REPORT No. 71

REPUBLIC OF KENYA

MINISTRY OF NATURAL RESOURCES, WILDLIFE AND TOURISM

GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE LOITA HILLS AREA

DEGREE SHEETS 50, S.E. QUARTER and 57, N.E. QUARTER

(with coloured geological map)

by

E. P. SAGGERSON, B.Sc. (Dunelm), Ph.D., F.G.S.
formerly Chief Geologist

Twenty Shillings - 1966

GEOLOGY OF THE LOITA HILLS AREA

DEGREE SHEETS 50, S.E. QUARTER and 57, N.E. QUARTER
(with coloured geological map)

by

E. P. SAGGERSON, B.Sc. (Dunelm), Ph.D., F.G.S.
formerly Chief Geologist

FOREWORD

The Loita Hills area, although less than a hundred miles from Nairobi, is little known to the ordinary traveller, though hunters are attracted by the big game there. The area lies on the western flanks of the Rift Valley west of the soda lakes Magadi and Natron.

Rock exposures are generally good, and Dr. Saggerson has been able to make a detailed subdivision of the rock-types, and to suggest a correlation with other parts of Kenya. In addition he has devoted a considerable amount of study to the complicated structures, and postulates two separate periods of folding to account for them. The Tertiary and Quaternary history of the area is mainly one of faulting and volcanicity associated with the formation of the Rift Valley.

The economic potential of the area proved disappointing, but this is perhaps offset by the relative abundance of water, and the author suggests that there are opportunities for development locally of farming and ranching schemes to replace or augment the stock-herding of the nomadic Masai.

Nairobi,
22nd December 1964.

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

CONTENTS

LIST OF ILLUSTRATIONS

PLATES

MAP

ABSTRACT

The report describes an area of approximately 1,200 square miles extent in the Rift Valley Province of Kenya bounded by longitudes 35° 30′ and 36° 00′ E., by latitude 1° 30′ S. in the north and by the Kenya-Tanzania border in the south. The area has been bevelled by the sub-Miocene and end-Cretaceous peneplains while Pleistocene to Recent dissection due to repeated rejuvenation is responsible for the mountainous Loita Hills that rise to over 8,500 ft.

Most of the area consists of highly folded and faulted Basement System quartzites, schists and gneisses of Precambrian age. These rocks form part of the Turoka Series and are characterized by the high-grade index minerals, sillimanite and kyanite.

Overlying the sub-Miocene peneplain rest melanephelinites and basalts and sediments of late-Tertiary age that in turn are overlain by Pleistocene lavas, tuffs, ignimbrites and sediments.

The petrography of the rocks and the effects of metamorphism and granitization on the Basement System rocks is discussed. It is shown that the Archaean rocks have been subjected to two periods of folding; recumbent folding being associated with the earlier movements. The volcanic rocks are affected by rift-faulting that commenced in late-Tertiary times. Small deposits of possible economic minerals are described and the water supplies of the area discussed.

GEOLOGY OF THE LOITA HILLS AREA

I—INTRODUCTION

The area described in this report is approximately 80 miles south-west of Nairobi and comprises those portions of the south-east quarter of degree sheet 50 and the north-east quarter of degree sheet 57 that lie within Kenya. It is bounded by longitudes 35° 30′ and 36° 00′ E., by latitude 1° 30′ S. in the north and by the Kenya-Tanganyika border in the south and has an area of approximately 1,200 square miles. The area mapped is covered by sheet No. 159 of Kenya and No. 27 of Tanganyika of the Directorate of Overseas Surveys, London.

The object of the geological reconnaissance, which was made between the months of February and July 1958, was to construct a geological map and assess the possibility of the occurrence of economic mineral deposits.

Maps.—In the preparation of the geological map aerial photograph mosaics, on a scale of 1 : 50,000 supplied by the Survey of Kenya, were used. The form-lines shown on the map were based on barometer readings taken at varying intervals during the survey. Heights were constantly checked against known altitudes and corrected for diurnal variation. Topography taken from an early map by C. Uhlig (1909)* was also used.

A number of trigonometrical stations recently established by a Military Survey Company have been given names known to the local inhabitants of the area, the Survey name being shown alongside the local name on the map.

Communications.—Communications in the area are poor. The main Narok-Tanganyika road passes through the area approximately from north to south, though between Entasekera and Ol Mesutie it is little more than a motorable track. Tracks from Morijo (on the main road) to Naigara in the north-western part of the area, and from Naigara to Ol Pusimoro in the area to the west of the present one, are the only other principal routes of communication.

Population.—The Loita Hills area lies in the Southern Province of Kenya and is administered from the district headquarters at Narok, situated 40 miles to the north. The inhabitants are nomadic tribesmen of the Purko and Loita clans of the Masai tribe who graze their large cattle-herds over the plains and grass-covered hills, the distribution of settlements depending largely on the presence of surface waters. Unlike other parts of Kenya water supplies are generally good and Masai *manyattas* are to be found scattered throughout most of the area. Only in the south-east corner are the Masai absent, probably due to lack of suitable water supplies, and to tsetse fly, but the presence of disused huts indicates an older habitation for this part of the Loita Hills. Recently a number of schools have been built in the Narok District, two of these being located at Narosura and Morijo.

For many years big-game hunters have been attracted to the area which has now become widely known because of its black-maned lions. Birds, game and in particular the bigger animals such as elephant, buffalo and rhinoceros are also plentiful in the forests or roaming the plains. Although not seen during the survey, the local inhabitants stated that hippo thrive in the Olngakualala swamp, at a height of 6,600 ft. In the south-eastern part animals periodically migrate to Lake Natron to eat salt.

Climate and Vegetation.—Rain falls mainly in the periods August-September and November-April. No rainfall data is available for the area but the following figures are quoted for Magadi, to the east, Narok to the north and Loliondo, 16 miles south of the Kenya-Tanganyika border.

---

* References are quoted on p. 58.

	Rainfall in 1956	Number of Rainy Days in 1956	Average Annual Rainfall	Number of Years Recorded
	in.		*in.*	
Magadi	16·87	65	14·65	31
Narok Meteorological Station ..	35·20	116	26·82	42
Loliondo (Tanganyika)	—	—	31·60	22

Rainfall in the forested hill regions exceeds 30 in. per annum, but at the foot of the Nguruman escarpment and south as far as Lake Natron, the climate is dry and hot, in marked contrast to the remainder of the area as indicated by the figures for Magadi situated 20 miles east of the escarpment.

The plains forming the western and northern parts of the area are drier than the hill regions, and support a grass and thorn scrub vegetation, the High Moisture Savannah of Edwards (1940, pp. 382-383), except along the principal river courses, where trees flourish. In the hills, large parts are covered by copses and dense luxuriant mountain forest. An extensive forest 25 miles from north to south and nearly eight miles wide, clothes the mountainous region west of the Nguruman escarpment, but elsewhere the forest is usually confined to deeply dissected valleys which divide the grass-covered hills.

Rock Exposures.—Exposures of Basement System rocks are fairly good and best seen in river-courses. Most of the hill-sides are covered by boulders and reliable structural measurements could only be taken on crests and ridges. A large part of the Nguruman escarpment is scree-covered and rock-sequences could not be measured except in almost vertical-sided gullies which were examined from a distance. Due to the dense forest no traverses were made across the Loita forest east of Entasekera. From an examination of aerial photographs it was possible to locate a small number of outcrops in the forest which indicate lines of geological structure and are shown on the coloured map.

II—PREVIOUS GEOLOGICAL WORK

A. Fischer, a German, was probably the first European to visit the area and passed along the foot of the Nguruman Escarpment in 1883, noting its parallel lines, abrupt cliffs and banded terraces (Fischer, 1884, pp. 58, 60, 75 and 76, and 1885, p. 199). Specimens of gneiss and basalt collected by him were described by Mügge (1885, pp. 238-264). A map accompanying a report by Fischer (1895) shows the route taken by him during his journeys through Kenya.

In 1893 J. W. Gregory made the first of his well-known *safaris* to East Africa and later published a paper (1894) indicating on a map the probable distribution of Alpine flora at the period of maximum glaciation in Kenya. The map was repeated in his "The Great Rift Valley" published in 1896. He considered much of the Loita Hills area to have been covered by such a flora. In another work Gregory (1920, p. 24) shows a profile from the Nguruman Escarpment through Magadi to Turoka, and commented on the age of the Rift Valley (*op. cit.*, p. 32). In 1921 he published his "Rift Valleys and Geology of East Africa" in which he mentions his visit to Lake Magadi. Specimens of gneisses and lavas were obtained from the Nguruman Escarpment for him by a Mr. G. St. Claire (Gregory, 1921, p. 179). Gregory recognized that the upper part of the escarpment within the present area is composed of Basement System rocks.

Another early explorer, von Trotha, crossed to Lake Victoria from the foot of the Nguruman Escarpment, west of Lake Magadi (von Trotha, 1897).

Kaiser (1898, p. 322) recorded lavas, including olivine and amygdaloidal basalts, from the base of the Nguruman Escarpment. His rocks were described by Kunzli (1901, pp. 150-160, 163-164).

C. Uhlig, a member of O. Winter-Stiftung's expedition to East Africa early in the century, considered that Rift faulting forming the Nguruman Escarpment, *Ostafrikanische Bruchstufe* occurred in two episodes (Uhlig, 1907, p. 489), and that the later faults had downthrown Ol Doinyo Sambu lavas to the east (*op. cit.*, p. 488). In a later account he commented on the metamorphic quartzites and ancient rocks of the hilly country at Entasekera (Uhlig, 1912, p. 564).

