleochroic. Smaller, more markedly pleochroic crystals of hornblende are present and large crystals of scapolite are common. Sphene and apatite are accessory minerals. 28/182 from one mile north of Nolwao, also exhibits a granular mosaic of epidote, a feature which seems to be typical of the calc-silicate granulites. Garnet and unusually large sphenes are other calc-silicates in this rock, and quartz and calcic plagioclase are subsidiary minerals. 28/144 from four miles north-west of Koiya, is an attractively-coloured rock in thin section, consisting of an equigranular mosaic of epidote, orange garnet, hornblende, calcic plagioclase and magnetite.

(c) Hornblende gneisses with plagioclase amphibolites

These rocks form relatively narrow bands in the biotite gneisses which are extensively developed in the central part of the area. This type also occurs in the west as part of the

semi-pelitic succession, but they are too narrow to be differentiated as such on the map. The hornblende gneisses are usually more massive than the foliated biotite gneisses and thus tend to form slightly more pronounced features than the latter type.

In hand specimen the hornblende gneisses tend to be more melanocratic than types mentioned hitherto and the plagioclase amphibolites are even more melanocratic. The difference between the two is essentially based on the amount of hornblende present in the two types. The plagioclase amphibolites have a greater percentage of hornblende than do the hornblende gneisses, and they generally form lenses within the hornblende gneiss outcrops.

In thin section the rocks are seen to consist of leucocratic minerals, hornblende and scattered crystals of various calc-silicate minerals. Specimen 28/111 from one mile east of Soita Nashepa, is a typical hornblende gneiss. The leucocratic minerals are quartz and microcline with small crystals of calcic plagioclase. Hornblende is the prominent melanocratic mineral, but there are also scattered crystals of diopside and idocrase. 28/106 from the same locality, has a high content of hornblende and is identified as a plagioclase amphibolite. Plagioclase and diopside are the other minerals present.

(d) Biotite-garnet gneisses

This type has been included in the semi-calcareous group of metasediments because of the high content of garnet in the one band that was mapped. This particular band outcrops a few miles north of the Merille laga.

In hand specimen the rock is a somewhat friable biotite gneiss with numerous euhedral pink garnets reaching approximately 5mm. in diameter. Within the outcrop of biotite-garnet gneiss is a mono-mineralic garnet band which, in hand specimen, appears to consist solely of closely packed, euhedral pink garnets up to 20mm. in diameter. Interstitial quartz is however visible in the thin section.

Thin section 28/216 from two miles north of the Merille laga, shows quartz and oligoclase as leucocratic constituents, with foxy-red biotite and large colourless garnets. 28/217 from the same locality, was taken from the garnet band within the biotite garnet gneiss outcrop. Large crystals of pink almandine garnet are seen with interstitial granular aggregates of quartz.

(iv) BIOTITE-HORNBLENDE MIGMATITES

Biotite-hornblende migmatites occur in the east of the map, forming a north-south belt from Koiya to Lontona. They consist of mafic host rock bands, composed of hornblende and biotite-rich gneisses, and quartz-felspar bands. Contortion of the banding is rare.

The migmatites form part of a synclinal structure, being possibly part of the core of a fold recumbent from the east, most of which has now been eroded away.

(v) ORTHOGNEISSES

(a) Amphibolites

In the extreme north, at Soito Narok near the Laisamis-Koiya track at 1°30′N, there occurs a line of small hills, devoid of vegetation and composed of a glistening black rock, resembling coal heaps in appearance (Plate Ib). These hills are in fact composed of an amphibolite which is dark green to black in colour. Small quantities of leucocratic minerals are visible in some of the hand specimens. Occasionally, ovoid segregations of coarsely crystalline amphiboles occur within the more normal type of amphibolite.

Thin sections of this amphibolite show the rock to consist of hornblende and/or actinolite with subordinate leucocratic minerals such as plagioclase felspar and quartz. Specimen 28/125 is typical of this rock type, in which strongly pleochroic crystals of hornblende are prominent, labradorite felspar is a persistent though subordinate constituent,

PLATE I



(a) Gorge cut in banded gneisses, Koiya



(b) Amphibolite hills, Soito Narok (foreground) and overturned fold in quartz felspar gneiss (centre)

PLATE II



(a) Dyke of biotite granite, Lerekere

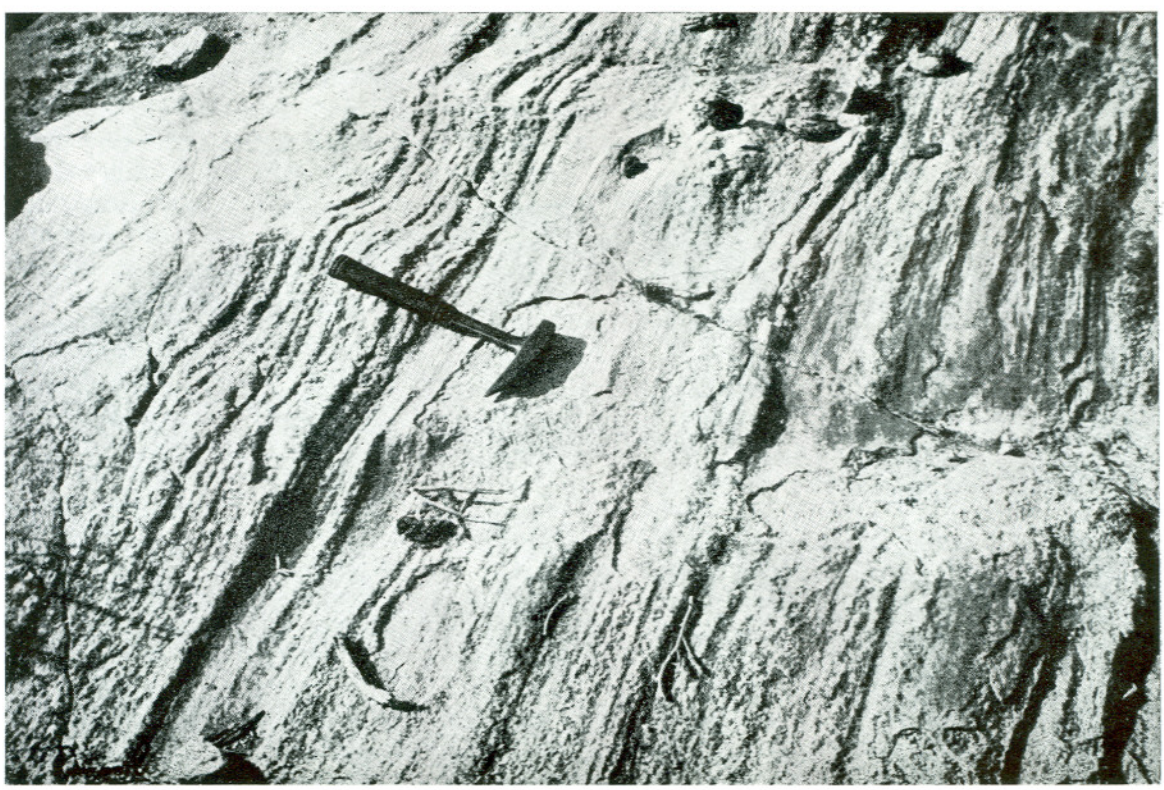


(b) Concordant pegmatite displaced by fault, west of Nolwao

PLATE III



(a) Gentle flexural slip folds in banded gneisses, Koiya gorge



(b) Undulose, near horizontal lineations on surface of biotite gneiss, Kauro laga north of Lenkaya

PLATE IV



(a) Calcareous sandstone capped by olivine basalt, near Kurato



(b) Ndonyuo Olnchorro, an explosion crater of agglomeratic ash, showing typical arcuate form produced by prevailing wind

colourless to light green diopside is present as a scattering of crystals, and rounded grains of quartz are evident. 28/160 from the southern end of Soito Narok, contains large crystals of hornblende. Actinolite, exhibiting a faint pleochroism from light green to pink, is the other mineral constituent.