Captain G. E. Smith a member of the Anglo-German Boundary Commission, traversed the Kenya-Tanganyika border from north-west to south-east and remarked on the high ground at Entasekera and Usubugo and to the abrupt drop from the top of the Nguruman Escarpment to a second shelf overlooking the Rift Valley (Smith, 1907, p. 254).

Kohlschütter (1911) carried out a geodetic survey of Tanganyika and part of Kenya, having established a recording station in the present area. A map showing his results is given by Krenkel (1922, p. 144 and 1925, p. 240) and part of this map is reproduced in Fig. 1.

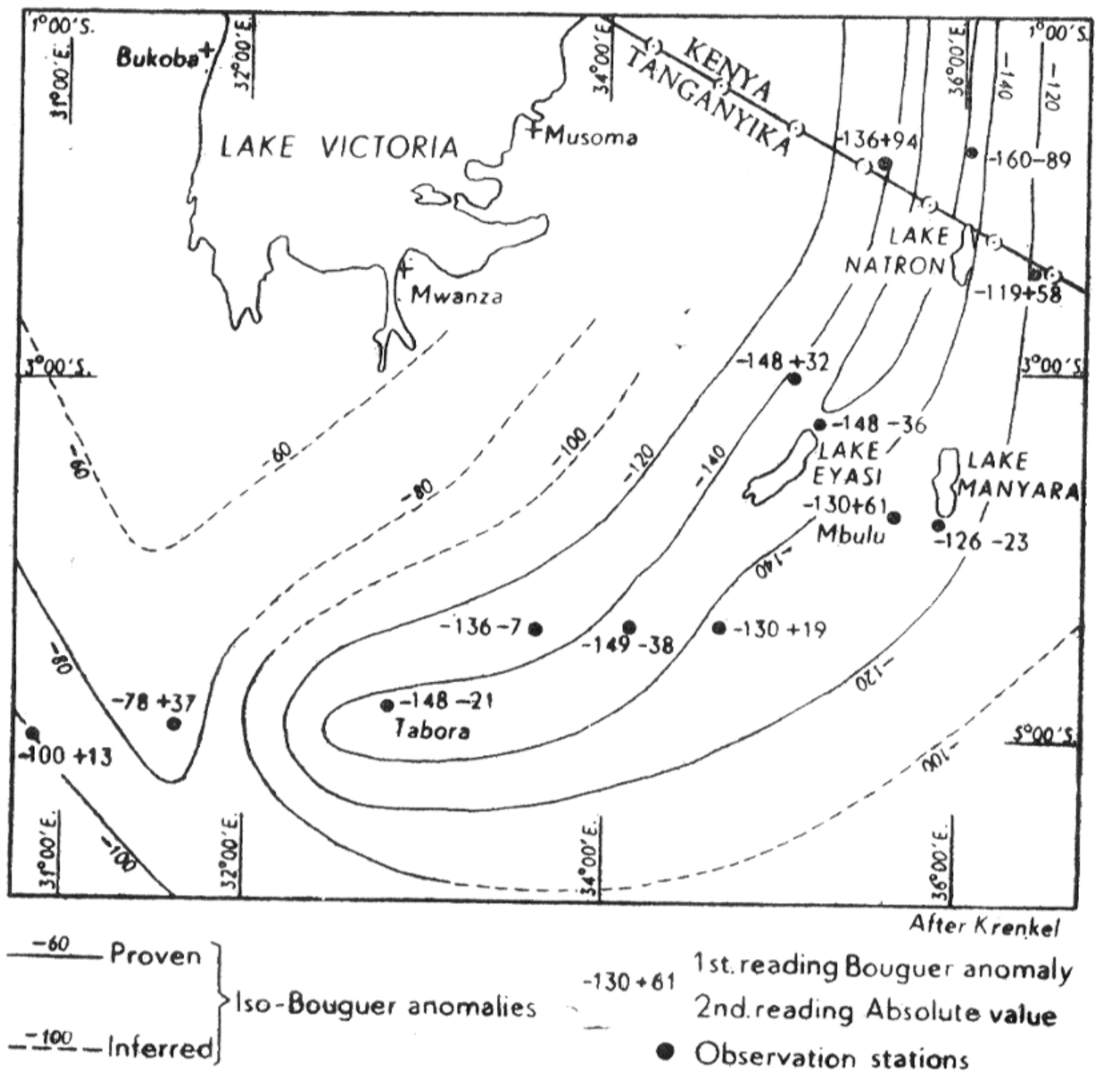


Fig. 1—Bouguer anomalies in the area south and east of Lake Victoria.

His results were later used by Bullard (1936) in an interpretation of gravity measurement in East Africa.

The topographical map produced by C. Uhlig (1909), which shows the south-eastern portion of the Loita Hills area, was based on the work of earlier explorers including members of the Anglo-German Boundary Commission, E. Kohlschütter and von Trotha.

On the coloured map accompanying his report, Behrend (1918) incorrectly indicated the boundary between the gneisses and volcanic rocks of the area. A similar distribution is shown on a map by Krenkel (1925, p. 342). Coloured geological maps published by the East African Survey Group (42nd Geological Section, S.A.E.) in 1942 and by the Geological Surveys of Kenya, Uganda and Tanganyika in 1952 also show too wide a distribution of volcanics in the area. An even wider distribution of the Recent volcanic rocks is figured by Dudley Stamp (1953, p.48).

Bailey Willis refers to the region west of the Nguruman Escarpment as the Serengeti Plateau which he recognizes as being composed of ancient gneisses (Willis, 1936, p. 264). He also comments on the nature of the faulting along the western side of the Rift Valley (*op. cit.*, pp. 38 and 143) which in Plate LI is shown to consist of three *en échelon* faults stepped westwards from north to south. Plate LVI in the same work is a photograph of Ol Doinyo Sambu and part of the west wall of the rift valley in the south-eastern corner of the present area. His interpretation of the faulting west of Lake Natron differs from that shown on a tectonic map by Krenkel (1925, p. 337).

A more recent work by C. Uhlig and F. Jaeger (1942) describes the physiography of the area at the base of the Nguruman escarpment near Lake Natron, and is illustrated by diagrams (*op. cit.*, pp. 25, 41 and 44) some of which depict the south-eastern corner of the area. Map 1 which accompanies the 1942 report shows more accurately the extent of the lavas.

In 1942, the eastern half of the area was prospected without success by a geologist and prospector of the Department for quartz crystals suitable for piezo-electric purposes. For this investigation the area was closed to prospecting and mining in January 1942 (Government Notice No. 45 of the 11th January 1942) and reopened in March of the same year (Government Notice No. 311 of the 31st March 1942).

P. C. Spink and J. A. Stevens (1946) wrote an account of the geography of the Nguruman escarpment west of Lake Magadi mentioning that the escarpment rises to 7,000 feet, "in steps by two grassy and well wooded plateaux . . . . . divided . . . . . by deep and precipitous valleys . . . . ."

Numerous authors mention the Nguruman escarpment and the fact that it forms part of the western wall of the Rift Valley, but do not specifically refer to the Loita Hills area.

III—PHYSIOGRAPHY

The Loita Hills area is composed mainly of Archaean rocks on which rest remains of volcanic rocks extruded in Tertiary and Pleistocene times. In addition terrestrial gravels, mudstones and calcareous soils rest on the older rocks and represent remnants of more extensive deposits that accumulated upon old land surfaces. The Archaean quartzites of the hill region have given rise to prominent but relatively smooth topography, while the plains that surround the hills are underlain by less resistant schists and gneisses.

The area, which may be divided physiographically into three units of totally different character, is dominated by a chain of hills extending in a broad arc from the north-western corner of the area to Emboornarok in the south near the Tanganyika border. A considerable part of these Loita Hills exceeds 7,000 feet in altitude and includes such peaks as Usubugo 8,668 feet, Naigara 8,078 feet, Emburkutia 7,788 feet and the high-level ridges of Usubugooirobi. The Loita Hills, relics of a more extensive high plateau—the Serengeti plain of Bailey Willis (1936, p. 260) have, since Cretaceous times, at least, been subjected to successive periods of uplift. They now remain as a mountainous area dissected by deep valleys and in the east clothed by thick forest. To the north at Usubugo the hill-tops form rolling, grassy moorlands while in the south, near Entasekera the country is more highly dissected, consisting of rocky crests and ridges separated by deep valleys. The denudation of the hills has been influenced by numerous faults, in particular those of the Naigara area. Since Miocene times consequent streams flowing westwards have developed along shatter zones, forming steep-sided valleys that cross the north-south strike of the rocks. A typical example is the west-flowing river Lairaka and its tributaries.

Fig. 2—Physiographical map of the Loita Hills area.

In the western part of the area the ground slopes gently towards the south-west forming the easterly extension of the Loita Plains. These grass plains are more typical of the flat savannah country so well developed to the west, and from the plains rise groups of hills formed of resistant quartzite bands (such as Olosolan and Enkoriga).

To the east of the hill ranges and overlooked by the Nguruman escarpment is the low-lying arid country forming the floor of the Rift Valley, which here slopes gradually towards Lake Natron (2,067 feet), the north-west corner of which lies in Kenya. The upper slopes of the escarpment consist of highly eroded Basement System rocks while in the south-east near Lake Natron, younger volcanic rocks form a steep scarp descending to the Rift Valley floor. The low-lying country in the Rift Valley is covered by pebble sheets and soils, overlying lavas of Pleistocene age. Numerous stream courses have cut into these deposits but only a few, such as the Pagasi river, have eroded their courses to any great depth. Due to irregular rainfall these streams flow seasonally.

The Loita Hills area has been successively bevelled by a number of erosion surfaces, remnants of which are represented by hill-tops and by various deposits that surround the present-day Loita Hills. The accordant summit levels of the hills are considered to be a relic of the oldest surface present in the area.

Four bevels were recognized during the survey (Fig. 2):—

P1 End-Cretaceous peneplain.