The Soito Narok amphibolite is concordant with the strike of the Basement System rocks in the vicinity and it is evident that it has been folded with them. In the area to the north near Laisamis extensions of this amphibolite have been incorporated in a big fold structure. It is likely that an intrusion of pyroxenite occurred during the major metamorphism and folding of Basement System rocks. The pyroxenite was amphibolitised during emplacement to a pure amphibole rock with little or no indication of its original identity.

The shape of the intrusion is elongate, being almost one and a half miles in length within the Kauro-Merille area. The maximum breadth of the amphibolite is a quarter of a mile, at its southern end near the Merille laga.

2. Metamorphism and Granitisation

The rocks exposed in this part of Kenya are a series of regionally metamorphosed sediments, with migmatitic rocks in the east. Biotite is very widely developed; garnet is developed more sporadically in rocks of a different original composition from, but isofacial with, the biotite gneisses, and sillimanite was found at only one locality. It seems therefore that the rocks have undergone medium grade regional metamorphism. This observation is consistent with the metamorphic features present in a very large part of the exposed Basement System metamorphic rocks in Kenya. A summary of the processes of granitisation operative in the Kenya Basement System rocks, as postulated by various authors in a number of reports, is to be found in the report on the Kinna area (Rix, 1967, p. 15).

3. Intrusive Rocks

(i) Serpentinised Peridotites

Kisepetai hill was discovered to be a serpentinised peridotite intrusion. On aerial photographs it is apparent that this intrusive body has displaced the Basement System metasediments surrounding it. The rock bands can be seen to bulge round the intrusion although on the ground this effect is difficult to follow. A band of hornblende gneiss, more prominent than most, was traceable round the eastern side of the intrusion, as has been indicated on the map. This shows the displacement of the metamorphic rocks by the peridotite. The hill feature has a shape typical of a homogeneous basic intrusion. The outlines are rounded and steep valleys dissect the mass. The hill is only sparsely covered with vegetation and has an apron of loose ultrabasic and gneiss blocks at the base.

In hand specimen the rock shows variable characteristics. Often it is light brown in colour with areas of darker brown or black crystals that glisten on fresh fractures. Other samples have a uniform brownish grey appearance, and occasional specimens are dark brown to black in colour, flecked with light brown coloration and are more obviously crystalline than some of the other weathered and amorphous looking rocks.

Most of the specimens are criss-crossed with quite narrow secondary quartz veins. A very weathered specimen of the serpentinised peridotite (28/49, described later) is light yellow to green in hand specimen and appears to be cellular or fibrous in texture. It has numerous small quartz veins within it.

The intrusive body has been invaded by narrow irregular and anastomosing magnesite veins. Such veins are quite common, particularly in the northern part of the intrusion, but they are extremely variable and never of any great thickness.

In thin sections, specimens from this intrusion show a number of interesting features. 28/50 from Kisepetai shows green antigorite pseudomorphs after olivine, with dendritic crystals of iron ore forming a skeletal network. A few larger crystals of magnetite also occur. The serpentine minerals form a trellis type of texture, pale green pseudomorphs of massive antigorite being surrounded by a lattice of crystals of fibrous antigorite, the latter having a lower birefringence than the cores. The optical characteristics of the thin fibres are difficult to determine, but it appears that some of the crystals forming the fibrous lattice are chrysotile. Some areas of very low to nil birefringence are thought to be serpophite, this mineral forming the core of some of the pseudomorphs. A colourless lamellar or fibrous mineral which shows length-fast character and has a higher birefringence than the other fibrous minerals (1st order brown-yellow) occurs as larger fibres in irregular patches and veinlets. The interference figure is biaxial positive with 2V in the range 20-40°. This mineral was identified as the colourless clinochlore, leuchtenbergite. Veinlets of quartz and turbid areas, which are probably small patches and veins of magnesite, are present. Small patches of remnant olivines occur, most having rims of iron ore.

Specimen 28/57 consists of a closely packed mosaic of antigorite pseudomorphs after olivine. The antigorite is colourless to very pale yellow, has a lamellar habit, and forms round clear areas with a scattering of iron ore granules in the centre of the pseudomorphs. Some relict olivines are evident, with lamellar crystals of leuchtenbergite. Thin section 28/52 shows similar features, with antigorite pseudomorphs after olivine, with dark brown cores of altered serpophite. Quartz veins are well developed in this specimen and elongated crystals of a mineral of length-slow character are thought to be tremolite.

A good specimen of a partially serpentinised peridotite is 28/257. The thin section shows an interlocking pattern of yellow pseudomorphs with occasional colourless cores. Under crossed nicols the yellow material is seen to be fibrous antigorite and the colourless crystals are remnant olivines, which are relatively common in this section. Good crystals of leuchtenbergite are also visible.

The presence of the remnant olivines in most of the thin sections and the shape of the pseudomorphs, particularly in 28/51, suggests that the greater part, if not all, of the original intrusive was composed of olivine crystals and was therefore a dunite. On the lack of further evidence, the intrusive has been designated as a peridotite rather than a dunite. Also, the term serpentinised peridotite is preferred to serpentinite because some indication of the original composition is present. It is likely that there were small amounts of pyroxene in the peridotite, which have now been altered beyond recognition. The presence of tremolite in 28/52 may support this, the latter mineral often being an alteration product of pyroxene.

Specimens of amphibolite were obtained from the base of the hill at Kisepetai, among the apron of talus. They could have originated from the contact zone between peridotite and metasediments because these fragments cover a strip of ground only 10 to 20 feet in width. The amphibolite might have been developed as a marginal rim to the peridotite mass during intrusion, the pyroxene(?) and olivine being converted to amphiboles near the contact. Thin section 28/253 from Kisepetai is an example of this amphibolite. The chief constituent is a light green slightly pleochroic actinolite, together with some quartz and plagioclase. Aggregates of a light brown fibrous mineral, the identity of which is not known, also occur. This rock, the altered marginal facies, is therefore the heteromorphic equivalent of a pyroxene-olivine rock with plagioclase. It is not known whether this rock extends as a narrow band right round the intrusive body but it may well do so. However, due to lack of concrete evidence and the narrowness of the band, it has not been shown on the map. There appear to be no aureole effects in the gneisses.

From the evidence quoted above, the conclusion is reached that this intrusion is later in age than the Basement System metamorphism, but no more exact assessment can be made. It was probably intruded as an olivine crystal mush at relatively low temperatures.

The field evidence precludes the peridotite from having been intruded as a magma derived from a hypothetical primary peridotite magma, which would necessitate very high temperatures which would have produced marked effects in the surrounding rocks.

The intrusion appears to be a stock or plug-like body which has been forced up into folded metasediments of the Basement System, forcing them apart mechanically. It has later been exposed by erosion, forming a hill due to its resistance to erosion relative to the surrounding semi-pelitic gneisses.