P2 Intermediate erosion bevel, probably of early Tertiary age.

P3 Sub-Miocene peneplain.

P4 End-Tertiary bevel.

The principal stages in the physiographic evolution of the area are:—

Period	Events	Results
Late Cretaceous ..	Erosion and peneplanation ..	End-Cretaceous peneplain, Pl. Mudstones, gravels, weathered schists.
Early Tertiary ..	Uplift followed by peneplanation.	Erosion bevel, P2. Iron-stained gravels.
Miocene	Renewed uplift followed by peneplanation.	Sub-Miocene peneplain, P3. Iron-stained gravels, mudstones, riverine deposits, calcareous soils.
Miocene	Commencement of volcanic activity, rift faulting and warping.	First Rift Valley faulting and formation of Nguruman escarpment. Consequent drainage to east and west developed on P3.
Pliocene ?	Eruption of volcanics	Melanephelinites, Kirikiti Basalts.
Plio-Pleistocene	Erosion to base level of Rivers Orkejulesai and Orkejuasur.	End-Tertiary bevel, P4. Kunkar sheets and iron-stained gravels of Ol Mesutie–Entasekera area.
	Renewed rift faulting, Eruption of Plateau Trachytes; rejuvenation of rivers Orkejulesai, Orkejuasur and Narosura.	Rift Faulting, Lengitoto Trachyte. Tuffs, agglomerates and ignimbrites. Narrow incised river valleys in the south-east.
Middle to Late Pleistocene	Ol Doinyo Sambu Volcanic Series. Renewed rift faulting. Continued dissection of R. Orkejulesai valley.	Ol Doinyo Sambu fault downthrows basalts to east 4,000 feet beneath Lake Natron. High Magadi beds.

The main erosion surface to which all others can be referred is the sub-Miocene peneplain which is recognized in many parts of the area, in particular at Naigara, Narosura and near Ilgeri (Fig. 2).

On the western side of the Loita Hills the Orido and Lairaka rivers flow across the well-preserved sub-Miocene bevel, while to the south-west of Morijo Loita and east of Ilgeri, a beautifully bevelled surface is sharply dissected on its southern edge by the south-flowing tributaries of the river Orkejulesai. In many of the river valleys that dissect the sub-Miocene surface are exposed iron-stained gravels, some sections more than 20 feet thick. Notable deposits are those at the head of stream courses west of Naigara where gravels, occasionally current bedded, and iron-stained grits are common. In the river Lekuruki, a tributary of the river Orido, grey and pale brown mudstones are intercalated in gravels while a single calcareous deposit of soil, kunkar and gravel was seen near the head of the river Idepes. Orange-brown superficial deposits similar to those at Naigara outcrop near the Tanganyika border in tributaries of the river Ol Mesutie. Other deposits resting on this surface are small patches of ignimbrite at a number of isolated localities. Although these rocks were probably derived from vents situated in fault-zones, the products of these vents were deposited upon a gently undulating surface as far as the western border of the area, and most probably originally were much more extensive. Red lateritized soils and gravels in the south-western corner of the area may also represent deposits on this erosion surface.

West of Naigara the sub-Miocene erosion surface lies at heights between 6,750 and 6,200 feet and slopes to the west-south-west at about 22 feet per mile (Fig. 3), indicating tilting towards Lake Victoria. Williams (1964, p. 7.) in the area to the west has recognized the same surface sloping to the south-west and overlain by phonolites. In the Migori area Shackleton (1946, p. 52) considered this sub-volcanic surface to slope at about 35 feet per mile towards Lake Victoria, and implied in a more recent account by the same author (1951, pp. 345-392) that it eventually passes beneath the lake. At Narosura the sub-volcanic surface, which is considered to be part of the sub-Miocene peneplain, is seen to be extremely smooth and slopes eastwards at 80 feet per mile from 6,400 to 5,400 feet towards the Rift Valley (Figs. 2 and 3). The surface has been only partly dissected by the Narosura river and its tributaries, due to preservation by volcanic rocks that probably once covered the ground as far west as the foot of the Loita Hills, where relics of the surface are represented by partially lateritized gravels exposed along stream-courses. The sub-lava surface where it is exposed in the Narosura river near the north-east corner of the area, occupies a position which corresponds with the eastward projection of the surface from the Narosura area (Fig. 3), while a remnant of the surface forms the plain at Lengitoto west of the river Olkejulormungushi. On this plain isolated patches of tuff indicate the extent to which the sub-lava surface is now eroded. Lavas out-cropping at approximately 6,300 feet on Olomboneg and Olduratolekarkoyo, and the bevels on ridges in the vicinity of the Tanganyika border, are considered to be remnants of the same surface, which here slopes in a south-easterly direction at about 17 feet per mile.

From the foregoing remarks and an examination of the profiles in Fig. 3 it is seen that the sub-Miocene and consequently the two older surfaces, have been warped along an almost north-south axis approximately parallel to the Rift Valley. The surfaces also slope to the south along the axis of arching, suggesting down-warping into the Rift Valley along the line of the NE.-SW. Sonjo fault in Tanganyika. Subsidiary warping of the sub-Miocene peneplain is indicated by its slope to the north-west in the south-western corner of the area. Following the warping initiation of a consequent drainage system took place and the present stream pattern developed.

The summits and ridges of the Loita Hills are regarded as having been bevelled by a surface which stands approximately 1,300 feet above the sub-Miocene surface, and the ridges and peaks of Naigara, Olosolan, Lengarani, Loisekin, Enkoriga and Ilgeri probably represent denuded remnants of the same bevel on the western side of the Loita

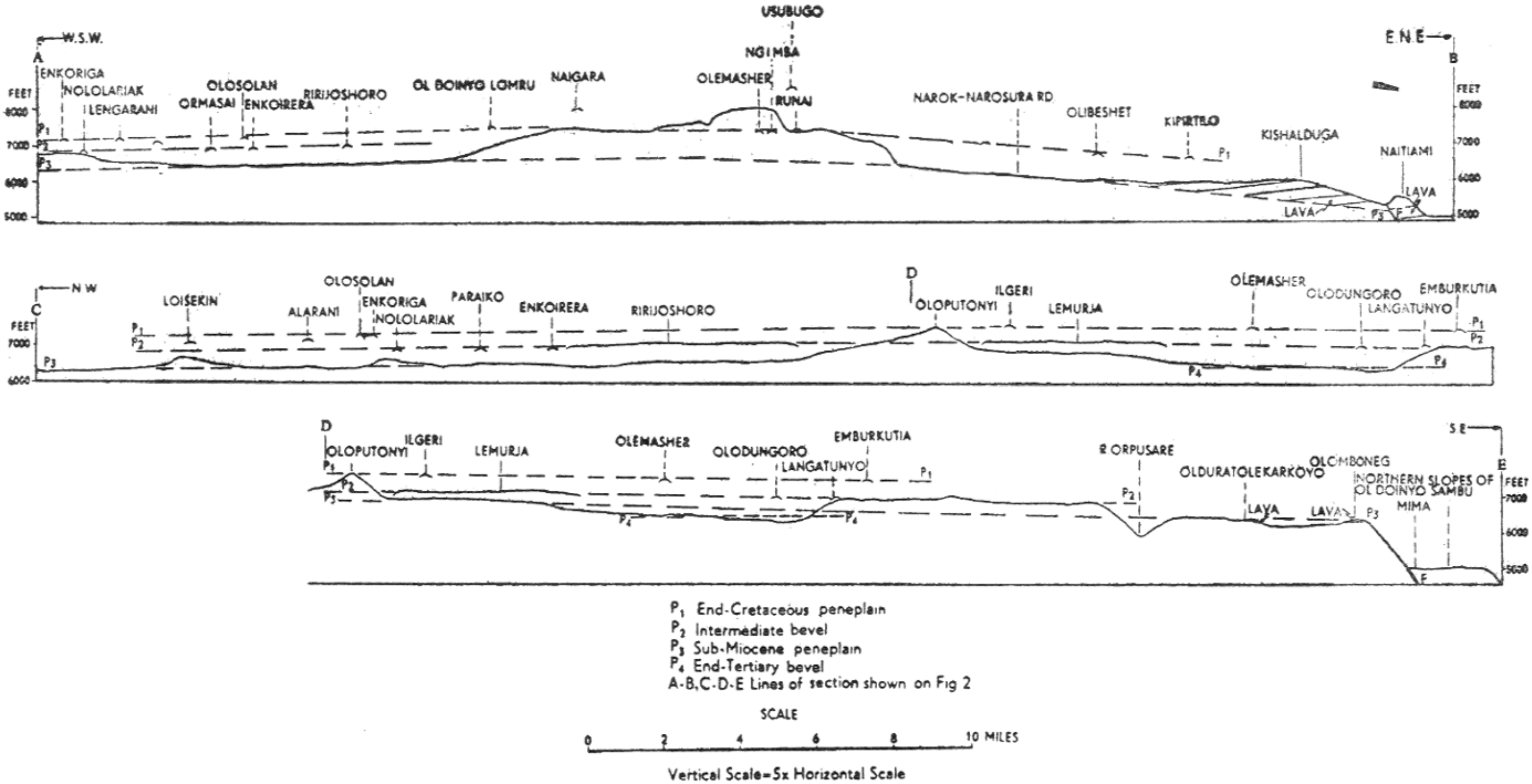


Fig. 3—Erosion surfaces of the Loita Hills area.

arch. Ngimba, Runai, Olibeshet, Kipirtilo, Olemasher and other ridges are remnants of the same bevel on the eastern side. This surface which is comparable with a high bevel in neighbouring areas to the west, has been recognized at numerous places in Kenya where it is found to lie about 1,200-1,300 feet above the sub-Miocene peneplain. In the Migori area of western Kenya, Shackleton (1946, p. 52) recognized the Kisii Highlands peneplain, lying at about 1,300 feet above the level of the base of the Miocene volcanic rocks, and tentatively correlated it with the end-Cretaceous peneplain. Usubugo must have been upstanding on this end-Cretaceous surface.