(ii) Biotite Granites

Three intrusive bodies were mapped in the Kauro-Sera region. One appears to be a small plug and the other two are dykes with a north-south trend.

The Lerekere dyke east of Kauro is the largest of the intrusive bodies and is visible on aerial photographs as a line having a discordant relationship to the strike of the gneisses. It is most prominent near Lerekere where it forms a wall cutting across the biotite and hornblende gneisses in that region (Plate IIa). Another smaller dyke occurs east of Lontopi, the strike being concordant with that of the gneisses. It makes a small feature, not comparable however with the wall at Lerekere. A small hill south of Sera is composed of the same rock and has a characteristic tor-like weathering, distinctive from the surrounding biotite gneisses. Its appearance is similar to the rocks from the two dykes, but it forms a small plug or boss.

In hand specimen these rocks are leucocratic, typically yellowish in colour, not unlike the quartz-felspar-biotite gneisses. They are however more resistant to erosion, due perhaps to the random orientation of the biotite crystals in the crystalline quartz-felspar mosaic. Only one specimen (28/93) shows any foliation of the biotite crystals.

In thin section, this rock is identical in composition to quartz-felspar-biotite gneiss, and without recourse to field evidence no distinction could be made between the two types. Specimen 28/77 from Lerekere is granitoid in appearance, with no visible foliation. Large crystals of microcline, euhedral quartz crystals and less numerous crystals of oligoclase form the leucocratic fabric. Oligoclase is subordinate to microcline in this example. Biotite is present as deeply coloured, markedly pleochroic crystals associated with bleached biotite. Smaller irregular crystals are thought to be sericite. Magnetite is an accessory mineral.

Thin section 28/87, also from the Lerekere dyke, shows large crystals of microcline, euhedral quartz crystals and a few interstitial crystals of oligoclase. Biotite, magnetite, bleached biotite or sericite are also present, together with accessory sphene and apatite. Myrmekitic intergrowth is displayed, blebs and laths of exsolved microcline occurring in quartz. 28/93, from the dyke east of Lontopi, and 28/104, from the plug south of Sera, are exactly similar in their mineralogy to the Lerekere type. The latter specimen shows albite edging on some alkali felspar crystals, and contains an unusually large sphene crystal.

These cross-cutting granitic bodies, being identical in mineral composition to metasedimentary rock types, are considered to be rheomorphosed metasediments, which have been intruded along planes of weakness as discordant granitic bodies during the last stages of the Basement System metamorphism.

(iii) Pegmatites

The pegmatite veins in this area are unusually persistent, often forming long, craggy outcrops on the tops of sloping ridges, but occasionally they protrude as a wall (Plate IIb). The pegmatite veins are in most cases concordant with the strike of the Basement System gneisses, and only a few fine grained pegmatites show a cross cutting relationship to them.

It is therefore difficult to demonstrate an intrusive origin for these rocks, although the veins are too large and persistent to have originated as auto-segregations from migmatites, and yet they are concordant.

In hand specimen they are coarse grained leucocratic rocks composed of quartz and felspar, the two minerals sometimes exhibiting a graphic intergrowth relationship. They are devoid of any large concentrations of mica, magnetite or other minerals, though small segregations of these minerals occur locally.

Number 28/176 from two miles north-east of Nolwao, is a specimen of fine grained pegmatite from a narrow vein showing a definite discordant relationship to the gneisses. It consists, in thin section, of quartz and sericitised felspar. 28/188 from two miles south-east of Sasani, exhibits in hand specimen graphic intergrowth between quartz and felspar.

(iv) Olivine Dolerites

A number of dykes of this composition were discovered in the northern part of the area, in the Merille region. They show an east-north-easterly trend, and in some cases have been intruded along faults. This trend is more or less parallel to the line of structural weakness suggested by the alignment of the cones of the Merille volcanic suite. The dykes typically do not exceed three feet in width, and are thought to have formed as feeder fissures of the plateau basalts.

In hand specimen these rocks are finely crystalline and melanocratic, and have a faint mottled appearance due to the presence within them of rounded areas of calcite-filled vesicles.

In thin sections the mineral composition is seen to be that of a typical olivine dolerite. Specimen 28/165 from two miles south of Serirua, exhibits a porphyritic intergranular texture, the olivine forming euhedral crystals. Euhedral crystals of plagioclase (andesine-labradorite) also occur. Some interstitial untwinned felspar is thought to be plagioclase. Small crystals of clinopyroxene and cubes and octahedra of magnetite are accessory.

Two miles south of Sasani a dolerite dyke (28/189) has been intruded along the major fault at that locality. Again, an intergranular texture is evident in thin section with olivine, titanaugite, andesine and magnetite as mineral constituents. Specimen 28/250 from four miles south-west of Kisepetai, has a faint mottling due to round, whitish patches in the otherwise dark rock. In thin section the rock is similar to the other types, but possesses numerous calcite-filled vesicles which give the rock its mottled appearance.

The dyke one mile west of Inkiposorogi (28/265) is a very fine grained dolerite which does not show the typical intergranular texture. The composition is similar to that of the other examples but calcite is ubiquitous, and zeolites are sometimes interstitial. It appears to have undergone considerable alteration.

No nepheline or other felspathoidal mineral was discovered in these dyke rocks, and for this reason they are thought to be associated (as feeder dykes) with the basalt floods now forming the plateaux. The latter are Upper Pliocene, and it would appear therefore that the dykes are also of this age.

4. Upper Pliocene Sediments

Pebbly sandstones occur in the north-eastern corner of the area, where they are capped by a thin lava and form a plateau 200 to 250 feet in height (Plate IVa). These sandstones are not very well exposed along the plateau since the lava tends to collapse, due to erosion of the soft sediments beneath it, producing screes which obscure the sediments. One or two good exposures of these rocks occur, and there the features of the sediments can be studied.

The rocks are friable, gritty, calcareous sandstones, generally whitish in colour with occasional red or green bands representing oxidising and reducing climatic conditions. No traces of bedding were found at any locality where the sediments are exposed. Rounded quartz pebbles are often found in the sandstones. Other features seen are pipes of more resistant material protruding from bare eroded surfaces of these rocks. The pipes are vertically disposed and are composed of calcareous material with fragments of extraneous minerals. No internal structure is visible in them, and they are thought to be recrystallised pipe-like concretions developed along percolation channels in the sediments. A thin section, 28/285 from two miles north-east of Kurato, shows these cylindrical concretions to consist of a mass of fine grained calcite enclosing small angular fragments of quartz and microcline. Some semblance of concretionary structure is evident round these fragments, but there is no regular structure within them as might be expected if they were fossilized rootlets.

Typical of the sandstones is 28/134, from the same locality. It is an arkosic sandstone which reacts strongly with acid, indicating that carbonate is an important component of the matrix. In thin section angular fragments of quartz, microcline, plagioclase and hornblende are embedded in a ferruginous, rather turbid matrix.

The slope of the sub-sediment surface is steep and has been postulated as a downwarp in the end-Tertiary bevelled surface as already mentioned. Evidence that the bevel was little dissected when the sediments were laid down is the preservation, by flood basalts, of a gneiss surface in addition to the sediment plain surface in this particular corner of the area. The gneiss surface is virtually flat, and upstanding above the present dissected ground surface. The possibility that the sediments infill a large valley in the dissected end-Tertiary peneplain is discounted and the presence of a broad, shallow downwarp elongated in a north-westerly direction is postulated. On the foregoing evidence, and also the fact that the surface of soft sediment was not dissected before lava covered it, the conclusion is reached that the sediments and the basalts preserving them were penecontemporaneous. Their age is shortly post mid-Pliocene (the age of maturation of the end-Tertiary peneplain) i.e. probably Upper Pliocene.

These sediments form the western boundary of the very large area of Plio-Pleistocene sediments blanketing most of eastern Kenya. Lava-capped sediment plateaux extend eastwards from the present area, Merti Plateau being the most southerly of these (Dodson, at the press; Matheson, 1971). Farther south, the sediment margin extends into the Kora Wells (Wright, 1973) and Kinna (Rix, 1967) areas, and formerly extended much farther west in the region of the Tana Valley, filling a graben at 38°30′N (Wright and Rix, 1966). South of the Tana River the very flat, gently dissected peneplain surface has resulted in both sediments and gneisses being covered with a thin veneer of superficial deposits, and the western margin of the sediments is conjectural.

The region which is most instructive from the point of view of a study of these east Kenya sediments is undoubtedly that stretching from the Tana River in the region of the Skot graben (Rix, Wright op. cit.) northwards to the Merti Plateau region (Matheson op. cit.) and thence north-westwards to the Barchuma-Kom (Dodson, at the press) and the present areas.

North of this region the sediments are found at ground level underlying the Kaisut desert round the edge of Marsabit mountain, and presumably extend beneath the volcanic rocks which form the mountain. Farther north-westwards the sediments are found in the Chalbi desert area where they were observed by Dixey (1948). The area of sediments east of the margin of deposition is singularly uninformative, forming as it does a monotonous sedimentary plain surface. Any information about the extent and thickness of sediments of this age farther east is likely to come from exploratory boring in the search for oil.

The conditions under which the sediments accumulated were almost certainly those of a lagoonal or swamp environment with fresh or brackish water conditions. A post-mid-Pliocene tilting movement initiated dissection of the peneplain and allowed the sea to encroach inland, particularly in the Lamu embayment, as shown on the map of the end-Tertiary erosion bevel (Saggerson and Baker, 1965). A large area of marginal lagoons and swamps is thought to have formed over most of the area now covered by the Plio-Pleistocene paludal sediments, this area being almost at sea level. Repeated or perhaps continuous warping or tilting enabled the accumulation of a few hundred feet of shallow water gritty sediment, having a calcareous cement and occasional water-worn pebbles.

These unconsolidated Upper Pliocene sandstones are quite distinct from the Pleistocene lake beds which formed in a number of areas in Kenya. Both types occur in the Kinna area (Rix, 1967) where it is apparent that the lake beds are younger. It is however rare to find the two types of sediment in juxtaposition so that the relationship between the two can be clearly seen. One such occurrence was described by Dixey (1948) in the Chalbi desert, where the Pleistocene lake beds formed in a depression in the older Upper Pliocene sandstones. At the coast at about this time, uplift and erosion occurred in Lower or Middle Pliocene times which initiated the deposition of unconsolidated shallow water sediments of the Marafa sedimentary phase in the Malindi area (Thompson, 1956).

5. Volcanic Rocks

(i) Plateau Basalts

The oldest volcanic rocks in the Kauro-Merille area are the flood basalts which form the cappings to the plateaux in the Merille region. These lavas are 10 to 20 feet thick in the present area and preserve both a metamorphic rock surface and a sediment plain surface, the latter in the north-east. The identity of these surfaces has been discussed earlier and the conclusion reached that the lavas are Upper Pliocene in age, having been extruded immediately after the deposition of the Upper Pliocene sediments and only shortly after the maturation of the end-Tertiary peneplain. At the present day the lavas form the resistant cappings of plateaux which rise above the present dissected plain surface. The plateaux vary in height from 50 to 80 feet at Marti Nkangos to 250 feet in the Merille region in the north-east, these figures representing the minimum and maximum amounts of erosion by the Kauro-Merille drainage system.

All the specimens collected from these plateaux are typical olivine basalts. In hand specimen the rocks show little variation from a dark aphanitic rock qualifying for the field name of basalt. Some are slightly more scoriaceous than usual, and others are somewhat vesicular, but most of the specimens are monotonously uniform.

In thin section the rocks show a uniform mineral composition. Specimen 28/62, from Nkangos plateau, is a typical example of this lava. Partly resorbed olivine phenocrysts with iddingsite borders are evident, and some completely resorbed crystals occur. All the olivine occurs as microphenocrysts, and is apparently never present in the groundmass. Clinopyroxene (augite) occurs as small light green crystals which form the major part of the groundmass. Granules of magnetite are scattered throughout the groundmass with laths of labradorite, the other major constituent. A few calcite-filled vesicles are evident. The mineralogy of this rock is typical of all the specimens obtained from the plateau lavas. Olivine basalt specimens from other lava plateaux are 28/116 from Marti Serteta, three miles north-east of Lenkaya, 28/84 from the Kauro lava plateau three miles south of Nalala, 28/208 from the plateau north of Merille and 28/130 from the lava capping the sediments in the north-eastern corner of the area.

These flood basalts have already been established as Upper Pliocene in age. They are therefore distinctly older than the Nyambeni volcanic episode (Pleistocene-Recent) but are more or less contemporaneous with the earliest phases of the Mt. Kenya volcanicity. The

main extrusive centre for these floods of lava is likely to have been farther north and therefore quite distinct from the Nyambeni centres. A striking demonstration of the difference in age between these lavas and the Nyambeni flows can be seen in the Chanler's Falls area (Williams, 1966) where the two lava groups are in close proximity. The plateau lava at Merti caps sediments some 300 to 400 feet above the Uaso Ngiro river dissection. Nyambeni lava flows immediately south of the river have, in contrast, flowed over the dissected plain surface into the Uaso Ngiro valley, forcing the river to follow the edge of the lava flow.

The plateau lavas may prove to be the southern fragments of the vast tract of flood basalts surrounding and presumably underlying Marsabit mountain, which is built mainly of pyroclastic rocks. Parkinson (1920, 1924) related the wide spread of flood basalt, forming the Dida Galgalla, north of Marsabit, to the plateau lavas in the Merille region, and expressed the opinion that they were parts of the same volcanic phase. It is highly probable that Parkinson's view is correct, and these plateau basalts may also prove to be contemporaneous with the Mt. Kenya volcanicity. Similarly, Marsabit mountain could have been an explosive phase contemporaneous with the Nyambeni episode.

It is unlikely that all the plateau lavas in the Laisamis-Merille-Merti region were formerly part of one extensive sheet. The most isolated plateau is Merti, which is 40 miles or so distant from the next plateau lava at Solberawawa (Dodson at the press). It is possible that there was a tenuous connection between the two, but it is more feasible to postulate a number of separate fissure eruptions giving rise to sheets of olivine basalt lava, some of which came into contact with one another, and others of which remained isolated. The coalescence of a number of lava sheets probably took place in the north to form the large areas of lava constituting the Dida Galgalla. Farther south in the Kauro-Merille region however, fissure eruptions were scattered more widely and were fewer, with the result that small discrete lava sheets were formed. It is likely therefore that the main region of extrusion was farther north and that the Merille region was on the southern fringe of the area affected by the fissure eruptions.