At an intermediate level between the sub-Miocene and end-Cretaceous surfaces and approximately parallel to them, another bevel, P2, can be recognized. It stands about 350 to 450 feet above the sub-Miocene peneplain and may represent the easterly continuation of a similar surface recognized by Shackleton in the Migori area (*op. cit.,* p.52). It probably represents an intermediate stage in a multi-phase cycle of erosion that culminated in the formation of the sub-Miocene surface (cf. Pugh, 1955, pp. 366-367) or it may be a major erosion surface of early Tertiary age.

This intermediate surface is considered to be represented by summit ridges on either side of the Loita Hills arch, as well as by a well-marked bench occurring at about 7,000 feet on the eastern end of Olodungoro, north-east of Entasekera. This bench is clearly visible from the north-west side when looking down the Olngakualala valley and on this intermediate surface iron-stained gravels are still preserved. Lateritized and iron-stained gravels occur on hill-sides and in some valleys, about 400 feet above the sub-Miocene surface at Naigara, and are also considered to indicate relics of the same surface. The hills south of Entasekera are bevelled by the same surface (Fig. 3) though it has been considerably dissected particularly in the Quaternary period.

Since the uplift which warped the sub-Miocene peneplain and older surfaces, the drainage pattern must have been considerably altered with the initiation of rivers flowing east and west of the Loita hills. It is probable that during the period of warping, incision of west-flowing streams occurred and the gorge of the river Orngaeenet through the Ririjoshoro ridge was formed. The courses of westerly flowing streams such as the rivers Orido, Lairaka and Orngaeenet bear little relationship to structures in the underlying Basement System rocks, though their tributary systems have been influenced by them in the Naigara area. Structure has played a major part in defining the courses of rivers that dissect the high ground south of Entasekera and in the northern part of Usubugooirobi. During the late Tertiary period such rivers as the Orkejulesai and its tributary the Orkejuasur eroded their courses to base-level, represented by the floor of the newly formed Rift Valley, which at that time was much higher than the present-day level. At this level calcareous soils and kunkar sheets were formed, remnants of which are preserved on well-marked terraces along river courses between Ol Mesutie and Entasekera, and a well-preserved bevel occurs at the same height on the north side of Idulele. This bevel occurring at about 250 feet below the sub-Miocene peneplain is therefore assigned to the end-Tertiary period and correlated with the plateau gravels of the Migori river (Shackleton, *op. cit.,* p. 53). Erosion that followed the new periods of rift faulting in late Tertiary and Pleistocene times is responsible for the deep dissection and rejuvenation of the river Orkejulesai, which now flows in a gorge-like valley, while incision of east-flowing rivers in the Narosura area has exposed the Basement System—lava contact near the eastern border of the area. On Usubugo the river valleys show evidence of at least two periods of rejuvenation, terraces being preserved at high altitudes where the headwaters of the rivers drain the mountain between Osarara and Usubugo beacon. With the advent of rift faulting all traces of the older peneplains have been progressively removed from the Nguruman Escarpment. Bailey Willis (1936, p. 261) commenting on the river valleys that dissect the Nguruman Escarpment says: "Ravines which cross these faults exhibit a simple "V" profile without benches. They represent a single cycle of erosion during the growth of the faults, which developed contemporaneously."

IV—SUMMARY OF GEOLOGY

The greater part of the area is underlain by metamorphosed sedimentary rocks of Precambrian age beloging to the Basement System, and includes quartzites, gneisses and pelitic schists. A number of the rocks exhibit the effects of granitization accompanied by migmatization that occurred during the first period of folding.

Resting on the Basement System rocks with unconformity are Tertiary and Quaternary sediments and volcanic rocks associated with the formation of the neighbouring Gregory Rift Valley. The Tertiary volcanic rocks include melanephelinites and ankaratrites that overlie the warped sub-Miocene peneplain; in the north-east corner of the area the melanephelinitic lavas are tilted gently westwards as a result of rift faulting. Overlying the tilted lavas are a series of trachytes that in turn have been affected by the rift faulting. Lavas and ignimbrites were extruded from a number of north-south vents and fractures, some of the ignimbrites flooding part of a valley that had developed after the outpourings of trachyte. In the south-eastern corner of the area the Ol Doinyo Sambu volcanics overlie the Tertiary basalts of the Kirikiti platform. Late faulting has sliced through Ol Doinyo Sambu downthrowing the eastern part of the volcano, which must now underlie Lake Natron. Pleistocene deposits are represented by pebble-beds and sands at the Pagasi river. Recent deposits include volcanic, black cotton and red-brown sandy soils, loams, lateritic ironstone, quartz sands, alluvium, boulder-beds and hill-wash.

Between Cretaceous and end-Tertiary times the area was subjected to peneplanation resulting in the formation of the end-Cretaceous and sub-Miocene erosion surfaces. Late warping and tilting associated with rift faulting affected these bevels. Various sediments of Tertiary age, found scattered throughout the area were formed on the sub-Miocene erosion surface and on intermediate and end-Tertiary bevels. Erosion subsequent to the mid-Tertiary period is attributed to repeated rejuvenation with deep incision of the principal river courses, particularly adjacent to the Rift Valley.

The Geological history of the area is summarized as follows:—

Age	Formation	Tectonic Movements and Erosional Phases
Recent	Soils, sands, alluvium, lateritic ironstone, boulder beds.	Earthquakes. Erosion mainly confined to river courses.
Upper Pleistocene	Lake Beds.	Ol Doinyo Sambu fault.
Middle Pleistocene	Ol Doinyo Sambu volcanics. Olivine melanephelinites of Loisiumurto. Tuffs, agglomerates, ignimbrites.	
Lower Pleistocene	Pebble beds and sands of Pagasi. Lengitoto Trachytes. Kunkar limestones.	2. Kirikiti–Nguruman fault. 1. Kipurses fault.
Late Tertiary	Iron-stained gravels of Ol Mesutie.	3. Formation of end-Tertiary bevel. 2. Tilting of Kirikiti Basalts. 1. Sonjo fault.

Age	Formation	Tectonic Movements and Erosional Phases
Pliocene	Kirikiti Basalts. Ankaratrites of Olomboneg and melanephelinites of Kishalduga.	Initiation of rift faulting, first Nguruman fault.
Miocene	Iron-stained gravels, mudstones, riverine deposits, calcareous soils.	2. Warping of sub-Miocene peneplain. 1. Uplift and sub-Miocene peneplanation.
Early Tertiary	Iron-stained gravels.	Formation of intermediate erosion level.
	Mudstones, gravels, kaolin deposits derived from muscovite quartzites of Usubugo.	
		End-Cretaceous peneplain.
	——Unconformity——	
Archaean	Turoka Series of the Basement System.	2. Folding about NW.–SE. axes and N.S. axes. 1. Recumbent folding about NE.–SW. axes. Commencement of granitization.

V—DETAILS OF GEOLOGY

1. The Basement System

The rocks of the Basement System of the Loita Hills area consist of metasediments of psammitic, pelitic, semi-pelitic and semi-calcareous origin of nearly uniform metamorphic grade and characterized by the presence of the index minerals kyanite and sillimanite. Quartzites are exceptionally well developed throughout the succession and the presence of current bedding and ripple-marks is proof of their sedimentary origin. The great thicknesses of quartzites and associated rocks suggest original deposition in the marginal areas of a geosyncline situated in eastern Kenya and are comparable in age with rocks described from north-west Kenya.

In the Namanga-Bissel area, some 100 miles to the east, Joubert (1957, p. 32) described quartzites and associated kyanite-bearing rocks from the Turoka Series of Parkinson (1913) and it is considered quartzites of the Loita Hills may represent the lateral equivalents of this series. Their northerly continuation can be traced through the neighbouring area to the west (Williams, 1964), and into the Sotik area to the north-west (Schoeman, 1949), and may occupy the same stratigraphical position as the quartzites of north-west Kenya.

The absence of associated crystalline limestones, that typify the rock successions in north-west Kenya and the Turoka Series east of the Rift Valley, and the very thick development of quartzites in the Loita hills region suggests, however, that we may here be dealing with an entirely different series of rocks not recognized in other parts of Kenya.

For descriptive purposes the Basement System rocks in the area are classified into the following groups:—

Calcareous	Calc-silicate granulites Plagioclase amphibolites Hornblende gneisses
Psammitic	Quartzites Muscovite quartzites
Semi-pelitic	Hornblende-biotite gneisses Biotite gneisses Biotite-magnetite gneisses
Pelitic	Biotite schist and gneisses Biotite-garnet gneisses Muscovite-biotite schists Muscovite and quartz-muscovite schists Kyanite-garnet schists Kyanite-andalusite gneisses Kyanite-sillimanite-garnet-biotite gneisses
Granitized and Migmatitic	Granitized gneisses Migmatites Granitoid gneisses Felspar porphyroblast and augen gneisses

The stratigraphical succession of the Basement System rocks in the Loita Hills area is as follows:—

Loita Hills Rocks (Turoka Series, in part ?)