(ii) Nepheline Basanites

A number of small, irregular lava flows occur on the surface of the lava plateaux, forming tongues and mounds of lava 10 to 30 feet thick that are generally devoid of vegetation. These flows are not found on the dissected peneplain surface presumably because, if any existed, they have been removed by erosion. Their age is likely to be Pleistocene, evidence for this being the fact that they overlie the plateau basalts and have a younger appearance than the latter, due mainly to the thinner bush cover. Also their absence on the dissected peneplain surface precludes them from being as young as the Recent lava cones and explosion craters in the vicinity of Merille. These small flows have a wide distribution on the surface of the flood basalts and are distinctive on aerial photographs, which also provide evidence of the location of the main centre of extrusion for this type of lava. They show a series of flows radiating from what may have been the major fissure, on the large lava plateau to the north of Kurato and north of the boundary of the present area at 1°30′N. Elsewhere very small, irregular flows occur, which are thought to have come from very small fissures some distance from the focus of extrusion described above. Similar small flows have been discovered on the lavas capping the Merti Plateau (Matheson, 1971) and in the Barchuma-Kom area (Dodson, at the press). These flows may represent a slight recurrence of activity along the main feeder fissures of the flood basalts. They were described by Dixey (1948) who noted that they were fresh looking and highly scoriaceous.

In hand specimen the lavas are aphanitic rocks which are indistinguishable from the olivine basalts. Thin sections however enable them to be identified as nepheline basanites, showing that this later activity had more alkaline tendencies. A typical section is 28/131, from parallel 1°30′N north-east of Kurato, which is a sample from the terminal portion of

one of the flows radiating from the main centre to the north. The section shows a porphyritic rock with an abundance of slightly titaniferous augite phenocrysts with a smaller number of olivine phenocrysts. The olivines show thin resorption borders of iddingsite, and the 2V indicates a magnesian composition. The groundmass is granular and consists of a second generation of clinopyroxene, cubes and octahedra of magnetite, laths of labradorite and interstitial primary nepheline. Calcite-filled vesicles occur.

Specimens of similar composition are 28/22, a nepheline basanite from a flow five miles north of Merille and 28/269, a porphyritic nepheline basanite from three miles east of Lodosoit. These rocks are typical representatives of the basanite fissure flows. Only one specimen from a fissure flow was found to be an olivine basalt in thin section. This is 28/157 from three miles north-east of Nolwao.

(iii) Basalt Scoria Mounds

A few scoria mounds occur on the lava plateaux of Marti Serteta, the north Merille plateau and the plateau in the north-western corner of the area. These scoria mounds are all considerably eroded and none has a very well preserved crater, the best preserved cone being Impusi Lempara in the north-west. The scoriaceous lava of these cones is olivine basalt. The cones are considered to be Pleistocene in age on the same evidence as that cited above for the age of the basanite fissure flows, and the two phenomena are probably penecontemporaneous.

The hand specimens of these lavas are uninformative, but they are generally more vesicular and scoriaceous than the plateau basalts. In thin section, 28/262 from Impusi Lempara is typical. The minerals present are olivine, clinopyroxene (augite) both as phenocrysts and groundmass crystals, and iron ore, often altered to hydrous iron compounds. Quartz xenocrysts occur and quartz and calcite vesicle infillings are present. The texture is not the intergranular type of the plateau basalts, the felspar in this specimen tending to be interstitial. Specimen 28/222, from the small cone near ART10 survey beacon, is another example of this rock type. 28/151 from Olmpas is atypical inasmuch as it is a mugearite, the oligoclase laths giving an overall extinction pattern.

These scattered manifestations of Pleistocene volcanic activity are probably correlatable with the earlier phases of the Nyambeni episode.

(iv) Recent Volcanic Rocks

A series of lava cones and associated lava flows occur in the north-central part of the area near Merille. These cones rest on the present dissected metamorphic rock surface, some of the lavas having flowed into and along the present Merille valley causing the river to be diverted along the edge of the lava flow. The lava cones and flows have a very young appearance on aerial photographs and the flows are distinctive on the ground. For these reasons the lavas are considered to be Recent in age. In addition to the lava cones, there are three phreatic explosion craters situated in the same region. These consist of agglomeratic ash, poorly consolidated and generally forming an arcuate or crescentic crater due to the prevailing wind from the south-east. To the north-west of these craters a thin veneer of volcanic ash occurs on the metamorphic rocks. This is usually only a few inches thick, and is sometimes secondarily compacted.

Both the lava cones and the explosion craters are in a good state of preservation, the former typically possessing a major crater with a number of small parasitic vents on the sides. Lava flows have in some cases breached the rim of the lava cones, which consisted at that time of clots of cooling lava, and flowed out on to the plain surface, e.g. Olmbaa Lesuguroi easterly cone and Mesasaa cone. In other cases the lava flows have issued from small 'blisters' on the sides of the main cone, e.g. Sasani and Olmbaa Lesuguroi westerly cone. The flows are composed of blocky lava and have only stunted vegetation established

on them. The craters of the lava cones are sometimes conical and deep, as Sasani north cone, but in other examples are very shallow, flat-floored depressions, as Olmbaa Lesuguroi westerly cone. Some have barely recognisable craters and are merely mounds of lava, as is Inkiposorogi.

The flows from these Recent cones were quite fluid. The flows northwards from Olmbaa Lesuguroi became rather tenuous down the slope of the Merille valley but thickened in the bottom of the valley and then flowed for some distance along the valley. This partial blockage of the Merille valley and resulting diversion of the seasonal river waters along the edge of the flow caused some ponding back of the Merille waters and deposition of alluvium over a large area upstream from the flow.

Perhaps the most interesting feature of these lava cones and explosion craters is their remarkable north-north-easterly alignment along what must have been a line of crustal weakness. All but one of the cones lie on this line (*see* Fig. 2), the Mesasaa cone occurring some distance to the south. This structural feature extends in a north-north-easterly direction to the north of 1°30′N, where a lava cone and a series of spectacular explosion craters, all situated on the Pliocene lava plateau, occur on this same alignment. Evidence that this cone (GT21) and explosion craters are part of the same suite of lava cones can be obtained from the petrology of the lavas. All the Recent cones near Merille are predominantly of olivine melanephelinite lava, with a few basanites. The cone to the north of 1°30′N was also found to be composed of olivine melanephelinite lava, a fact which substantiates its connection with those farther south. Numerous other cones of this age are thought to occur between Laisamis and Marsabit and probably farther north still. Some were possibly contemporaneous with the last stages of the Nyambeni volcanicity, although most were probably even younger, and the writer would place the Merille volcanic rocks as Recent in age.

In hand specimen the lavas are uninformative dark, fine grained, basaltic rocks. In thin section nearly all the specimens obtained proved to be of olivine melanephelinite; a few of them contained minute needles of felspar and one specimen was an undoubted basanite.

Specimen 28/43, from the southerly cone at Inkiposorogi, is an olivine melanephelinite and exhibits all the features typical of these rocks. Magnesian olivine is ubiquitous as microphenocrysts but is absent from the groundmass. Clinopyroxene, a green-brown augite, is the major component of the groundmass and occurs chiefly as very small lath-like crystals. Magnetite forms a scattering of minute crystals, and the presence of oxidised iron ore was also noted. The other mineral component, nepheline, occurs abundantly interstitially in the groundmass. Felspar is absent. The fineness of the grain of the lava results in the rock having a fine granular texture under the microscope.