	Approximate Thickness (Feet)
Hornblende-biotite and biotite gneisses partly granitized (Narosura and south of Olosolan)	4,000
Olosolan quartzite	1,000–4,500
Biotite and muscovite-biotite schists and gneisses and hornblende-biotite gneisses (Narosura and Lemisikio valley)	4,000
Usubugo (gritty) quartzite (Usubugo, Naigara, Lengarani and Olibeshet)	3,000
Olibeshet quartzites with pelitic schists (Olibeshet, Usubugo, Naigara)	1,200
Muscovite quartzites and schists and muscovite-biotite schists, thin quartzites. Garnet developed locally (Naigara and Lengitoto)	3,400–4,400
Kyanite-bearing schists and gneisses, biotite-garnet gneisses. (Naigara, Ormelil, west of Ilgeri, Paraiko)	1,200
Muscovite quartzites (Usubugooirobi and possibly Runai and Enkii)	1,400–1,700
Morijo quartzite (Morijo, Ilgeri, Pololet, Sukudie, Usubugooirobi)	1,600–4,000
Granitized biotite and hornblende-biotite gneisses (Enemisikio)	
Muscovite-biotite and muscovite schists with minor quartzites and amphibolites. (Morijo and west of Ilgeri, Naigara) Quartzites (Entasekera hills)	4,000 ?
Olemasher (gritty) quartzite (Entasekera hills)	4,600
Muscovite-biotite and kyanite schists (Olngakualala)	6,000 ?
Possible maximum thickness	43,000

Thicknesses quoted are approximate as the rock bands are lenticular and variable partly due to tectonic movements. In the stratigraphical table the lesser figures represent the average thickness of bands, the greater figures indicating the maximum thicknesses at isolated localities seen during the survey. Altogether something in excess of 40,000 feet of quartzites and associated rocks are thought to be present in the area. A simplified geological map showing the principal quartzites uncomplicated by minor faulting is shown on Fig. 4.

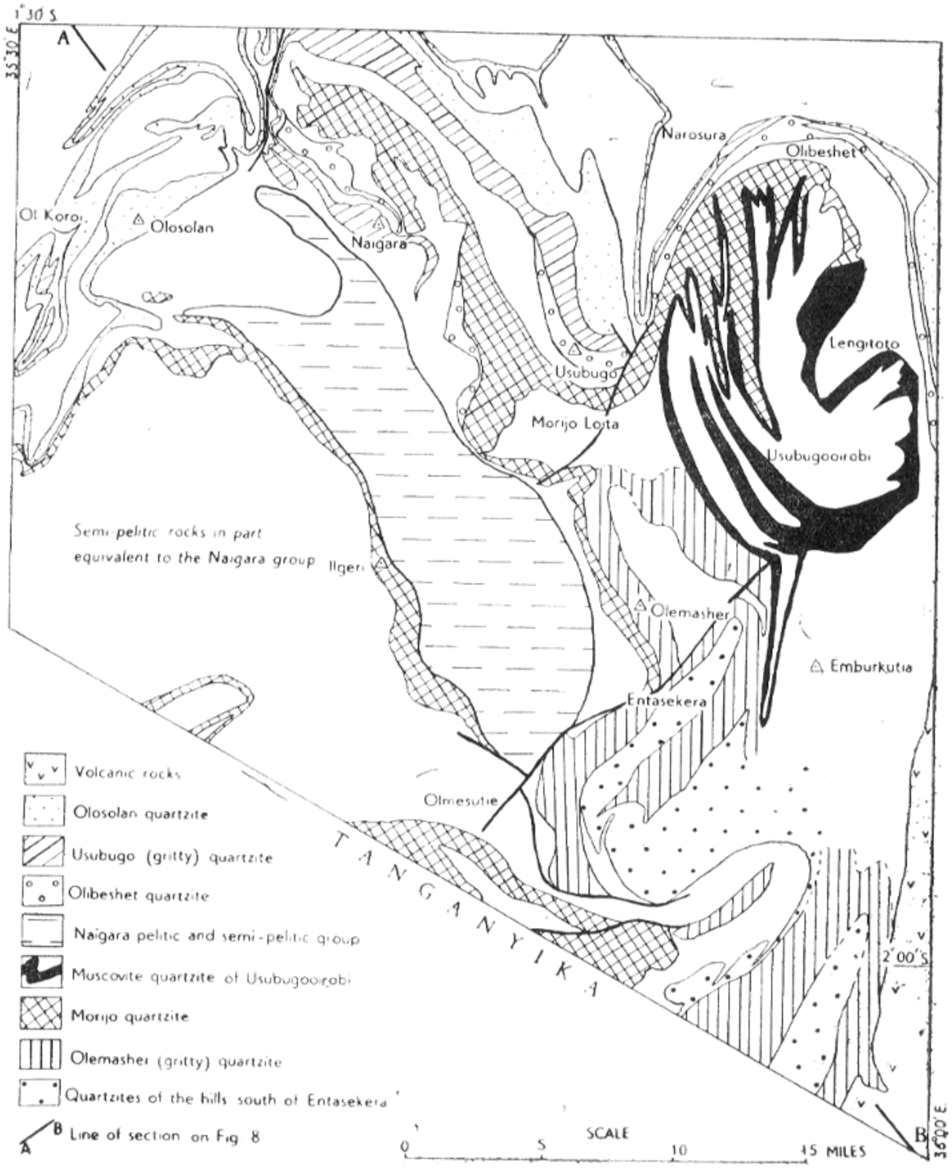


Fig. 4—Simplified geological map showing principal quartzite bands in the Basement System of the Loita Hills area.

The characteristic rocks of the present area are metamorphosed sandstones and grits forming prominent bands that may be traced for long distances. In response to intense folding during two periods of movement the quartzites have been intricately folded, thrusted and faulted, whilst sliding has played a prominent part in the formation of discordant structures. In addition tectonic thinning, lateral variation and original lenticular deposition have produced variable successions that are frequently difficult to correlate with certainty at the present time.

The area at Usubugooirobi and between Naigara and Entasekera consists of a refolded, recumbent anticline plunging to the south-west that has been driven north-westwards. Occupying the Naigara part of the recumbent structure are rocks characterized by the presence of kyanite-bearing bands that are here correlated with the pelites of the Ormelil antiform.

At Morijo Loita there is a succession of muscovite schists some with biotite and quartzites surrounded by two different formations and thus appears a problem typical in the Dalradian Highlands of Scotland. A junction occurs on the eastern side of the triangle where muscovite quartzites of Usubugooirobi are in contact with these Morijo rocks and it is thought this junction forms a slide that probably surrounds the whole block and is again seen at Lengitoto on the eastern side where a discordance is disclosed (Fig. 17).

The Olosolan, Morijo and Emboornarok complicated folding is responsible for discordances between rocks that are widely separated in the stratigraphical table. North-west of Naigara the Usubugo gritty quartzite is cut off by a slide but the band reappears again at Lengarani. Admittedly part of this is possibly due to lateral variation in the original rock but the abrupt break in the band at Ol Doinyo Lomru suggests a faulted contact. A similar discordant break is envisaged along the line of the Morijo faults (slides), widely separating the same band from that on Olibeshet. At Emboornarok a number of discordant junctions between different quartzite bands and pelites is suggested by the abrupt disposition of the bands and their convergence at acute angles. The position of the granitized gneisses at Enemisikio is obscure but they are considered to occupy a low position in the sequence. They are associated with muscovite-biotite schists and thin quartzites at Ol Mesutie and similar granitized biotite-rich rocks associated with muscovite-biotite schists are reported by Williams (1964, p. 19). There is an apparent discordance between these rocks and the pelitic bands west of Ilgeri though granitization and multiple folding (and poor outcrops) have obscured the nature of the contact. The presence of hornblende in the rocks of the north-west corner of the area and the fact that they represent the top of the sequence suggest that they may be the lateral equivalents of the lower portion of the Limestone group of the Turoka Series in the Namanga-Bissel area (Joubert 1957, p. 32) though limestones of that group are absent in the Loita Hills area. The style of folding and thick sequence of quartzites suggest that the rocks of this area comprise a separate group, within the Precambrian of Kenya.

Finally it must be stated that in this area of complex structure and stratigraphy further detailed mapping beyond the scope of the present report will help to confirm and no doubt reveal errors in some of the tentative correlations now made.

(1) Metamorphosed Calcareous Sediments

Metamorphosed calcareous sediments are restricted in occurrence in the Basement System rocks of the Loita Hills and are usually confined to thin bands and lenses in the western half of the area. The lack of crystalline limestones so characteristic of many other areas is striking.

(*a*) *Calc-Silicate Granulites*

A single lens of calc-silicate granulite separates quartzites of differing lithology outcropping on the northern slopes of Olibeshet, east of Narosura. The medium to fine-grained rock which is associated with thin garnetiferous amphibolites, is bright green in appearance and occasionally spotted with dull-red garnets. Banding is poor. In a thin section of specimen 50/292* the granulitic rock consists of xenoblastic green hornblende, strongly pleochroic from green to blue-green to very deep green, associated with a pale lemon-yellow epidote. Quartz and black iron-ore are accessory. Minor occurrences of calc-silicate lenses outcrop in the river Ladooru, south of Paraiko on the western border of the area while boulders of this rock type are occasionally seen in the river beds west of Naigara.

* Numbers prefixed by 50/ and 57/ refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

(*b*) *Plagioclase Amphibolites*

Plagioclase amphibolites derived from the metamorphic alteration of sediments are not abundant and the majority of those mapped are considered to represent intercalations in pelitic and semi-pelitic rocks west and south of Naigara. Their close association with kyanite-rich schists is notable. All specimens collected show a uniformity in colour, texture and mineral composition and rarely exibit foliation. They are typically medium-grained melanocratic, granular rocks consisting essentially of hornblende, andesine and less frequently, diopside. The hornblende, which invariably forms more than 50 per cent of the rocks, is characteristically pleochroic, and forms xenoblastic to sub-idioblastic crystals and also replaces pyroxene, as in specimen 50/321 from the river Olodoaale, seven miles south of Naigara. The hornblende is occasionally sieved by quartz (50/339). Felspar is usually a medium andesine but ranges in composition from Ab_{70} to Ab_{50} in the specimens examined. The mineral is twinned on the albite, pericline and Carlsbad laws and is often intergrown with quartz. The remaining minerals are pale-green diopside, as in specimen 50/379 from Ilgeri, quartz which occurs in xenoblastic crystals, in clear pools or replaces other minerals, and accessory apatite, magnetite and sphene.

Actinolite schists form lenses in plagioclase amphibolites outcropping in gullies on the south bank of the river Olkejuasur, two miles south of Naigara. The schists occur in discontinuous lenticles and are considered to be altered calcareous sediments. These rocks are soft and friable and are comprised essentially of pale yellow-green fibres of asbestiform actinolite.

(*c*) *Hornblende Gneisses*

A thin band of hornblende gneiss outcrops on Loilela in the south-western corner of the area. In hand-specimen the gneiss is a hard, even-granular, grey rock spotted with hornblende. Microscopic examination of specimen 50/377 shows the rock to consist of a granoblastic mosaic of quartz, plagioclase and hornblende sieved by quartz and containing relic patches of diopsidic pyroxene. Another specimen 50/396, from the river Ormanangie, near Entasekera, is a mesotype rock spotted with small hornblende grains. The hornblende occurs as small ragged crystals in a heteroblastic mosaic of quartz and oligoclase. Garnet is a rare mineral in this rock.

(2) Metamorphosed Psammitic Sediments

The metamorphosed psammitic sediments are considered to have been derived by alteration from fine to coarse-grained sandstones, arkoses and grits. Iron ore is present in all rock types while a green mica (fuchsite ?), muscovite and tourmaline are also common accessories.

These rocks form the most resistant outcrops in the area and everywhere form prominent features that include the Loita Hills, an arcuate mountain range between Enkii in the north-west through Usubugo and Emburkutia southwards to Olomboneg near Ol Doinyo Sambu in the south-east of the area (Fig. 4). Jointing is particularly well developed, and on weathering the quartzites break along these joint-planes into rectangular blocks that form screes and talus masses beneath steep and vertical slopes. Typical are the south-facing slopes of Usubugo above Morijo Loita where northerly dipping white quartzites form a prominent east-west trending scarp-edge. Screes cover the lower slopes of most hills and thus conceal the true width of the quartzite outcrop. Huge slabs and blocks are characteristic in areas underlain by the metamorphosed grits. The softer muscovite-rich quartzites weather more easily and in the main hills west of the Nguruman escarpment rivers and streams have often excavated their courses along such bands.

The quartzites show little or no effects of granitization though the presence of kyanite in them and in associated rocks indicate that they have been subjected to high-grade metamorphism. Linear structures are very common in the quartzites and include linear arrangements of quartz crystals, marked grooving, rodding and less frequently, mullions.

(*a*) *Quartzites*

The quartzites of the Loita Hills comprise a widespread formation that can be traced from the area near Sotik (Schoeman, 1949) through the neighbouring area to the west and north-west of the present one (Williams, 1964) and into the Loita Hills area and thence southwards into Tanganyika. Quartzites described from the Namanga-Bissel area of Southern Kenya (Joubert, 1957) and by various authors in north-western Kenya are possibly the lateral equivalents of the same group of rocks.

The quartzites are massive or flaggy well-jointed rocks, sometimes felspathic and with a small but variable muscovite content. Even the most pure quartzites, however, contain a few flakes of mica and may be stained by thin films of iron oxide along crystal boundaries and fractures in the rock. Rare kyanite was seen in thin schistose layers in the quartzite at Narokoluguny (south of Naigara). Original depositional features are almost obliterated due to a well-developed lineation and the complete recrystallization of the rocks as evidenced by their crystalloblastic texture. Their distribution, structural fabric and good exposures give a clear indication of the complicated structures within the Basement System rocks.

It is possible to separate the quartzites on lithological grounds though many bands of slightly differing lithology grade laterally into one another. Three main varieties can be identified, white massive quartzite, felspathic quartzite and pink coarse-grained, gritty quartzite.

(i) *White Quartzites*

The rocks of this group are mainly white to glassy and fine to coarse-grained, although in many instances they are pale-green, pink or grey depending upon impurities which include green mica, oxidized iron ore and magnetite. Specimen 57/3, from Njoronaibor on the southern border of the area is an emerald green quartzite, the colour being due to a bright green mica, probably fuchsite. Scattered throughout the rocks are streaks and thin lenses of magnetite while occasional concentrations of muscovite form thin folia on the bedding planes. Most of the tourmaline discovered during the survey is associated with the purer white quartzites, the mineral forming suns and crystal aggregates in the rock or occurring in small quartz veins that have invaded the quartzites. The rocks are well-bedded and jointing has developed at right-angles to the strike and dip, imparting a block-like character to the outcrops. Bedding partings are often closely spaced giving the rocks a flaggy appearance though in many outcrops the quartzites are more massive. Preferred orientation of constituent minerals and grooved blocks are common in this group. Undoubtedly these white quartzites consisted of fairly pure sandstones which have since been recrystallized under conditions of high-grade metamorphism.

In thin sections the quartzites show little variation consisting almost entirely of a xenoblastic mosaic of quartz crystals with sutured interlocking borders. The grain size is variable generally up to 1 mm. though in the field some very coarse-grained bands were observed. Strain-polarization is shown by many of the quartz grains which are sometimes dusty with inclusions. Muscovite is a common accessory occurring as tiny flakes, frequently with a preferred orientation either interstitially between the quartz grains or completely enclosed by them. Sphene was noticed in one thin section.

(ii) *Felspathic Quartzites*

Felspathic quartzites have an erratic distribution showing every gradation to the purer white quartzites in the field. Local developments of felspathic quartzites are to be found throughout the Loita Hills but the main outcrops can be studied in the river Ngarianarok, south of Runai (five miles west of Narosura), on Usubugo and in the tributaries of the river Olkejulormungushi near the eastern border of the area. The rocks at these localities are considered to be the lateral equivalents of one another. Felspathic quartzites are readily recognized by the presence of kaolinized felspars that fleck the rocks. In most specimens the felspar forms up to five per cent of the essential constituents.

In specimen 50/280, from the southern slopes of Runai, the felspar is concentrated in extremely thin folia on what is presumed to be original bedding-planes though it is also disseminated throughout the rock. Banding, which is emphasized by the felspar, is particularly noticeable in hand specimens, and specimen 50/307 from Usubugo shows numerous bands the finest grained being stained orange-buff and measuring approximately 1 mm. in thickness. The more coarsely grained bands are in pale, contrasting colours of pink, grey or white. It is suggested that this is an original sedimentary feature and probably represents a form of graded-bedding. Other sedimentary structures in the quartzites at the localities mentioned above are current ripple-marks. The ripple ridges have a wave-length of about 30 mm. and amplitude of 5 mm. in specimen 50/281 from Runai. Plate I (*c*) shows a ripple-marked block from a locality near the river Olkejulormungushi.

(iii) *Iron-stained, Coarse-grained Quartzites*

Generally these are massive-bedded rocks forming a distinctive member within the quartzite group. At least two horizons can be traced throughout the area, the best exposures being seen on Usubugo and in the neighbourhood of Entasekera and south-east of Ol Mesutie. The rocks are characterized by a coarse granoblastic aggregate of quartz grains that occasionally measure one inch in diameter. These metamorphosed grits are usually pink to deep red due to ubiquitous staining by iron oxide on crystal margins. Impurities include iron ore and sparsely distributed mica. The quartzites weather easily and blocks and pavements are frequently surrounded by quartz sands as seen on Ormelil ridge, south of Entasekera. The colour of the quartzites results from disseminated hematite dust which is nearly all outside the quartz grains. The erratic distribution of colour is an unreliable guide in studying the stratigraphic relations of this member of the quartzites though locally it can be applied.

(*b*) *Muscovite Quartzites*

The pale grey, brown and white muscovite quartzites occur in flaggy bands separated by mica-rich foliation planes. Muscovite is never porphyroblastic and occurs as small lustrous flakes in thin folia or profusely distributed throughout the rocks. Many of these quartzites grade laterally into quartz-muscovite schists and granulites though these are generally a local variation and not characteristic of the whole.

Many of the muscovite quartzites are distinctly bedded while some are strongly cross-bedded. The cross-bedded variety are iron-stained and outcrop on Usubugo and on Usubugooirobi where they have been intricately folded within the purer quartzites.

The cross-bedding is frequently curved, the foreset beds being concave upwards and meet the topset beds at an angle and merge with the bottom-sets in a gentle curve. Similar features in the Glencoe quartzites of Scotland have been described by Vogt (1930, p. 70) who considered the cross-bedding to be a normal delta type laid down in standing water. In some localities the cross-bedding is sigmoid shaped. The original sedimentary features of the rock have been remarkably preserved and it is with difficulty that true dips can be measured in these rocks. Examination of the cross-bedded units indicates that the rock sequence in the Loita Hills is not inverted. The thickness of the cross-bedded units varies considerably from one locality to another ranging from a few inches to over 20 inches. The scale of the cross-bedding probably bears a relationship to grain size though a detailed examination of the rocks was not undertaken to determine the significance of this feature. Like the pure quartzites these rocks consist of an interlocking mosaic of quartz grains with small, orientated, nearly colourless flakes of muscovite frequently enclosed in quartz crystals. In some hand-specimens like 50/306 from Usubugo the quartz grains are elongated having a marked preferred orientation. The grey and white muscovite quartzites occur throughout the quartzite succession but outcrop mainly in the north-western part of the area.