The lava from the north cone at Inkiposorogi, 28/46, is an olivine melanephelinite containing small angular crystals of a blood-red isotropic mineral with rims of iron ore. It was identified as melanite garnet, in preference to perovskite, on the criterion of the roughish surface texture of the mineral in thin section. Numerous granular aggregates of olivine crystals are seen, and there are some calcite-lined vesicles. Specimen 28/53 from Mesasaa is a slaggy olivine melanephelinite, the slaggy crystalline material forming a framework enclosing large vesicles filled with fibrous zeolite. 28/184, from the Sasani lava flow, is an olivine melanephelinite consisting of large olivine phenocrysts and abundant nepheline, easily detectable in thin section. Augite and magnetite form the groundmass, together with interstitial nepheline.

The cones at Olmbaa Lesuguroi have a tendency to be basanitic in composition, in contrast to the rest of the Merille cones. Sample 28/231, from the eastern cone at Olmbaa Lesuguroi, is a nepheline basanite. In thin section it is similar in mineral composition to

the rocks described above except that it contains scattered needles of felspar. Specimen 28/225, also from the flow from the eastern cone, is however an olivine melanephelinite, showing that the mineral composition is variable within a single flow. Lava from the central cone, 28/232, is a vesicular nepheline basanite with a striking ropy texture (*pahoehoe*). Thus these rocks from Olmbaa have definite affinities with the olivine melanephelinites and indeed are very close to these rocks in composition while technically being basanites.

The explosion craters of this episode are composed of bedded agglomeratic ash which dips away from the centre of the crater. They are low on the south-east side facing the prevailing wind direction and highest on the opposite side, with a tail of ash to the north-west. The agglomeratic ash consists of blocks of metamorphic rocks and lava in a matrix of fine lava fragments. The eastern cone at Ndonyuo Olnchorro is a good example of these explosion craters (Plate IVb). Bedded volcanic ashes are seen in a stream bed immediately west of the explosion crater north of Serirua. The xenoliths in the agglomeratic ash range from a few inches to one foot in diameter, very few exceeding this maximum.

A specimen of secondarily compacted volcanic ash was obtained from the thin ash cover north-west of the Merille explosion crater. Thin section 28/193 shows this ash to consist of angular fragments of quartz, andesine, microcline and hornblende from the metamorphic rocks and rounded fragments of olivine melanephelinite lava from subsurface magma. Olivine crystals are also present, and all the fragments are embedded in a fine matrix of ash which has been compacted by secondary calcareous cementation, specimens of the ash reacting strongly with acid. The fragments of metamorphic rocks in the agglomeratic ash have not been altered. However, altered xenoliths, presumably of metamorphic rocks, were found in the lavas at Sasani cone and the cone near Serirua. These are of two types, both of which reach a few inches in diameter. Both types are granular, somewhat friable rocks, one being light green and the other a reddish brown burnished or iridescent colour. These xenoliths are thought to be altered calc-silicate rocks or limestones from the Basement System.

Volcanic Rocks—Conclusions.—The interesting feature concerning the volcanic geology of this area is the tendency towards increasing alkalinity in the younger lavas. However, the lavas in this area are not proposed as a differentiation sequence but rather as three distinct and successive episodes of extrusion. The tendency for the late period of extrusion to be nepheline-rich is very evident.

The Pliocene floods were of olivine basalt, the lavas of the second extrusive phase were olivine basalt scoria cones and basanite fissure flows, whereas the Recent volcanic rocks of Merille are predominantly olivine melanephelinites with a few basanites. The explosion craters are clearly part of the same phase as the latter cones because fragments of clots of olivine melanephelinite lava occur in the ashes.

It is likely that most of the small youthful lava cones between Laisamis and Marsabit are composed of olivine melanephelinite. Lavas of this type are found farther south within the Nyambeni Volcanic Series (Rix, 1967) and it is thought likely that the focus of activity in late Pleistocene-Recent times moved north from the Nyambeni to the Marsabit region. Relatively small scale and scattered activity then gave rise to a number of Recent lava cones between Merille and Marsabit mountain, which was a centre of Upper Pleistocene-Recent explosive activity.

6. Quaternary Superficial Deposits

(i) Calcareous Crustal Deposits

A number of patches of calcareous surface deposits were mapped in different parts of the area. Large patches of kunkar limestone (calcrete) occur in the Sera region and smaller patches occur near Olmbaa and north of Olmpas. Small scattered patches of this rock type have not been differentiated on the map. These crustal deposits originate by

alternate leaching and desiccation under extreme tropical weathering conditions. This results in the deposition of carbonate-rich material that forms a cement for grains and fragments of the underlying rock type. Calcrete is also developed locally on crystalline limestone in the central part of the area.

A good specimen of calcrete developed on crystalline limestone is 28/238 from three miles south-east of Olmbaa Lesuguroi. Large calcite crystals are seen to be enclosed in a calcareous matrix which forms concretionary structures round them. Quartz fragments and a large fragment of quartzite also occur within the matrix. Leaching and secondary deposition has resulted in secondary calcite veins which permeate the matrix.

(ii) Ferruginous Crustal Deposits

A small patch of ferruginous material was mapped three miles north-east of Nolwao. It is a friable sandstone containing fragments of metamorphic rocks and is brown in colour in hand specimen. In thin section, 28/175, this sandstone is seen to contain angular fragments of quartz, microcline, plagioclase and magnetite in a ferruginous matrix.

This rock, which is relatively unconsolidated for a surface concretionary deposit, may have formed in a small Quaternary lagoon in a hollow in the metamorphic rock land surface.

(iii) Siliceous Crustal Deposits

A small patch of brown rock, veined and apparently altered, was discovered south of Kisepetai. The thin section, 28/283, from this locality indicates that the rock is a ferruginous silcrete. Rounded crystalline aggregates of quartz are surrounded by other quartz crystals, and hydrous iron alteration is evident.

(iv) Pebble Sheets

A small patch of quartz pebbles was encountered three miles north of Merille. The pebbles are quite angular and could be residual from a patch of coarse gravelly sediment. No extensive pebble sheets occur in the area, although the sands overlying the metamorphic rocks and the sediments tend to be coarse and to contain pebbles, those overlying the sediments containing rounded pebbles.

(v) Lacustrine Marls

A patch of light grey-green, fine grained marl occurs at 1°30′N immediately to the east of the Marsabit road. There is a basal layer of coarser conglomeratic material and also some slightly coarser horizons within the marl. The rock has a rapid reaction with acid, indicating the calcareous nature of the deposit. The marl is thought to have accumulated during the Pleistocene period in a depression in the land surface. It shows only vague traces of bedding, indicating that the pool was agitated by currents or rapid influxes of material. The clay expands slowly and disintegrates in water, but it is in no sense thixotropic and cannot be regarded as a bentonite.

(vi) Recent Alluvium, Sands and Soils

Sands are widespread on both the metamorphic and sedimentary rock terraces. Pink and white sands occur on pebbly sandstones in the north-east, rounded pebbles being occasionally found in these sands. Coarse red sandy soils are developed on the metamorphic rocks; they are extensively developed in the south-east near Sera and in the west where they extend to the foot of the Mathews Range.