(3) Metamorphosed Semi-Pelitic Sediments

(*a*) *Hornblende-biotite Gneisses*

Hornblende-bearing biotite gneisses are closely associated with brown biotite gneisses and schists, the best exposures being found west of Naigara, mainly between the quartzitic ridges of Olosolan and Ririjoshoro. Other occurrences were also mapped north of Olosolan and a number of minor bands were noted near the road between Entasekera and Ol Mesutie and west of Narosura. With increase in hornblende content these rocks grade into plagioclase amphibolites.

The hornblende-biotite gneisses are mesotype rocks of dioritic composition, weathering easily so that outcrops are usually only found in stream sections such as the rivers Lairaka and Ilmur. It is usual to find both hornblende and biotite disseminated throughout the rocks in the majority of exposures though in specimen 50/352 from the river Idepes, four miles south-west of Naigara, there is a tendency for the hornblende to be concentrated in aggregates. In thin sections they show medium-grained xenoblastic granular textures and exhibit a weak gneissosity. Subidioblastic green hornblende, pleochroic from yellow-green to deep green, is intimately associated with dark brown or yellow-brown biotite flakes. Plagioclase is always present and was determined as oligoclase (An_{26} to An_{36}), which is accompanied by variable amounts of microcline and quartz, whilst sphene, zircon and iron ore are accessory. The plagioclase felspar is cloudy with inclusions and alteration products, partly sericitic.

(*b*) *Biotite Gneisses*

Most of the biotite gneisses are considered to be the metamorphic equivalent of semi-pelitic sediments. They are interbedded in hornblende-biotite gneisses that underlie the plains in the western part of the Naigara location, and occur also in the pavements in the north-east corner of the area. A single discontinuous band is probably represented by the outcrops at Ilgeri, west of Limoroki, the outcrops along the western foot of Naigara hill and locally in the muscovite-biotite schists and gneisses north-west of Entasekera. Minor occurrences of biotite gneiss were mapped at Olortet, north-east of Olomboneg. The biotite gneisses vary considerably in thickness, possibly exceeding 3,000 ft. at Enkoriga near the western border of the area.

The rocks are pink and grey gneisses which occur in thin alternating bands in variable proportions. The light bands are composed of quartz and felspar and the darker bands contain concentrations of biotite. Often the rocks are well foliated due to orientated biotite flakes but in many outcrops they are partially granitized and have assumed a granoblastic texture with poor to moderate foliation; in some exposures, therefore, foliations and lineations are difficult to recognize. Rarely, small felspar porphyroblasts have developed in the leucocratic bands as in specimen 50/335 from six miles west of Naigara. Biotite-rich bands characterized by dark mafic schlieren are typically schistose, weathering to friable masses. The texture of the biotite gneisses is characteristically xenoblastic to granoblastic with felspar, quartz and strongly pleochroic biotite forming the principal constituents. Both sodic oligoclase and microcline occur but the ratio of the two varies considerably. The felspars are xenoblastic, having irregular borders, and are intergrown with quartz and biotite flakes. The plagioclase is clouded due to alteration, but the microcline which often replaces and interlobes with plagioclase occurs as clear crystals. Quartz pools within the felspar are not uncommon. Where microcline displays a replacement relationship towards the plagioclase, it is surrounded by a bleached zone (specimen 50/325 from the river Olngaeene). Apatite, sphene and iron ore are accessory.

(*c*) *Biotite-magnetite Gneiss*

Magnetite is mostly a minor constituent of the biotite gneisses of the area, but in one band, several feet thick, outcropping four miles south of Naigara in the river Lepolosie the rock contains between 4 per cent and 10 per cent of the mineral. The gneiss (specimen 50/346) is similar to the biotite gneisses consisting of quartz, felspar and biotite with well-developed crystals of magnetite dispersed evenly throughout the rock, giving the rock a characteristic appearance and a specific gravity in excess of the normal biotite gneisses. The origin of the magnetite is considered to be sedimentary and not igneous.

(4) Metamorphosed Pelitic Sediments

Kyanite and sillimanite gneisses and schists occupy parts of the limbs of major folds at Naigara and east of Emboornarok. Elsewhere alumina-rich pelitic schists were mapped in the river Olngakualala, along the valley of the Orngaeenet, at Enkii, north-west of Naigara and on the western slopes of Loikirisia, south-east of Narosura. At most of these localities biotite and biotite-garnet schists and gneisses are interbedded with the kyanite and sillimanite rocks while muscovite is present in some or all of the bands.

The metamorphosed pelitic sediments are divided into the following groups:—

(*a*) Biotite schists and gneisses.

(*b*) Biotite-garnet gneisses.

(*c*) Muscovite-biotite schists.

(*d*) Muscovite and quartz-muscovite schists.

(*e*) Kyanite-garnet schists.

(*f*) Kyanite-andalusite gneisses.

(*g*) Kyanite-sillimanite-garnet-biotite gneisses.

(*a*) *Biotite Schists and Gneisses*

Dark fissile rocks, usually fine- to medium-grained and containing abundant biotite folia, are interbanded in schists of pelitic origin and less commonly in biotite gneisses and granitized gneisses of semi-pelitic origin. They represent bands of restricted extent, being characterized by lustrous black mica and occasionally garnet. These rocks are separated from the biotite gneisses of semi-pelitic origin by their schistose appearance, biotite content and rock associations.

(*b*) *Biotite-garnet Gneisses*

Schistose biotite-garnet gneisses are interbedded in highly argillaceous rocks and in particular are associated with kyanite-sillimanite rocks. They occur in the south-eastern corner of the area where exposures can be seen in the river Orpusare and in the lower and upper reaches of the river Orngaeenet and at Narosura where the garnet is sparsely distributed in granitized biotite gneisses. The rocks are uncommon, and the garnets irregular in their distribution, even within the same band.

They are medium-grained dark gneisses sprinkled with small dull-red garnets grading both laterally and along the strike into dark biotite schists and gneisses. The biotite flakes are concentrated in folia that impart a marked foliation and schistose appearance to the rocks. Outcrops are generally poor and are usually confined to stream sections.

Microscopic examination of specimen 50/386, from the river Orpusare, shows an irregular mosaic of quartz, microcline-microperthite and plagioclase which is andesine of composition An_{34}. The rock contains clear quartz which forms irregular, lobed grains replacing plagioclase. The presence of large crystals of microcline sometimes enclosing the plagioclase in myrmekitic growths suggests that the potash felspar has been metasomatically introduced and has enclosed numerous granules of quartz. Angular grains and the granular texture of the rock suggests crystallization during deformation.

(c) *Muscovite-biotite Schists*

These rocks form one of the principal bands in the Naigara synform, the band being traceable nearly throughout its entire length. They are particularly well developed near Entasekera, where they have been invaded by thin aplites and migmatizing fluids, while at Naigara they are interbanded in quartzites, muscovite quartzites and schists. West of Ol Mesutie similar rocks occur though here biotite is subordinate to the muscovite. Thin muscovite-biotite-rich bands are also associated with muscovite schists at Narosura where they grade laterally into biotite gneisses and also outcrop in the Lengitoto valley at latitude 1° 35′ S. At the latter locality the rocks have a tendency to be gneissose, with muscovite and biotite associated in dark folia. Other occurrences of these muscovite-biotite schists are seen south of Morijo in the Olngakualala valley north of Olosolan and in the western part of the Lairaka valley when they are associated with mica schists and gneisses. In all localities rapid alternation of the biotite and muscovite content in the rocks is apparent.

The muscovite-biotite schists display a well-defined foliation that assists rapid weathering, with thin bands of quartz and felspar alternating with mafic layers containing dark-coloured biotite and white or pale-green muscovite. In most specimens collected the grain-size is fairly uniform, specimen 50/322, from the river Olodoaale, six miles west of Morijo Loita, being a grey granulitic rock. The preponderance of biotite or muscovite imparts a characteristic colour to these schists.

In the hand-specimen the schists are meso-type to dark grey fissile rocks abundant in mica. The essential minerals are seen in thin section to be biotite, muscovite, plagioclase and quartz. The biotite is generally xenoblastic and associated with the muscovite. Quartz, the principal constituent, forms an interlocking mosaic and exhibits undulose extinction whilst albite-twinned plagioclase is subordinate and referable to an acid andesine. Magnetite forms subidioblastic crystals and is a significant accessory in most rocks.

(d) *Muscovite and Quartz-muscovite Schists*

Muscovite-rich schists are among the most interesting rocks in the area, forming a well-foliated series interbedded within the main quartzites. These rocks are characterized by their extreme fissility, their colour and their weathering products. They are best studied on Usubogo, Naigara and north-north-west of Narosura. Elsewhere they occur as minor bands within other rock-types as at Embongit, west of Naigara, in the Lengitoto valley and in the gullies on the south-western slopes of Olomboneg.

The quartz-muscovite schists do not form continuous horizons but occur as lenses and thin bands within the quartzites, mainly on Olibeshet and in the muscovite schists and quartzites near Narosura, in the river Lekuruki north-west of Naigara and in the river Emorogi west of Morijo Loita. At both localities they grade rapidly into quartzite. Typical of these rocks is specimen 50/291 from Olibeshet, a leucocratic rock containing a granoblastic aggregate of quartz and white muscovite with abundant magnetite. In the Narosura area the muscovite is often pale green imparting a characteristic colour to the rock (specimen 50/278) which is also seen to contain tiny flakes of bronze-coloured biotite. At the confluence of the river Lairaka and Idepes these rocks (specimen 50/337) consist of alternate layers of quartz and muscovite, tourmaline measuring up to 0.5 in. being associated with the latter mineral. Similar but tourmaline-free rocks occur as thin bands in the muscovite-biotite schists in the river Lekuruki. Outcropping in the Naigara-Usubugo areas are the true muscovite schists many of which show intense alteration. At Naigara the schists are composed almost entirely of green muscovite with very thin folia of quartz, while northwards the bands are richer in the latter mineral. In some localities they are fine- to medium-grained rocks with wrinkled schistosity planes, on which are smeared small patches of finely crystalline magnetite, with ilmenite present in some examples. Other rocks have been partially granitized and exposures in the rivers Rimeregele and Naruatarakua west of Usubugo show the widespread development of pink felspathic augen flattened parallel to the foliation planes. Apart from the augen, in specimen 50/350 from this locality, the rock is comprised mainly of green muscovite with a little brown biotite.