Alluvium has been deposited along some of the major river courses and two alluvial terraces exist near the junction of the Santait and Merille rivers. Alluvium in this region is very widespread and it is thought that the lava flow from Olmbaa Lesuguroi partially dammed the river, initiating deposition of silt during flood periods, to the west of the lava flow.

Two large areas of black cotton soil are present in the west. These soils support only a stunted vegetation and occupy slight hollows that are areas of bad drainage. The soils themselves frequently contain quartz fragments in the black clay matrix.

VI—STRUCTURE

1. Folds

(i) Major Structures

The major structure of this area is a series of low amplitude, long wavelength folds, the axes of which lie approximately north-south. These axes are undulating, producing fold closures facing both north and south (Fig. 2, at end). This straightforward picture is complicated only in the north-east where the outcrops of Basement System metamorphic rocks show a marked east-west trend.

The section on the coloured geological map shows the major features of the structure and certain major folds are evident. From east to west these are the Gue river syncline, the presumed anticline beneath the lava at Olmpas and the three major folds between the Kauro laga and Olmbaa Lesuguroi. Of the latter folds, the two synclines are best exposed, one having closures both to north and south forming a "boat" structure and the other closing northwards only, the axis flattening out southwards.

West of Olmbaa Lesuguroi an anticlinorium of low amplitude folds stretches westwards beyond Kisepetai. The major axis is there north-south and nearly horizontal. A major syncline in the Santait region and its complement, the Lodosoit anticline, are observed before the metamorphic rocks are obscured by sand cover to the west of Lodosoit. This section is considered to be representative of the major structure of the region. Although it is not a true structural section, that is a section at right angles to the plunge of the axis, it shows a good approximation to the shape and amplitude of the folds because the axis never dips very steeply in this part of the area.

To the south of the plane of the section similar fold structures continue. There is a slight twist in the major anticlinal axis in the Lenkaya region and other folds are seen to die out on the flanks of the anticline. There is a major culmination west of Lenkaya, and the fold axis dips at a steeper angle on the south side than on the north. This produces the synclinal closures well seen at Nalala and Lontopi, and the anticlinal closures north-west of Kauro and near Lerekere. These folds show reversals of the direction of plunge of the fold axis; at Nalala and Lerekere the axis plunges southwards whereas at Lontopi and north-west of Kauro it plunges northwards. Thus, the undulations whose axes are at right angles to the main axis are not constant in an east-west direction but tend to fade out and disappear.

To the north-east of the plane of the section the fold structures become more complex. The anticline west of Sasani has been bent over eastwards north of the Merille laga and the plunge of the north-south axis of this fold steepens northwards. The result of this is that the outcrops swing to take on an east-west trend, the fold closes eastwards and those beds in the centre of the almost cylindrical fold close westwards as well as eastwards. Near to this major bent fold overfolding has occurred, and the fold north-east of Sasani shows an overturned limb on the eastern side. The axis of this overturned fold plunges north-north-west at a moderately steep angle.

(ii) Minor Structures

Foliation—is widespread throughout the area, particularly in the centre, and is best developed in the biotite gneiss succession and the finely banded succession of semi-pelitic rocks. The orientation of biotite crystals in the rocks is the most important factor in the

development of foliation, but the hornblende content of some rocks results in orientation and some foliation being developed. The existence of the rock successions mentioned above and the variation from foliated to massive types within the succession provides a vivid impression of the folds on aerial photographs.

Lineations—occur as linear structures on exposed surfaces of rocks, usually foliation planes. Measured lineations within the Kauro-Merille area generally plunge north or south at a very low angle. Only in the north-east do the lineations swing away from this north-south direction and take on a steeper angle of plunge. Linear structure is shown in Plate IIIb.

Minor Folds.—The orientation of axes of minor folds is often an important adjunct to the lineation measurements. The minor fold axes may parallel the major fold axis but more often they are found to be approximately at right angles to it. This is rarely an indication of a second period of folding; it is a reflection of the stresses which are inevitably present at right angles to the major stresses which produce the large folds. These small "corrugations" are thus penecontemporaneous with and superimposed upon the major structures.

There are a number of minor folds mapped in the present area, some of which reflect the style of the major folding. Gentle flexural slip folds can be seen in Koiya gorge (Plates Ia and IIIa). A gentle fold on a larger scale is present south of Serirua, the axis of which is parallel to that of the major fold.

Minor folds which reflect the style of the major folds in their vicinity are to be seen north-east of Nolwao hill. There, near the edge of the lava plateau, the limestone bands can be traced out on the surface, and seen to form a number of small overturned folds. The zig-zag effect of these bands, protruding a foot or so above the foliated biotite gneisses, is quite striking.

Stereograms of Minor Structures.—For the purpose of plotting the structural data and to illustrate the overall structure more clearly, the minor structures have been plotted on three stereograms, each of which represents a portion of the area surveyed (Fig. 2 (*a*), (*b*) and (*c*)). Minor fold axes are plotted with lineations. Each of these sub-areas is dealt with separately below:—

Sub-Area 1.—This covers the southern part of the area, south of Mesasaa, Lenkaya and Siepi, and includes the Nalala, Sera, Lontopi and Kauro folds. The stereographic plot Fig. 2 (*a*) of the minor structures shows that the structure is homogeneous, the fold axis being virtually north-south. This axis is gently undulating and plunges both to north and south, but in either case the plunge is never more than a few degrees. The plots of the foliation measurements show that most of the dips are moderate and there are no vertical or steeply dipping beds. This is consistent with the overall picture of long wavelength, low amplitude folds.

Sub-Area 2.—The stereogram is composed of the plots of lineations and foliation measurements from the central and northern portions of the area (Fig. 2 (*b*)). The folds in this tract of country are continuations of the folds south of Lenkaya and Inkiposorogi. The major structure is straightforward and exposure is good, with the result that a qualitative interpretation can be made from aerial photographs. Structural measurements confirm the initial interpretation and provide a quantitative and statistical assessment of the structure. The stereogram shows the field to be homogeneous with respect to a virtually north-south axis, which is undulating. Statistically, the tendency is for the axis to plunge northwards at a shallow angle, probably in the region of 10°. The plots of poles to foliation planes again show the lack of steeply dipping and vertical beds.

The features of this stereogram are very similar to those of Sub-area 1 (Fig. 2 (*a*)), showing that structural homogeneity extends over a large part of the area.

Sub-Area 3.—This covers the north-east where bending of folds and overfolding has taken place (Fig. 2 (*c*)). The minor structures are particularly important in this area to elucidate the initial interpretation of the structure. Without them it is possible to postulate an east-west fold axis that is cross folding, using the east-west striking rock beds and closures as evidence. However, the foliations indicate that some closures, difficult to interpret as open folds, are in fact overturned folds. The lineations indicate that no second axis is involved and (with the exception of a few mentioned below) have a persistent north-south trend.

A few lineations indicate an axis plunging to the west-north-west. Most of these are however linear structures, possibly slickensides in the closures of overturned folds, such as that north-east of Sasani, or minor fold axes at right angles to the main axis such as those at Konja.

Thus, in spite of the complications in the form of the outcrops in this region, the major fold axis remains in a north-south direction, trending to the north-north-east, and the field is therefore homogeneous. The axis has a definite tendency to plunge more steeply northwards here than elsewhere in the area.

Summary.—The information derived from the plotting of minor structures substantiates the initial interpretation of the features of the major folding. It also clarifies the interpretation of the area of more complicated folding in the north-east. Essentially the Kauro-Merille area consists of a homogeneous field of low amplitude long-wavelength folds folded with respect to a north-south undulating axis. The writer considers that the irregularities in the north-east are due to local disturbance during the main orogeny, producing bent and overturned folds over this limited area. This area of overturned folds extends northwards towards Laisamis, but north of that locality the metamorphic rocks are completely blanketed by lava and the sand of the Kaisut desert, which probably overlies sediments.

2. Faults

Faults are not common, but those which are present are clearly visible on aerial photographs due to the aridity of the country and the consequent sparse vegetation cover. The faults themselves show up as light coloured lines representing the fault breccia zones, and the displacement of rock beds on either side of the faults enables them to be picked out easily. Most of the mapped faults lie in the northern part of the area where exposure is better than elsewhere. It is possible that some faults exist in the south which are not discernible due to poorer exposure or thicker bush cover. The major faults have a pronounced easterly or east-north-easterly trend, and some have dolerite dykes intruded along the fault planes.

The Kamotonyi branching faults occur near to parallel 1°30′N, the longer of which is mappable for almost seven miles until it disappears under a lava plateau. Two dolerite dykes are seen intruded along the fault plane, and it is possible that a thin connecting dyke or stringer occurs along the whole length of the fault. The relative displacement of a band of quartz-felspar gneiss near the eastern end of the Kamotonyi fault is 200 yards, and the width of the zone of brecciated rock is approximately 30 yards. Similar displacement of the protruding leucocratic hornblende gneiss bands is evident to the west of the Marsabit road before the faults die out north-west of Kamotonyi.

A fault about one and a half miles in length occurs near the Merille laga east of the Marsabit road crossing. It trends east-north-east and is visible on aerial photographs as a sharp dividing line between displaced rock beds. On the ground it is seen to displace a

prominent band of quartz-felspar gneiss (about 200 yards relative displacement) and also a limestone band. The zone of brecciated rock is only about 10 yards wide. Both this fault and the Kamotonyi faults downthrow to the south.

A small fault occurs south-east of Serirua and is unique in this area in that it trends north-west. It is about three-quarters of a mile in length and has a brecciated zone approximately 20 yards wide. It displaces a very prominent band of quartz-felspar gneiss which bends into the fault zone.

A fault trending east-north-east crosses the major folds between Olmbaa and Nolwao, and is four miles in length. It is well exposed where it crosses the synclinal folds but is obscured on the crest of the anticline where a sand cover exists, and it has been shown at this point as an inferred fault. The displacement along this fault is not more than about 30 yards and the brecciated zone only 5 to 10 yards wide; the fault downthrows to the north. Near the western end of the fault displacement of limestone and quartz-felspar gneiss bands can be seen. The most striking demonstration of the presence of this fault is near the eastern end, where a protruding pegmatite vein is displaced (Plate IIb). Parallel to this fault and 100 yards from it is a dolerite dyke, which is about one mile in length and cuts across the pegmatite vein at this locality. It is thought that this dyke was intruded along a small parallel fracture.

One further structural feature remains to be discussed, the alignment of the majority of the Recent volcanic cones along a generally north-easterly line. The western cones between Inkiposorogi and Sasani follow an east-north-easterly alignment approximately parallel to the trend of the faults discussed above. From Sasani to the explosion craters near Soito Narok the cones follow a north-easterly alignment, tending towards the north-north-east. This alignment of Recent cones continues north-eastwards to the north of the present area. The cones are considered to be situated on a line of crustal weakness, Recent in age, the nature of which is conjectural. It may have been a region of crustal tension which did not develop into a true fault but was pronounced enough to result in the eruption of lava cones from fissures situated on it.

VII—ECONOMIC GEOLOGY

1. Minerals

The following are deposits discovered in this area:—

Magnesite.—Numerous magnesite veins, formed by the action of carbon dioxide on the ultrabasic rocks, were found associated with the Kisepetai serpentine. The veins are generally small, rarely exceeding one foot wide. They are impersistent and seem to have an irregular disposition. The veins are exposed chiefly on the summit ridges of the serpentine and are therefore not easily accessible due to the steepness of the sides of the intrusion. In thin section the magnesite is seen to be a homogeneous rock, consisting of minute crystals of magnesite.

Garnet.—A small band of rock consisting largely of garnets but with a little quartz, occurs four miles north-east of Merille. This band occurs in biotite-garnet gneisses and is approximately 6 to 9 inches thick, tapering over a distance of 30 yards and merging into the gneisses. The garnet (almandine) is pinkish violet in colour and separated by small amounts of quartz.

Ilmenite.—Small segregations of ilmenite occur in some of the pegmatite bands. They do not reach a diameter of more than a few inches and are of no economic importance.

Sand.—Unlimited supplies of clean quartz sand are available from the sand rivers in the area, particularly the Merille and Kauro lagas. At present there is little use for this in the area.

Clay.—A small area of calcareous clay was discovered in the northern part of the area near the Marsabit road. This clay is not bentonitic and is probably too calcareous to be of value to industry.

Road metal.—The Recent lava cones, particularly those at Inkiposorogi and Olmbaa Lesuguroi, may provide useful supplies of resistant road metal, if it is required in the future. The present surface of the main Isiolo-Marsabit road is sandy and is kept in reasonable condition by the local authorities.

Limestone.—Crystalline limestone bands are present within the Basement System succession. Some attain a considerable thickness and the bands south of Ndonyuo Olnchorro are the most important, particularly where they thicken in the nose of the syncline east of Olmbaa Lesuguroi. An important consideration if any development of these deposits is contemplated is their difficulty of access and resulting high transport costs. In these circumstances a deposit must be considerable before it becomes economic. All the deposits in the present area are considered by the writer to be sub-economic.

Radioactive Minerals.—Radiometric monitoring was carried out during day to day traversing but no anomalies were found.

2. Water Supplies

This tract of country has a very low rainfall and most of it is covered with stunted thorn bush. However the region is relatively well endowed with water supplies compared with areas farther north and north-east, where semi-deserts of lava and sand occur. Water is held in the sandy beds of the Kauro and Merille systems and there are a number of points along these lagas where the supply is permanent, although the level drops considerably in the dry season. These permanent watering points include Kauro and Sereolupi, where trading centres have been established, and Kinya, Lenkaya, Kapai and Sera, all of which are in the southern part of the region. These watering points are in Samburu country and are used for watering cattle, sheep and goats.

The permanent watering places in the north are along the Merille-Lodosoit drainage system. Koiya and Lodosoit have trading centres and the former also has a Game Ranger post. Other major watering points are Kamotonyi and six main wells in the Merille (or Serirua) laga between the main road bridge and the Soito Narok hills. Downstream from the latter locality the river flows on sediments and becomes an aggraded, tapering and braided stream in which water is readily available only in the wet season. The Merille is very important as a watering place for camels owned by the Rendille who inhabit the regions to the north of this river.

The source of sub-surface water is more obvious in the case of the Merille laga than in the case of the Kauro system. The former drains the slopes of the Mathews Range, some distance west, and would be expected to have a reasonable supply of water. The Kauro, on the other hand, drains the relatively flat area, with a few large inselbergs, to the south of 1°00′N (Jennings, 1967), yet in both rivers some sub-surface flow can be detected in the wells. The writer considers that some water reaches the Kauro system from shatter zones in the metamorphic rocks.

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