In valleys of the Osarara on Usubugo the schists have been highly weathered and intensely altered and are now bright, multicoloured rocks. All resemble superficially low-grade phyllites and slates, probably due to the weathering of extremely fissile rocks rather than retrogressive metamorphism. A typical and nearly fresh specimen (50/311) is a grey fissile schist from an east-flowing river course west of Dasati. A little kaolinization is noticeable in the hand-specimen though microscopic examination indicates a fairly fresh rock. In thin section this rock consists of quartz, felspar and mica. Two felspars are present but are never so abundant as quartz. The plagioclase is twinned albite and the potash felspar microcline that does not show replacive relationship with the albite. The felspars and quartz together make a finely foliated aggregate of elongated crystals parallel to the schistosity through which small flakes of mica are profusely scattered. Muscovite predominates over biotite and is colourless while the biotite shows a pale brown colour with strong pleochroism, from colourless to yellow-brown. The accessory minerals in these rocks are magnetite, zircon and sphene. Limonite is an alteration product of the iron ore.

West of this locality the alteration of the schists becomes progressively more intense. On hill-sides at Osarara the schists are practically beyond recognition and now consist of highly kaolinized colour-banded rocks. The gradation of colour was noticeable in the field though crude colour-banding is probably due more to the original composition of the schist than to selective alteration of homogeneous rock. A number of gullies expose these rocks sufficiently to indicate that they grade gradually into unaltered muscovite schists. Quartz pegmatites that have invaded the now altered rocks show no sign of alteration. Small islands of unaltered, mica-rich rock are evident in some hand-specimens collected from these localities. The most highly altered rocks outcrop in the river Alarashi and consist of finely colour-banded kaolin-rocks of soft soapy texture resembling water-laid sediments. Plate I (*a*) shows the banding in a specimen from this locality. In thin sections of specimen 50/310 and 50/365 from Osarara the rocks are seen to consist of amorphous material with hydrated iron oxides. Specimen 50/310, however, contains unusual but well-developed crystals of kaolin. Little quartz is present in any of the thin sections examined. The transformation of mica into kaolinite is a well-known sedimentary process and Tomkeieff (in Exley 1959, p. 227) draws attention to the production of kaolinite and other clay minerals through the action of ground-waters charged with humic substance. The occurrences suggest that these rocks have been altered in an ancient shallow lake that probably existed on the end-Cretaceous peneplain.

(e) *Kyanite-garnet Schists*

Garnetiferous kyanite schists were mapped in the river Orngaeenet where they are interbanded with kyanite-sillimanite schists. They are very dark fissile rocks with wrinkled foliation and contain abundant but small blue kyanite, embedded in muscovite-biotite-quartz schists. A thin section of specimen 50/380 from half a mile north-west of Olopilukunya is seen to contain kyanite, tabular muscovite with red-brown biotite, quartz and plagioclase. Garnet is present in sub-idioblastic crystals that are highly sieved by quartz grains. The idioblastic kyanite blades which occur with biotite frequently enclose small flakes of that mineral. Another band from Embaluai, south-west of Morijo Loita, is a kyanite-garnet-muscovite schist (50/319) containing small lenticular quartz segregations parallel with the foliation planes. Another section of the rock shows kyanite to be intergrown with muscovite but without replacement, and associated with a green-brown biotite.

(f) *Kyanite-andalusite Gneisses*

Exposures of these rocks occur at and near the track at Enkii, north-west of Naigara, where they are present in a small lens with muscovite quartzites. It is a hard, massive quartzose gneiss with patchy development of pale-green kyanite and some iron-ore. In thin section of specimen 50/333 the rock contains kyanite and andalusite in a xenoblastic aggregate of quartz, plagioclase and microcline. The kyanite crystals are poorly developed and are associated with irregular crystals of andalusite that have crystallized with the kyanite, no evidence of replacement between the two minerals being observed. The pale-yellow, pleochroic andalusite has a slightly lower refractive index than the colourless kyanite and is twinned in a single subidioblastic grain. Albite-twinned oligoclase is set in a quartz mosaic, both minerals being replaced by microcline.

(g) *Kyanite-sillimanite-garnet Schists*

The principal exposures of pelitic rocks indicate that they are in the main kyanite-sillimanite schists with a variable proportion of garnet that forms only a minor but important constituent of these rocks.

They are mesotype rocks in which are embedded blue crystals of kyanite. Folia rich in sillimanite are common while numerous layers are sparsely sprinkled with deep-red garnets. Brownish-green biotite which is the common dark constituent is very often associated with a lustrous white muscovite. In some sections, as in the river Rimeregele, east of the Naigara-Morijo track, the rocks contain schistose lenses composed of large kyanite crystals in blades up to 2 in. in length with some quartz. Sheaves and clusters of white fibrolitic sillimanite characterize the outcrops in the rivers Lairaka and Idepes, and are prominent as opaque white patches on weathered surfaces. Alteration of the associated iron minerals common in these rocks has stained them pink. No development of *faserkiesel* so typical in similar rocks in other parts of Kenya was observed in the area. Tourmaline is a minor constituent in these rocks and was noticed in particular in the schists outcropping on the western slopes of Loikirisia. Kyanite and sillimanite-bearing schists and gneisses exposed in the river Oloibortoto, two miles east of the border of the present area, are probably the lateral equivalents of rocks concealed by lavas north of Olibeshet and Kipirtilo in the north-eastern corners of the area.

The sillimanite shown in thin sections of these rocks (50/336 from the river Lairaka) consists of fibrolite needles in radiating bunches in a mosaic of quartz grains and black iron ore. No replacement relationship between kyanite and sillimanite was observed and andalusite is absent. Quartz and oligoclase are the light-coloured constituents of these rocks. Muscovite in elongated tabular crystals is prominent and contains strings of magnetite grains along the cleavage traces. Associated biotite is strongly pleochroic from yellow-green to black.

The groundmass in specimen 50/344 from the river Rimeregele is composed of a heteroblastic aggregate of quartz and twinned oligoclase together with strongly pleochroic biotite and garnet. The garnet occurs in large cracked grains of subidioblastic habit having dark borders and containing numerous inclusions. Iron ore and large irregular grains of apatite are present.

(*h*) *Sillimanite-garnet-biotite Gneisses*

In the river Rimeregele, south of Kotel on the western slopes of Usubugo, thin sillimanite-garnet gneisses are interbanded among muscovite and biotite-bearing schists and gneisses. These are hard, flaggy, granoblastic rocks in which thin dark folia consisting mainly of biotite and orientated sheaves of sillimanite are spotted with small dull-red garnets. The groundmass is seen to consist of xenoblastic quartz and oligoclase with biotite and in a thin section of specimen 50/343 the biotite is strongly pleochroic from pale yellow-green to deep green. Iron ore and apatite are common accessories.

(5) Granitized Gneisses and Migmatites

Included here are the gneisses considered to have originated from the regional metasomatism of pelitic and semi-pelitic sediments. These gneisses contain microcline of metasomatic origin and form a distinct group of rocks, a mixed, irregular sequence that includes plagioclase-quartz-biotite gneisses, granitized gneisses, *augen* and porphyroblastic gneisses and migmatites. The isolated stream sections where they are exposed make their division on the map difficult and hence they are classified together.

(*a*) *Granitized Gneisses*

West and south of Ririjoshoro ridge the rocks are mainly granitized biotite gneisses of pelitic origin, occasionally associated with hornblendic rocks which represent metamorphosed semi-pelitic sediments. They are typically grey to pink gneisses of slabby or blocky appearance, though occurrences of rounded outcrops are not uncommon, as at Ntaragua. In much of the rock alternate light and dark layers impart a crude banding, probably relict bedding, parallel with the foliation. At many localities they are composed of varying proportions of biotite-rich gneiss and quartz-felspar rock occurring as interlayered sheets. The biotite is usually concentrated in dark streaks, bands and *schlieren,* though increase in the leucocratic components frequently obliterates this rock fabric and the gneisses then assume a granitoid appearance. *Augen* gneisses are closely associated with these almost homogeneous granitoid rocks and broad banding is evident where the two rock-types occur together. Pink microcline augen are roughly aligned in a foliated grey matrix, giving the rock a distinctive appearance. River sections expose pavements and ribs of grey and pink gneiss cut by dykes of granite-pegmatite or invaded by thin *lit par lit* and ptygmatic injections. In many instances off-shoots from discordant sheets have penetrated the foliation planes. Pods and lenticular segregations of granitic material are also common.

Similar rocks outcrop between Naigara and Entasekera where they occupy the Naigara synform. They differ somewhat from the rocks in the area just described in that banding and foliation is more pronounced and, except for local intense migmatization, it can be shown that the region of granitization is limited to the south-western corner of the area, with a decrease northwards and eastwards towards the hill ranges. The rocks give way to places where rocks consist of augen gneisses and other schists and gneisses containing porphyroblastic felspar while microcline becomes less noticeable in thin sections of these rocks. In rocks of semi-pelitic origin, hornblende is an essential constituent and is present in variable proportions in different rocks along the course of the river Orngaeenet and its tributaries. Rare crystals and nodules of a green mangano-apatite are present in particular south of Naigara.

In hand-specimen the granitized gneisses are characteristically xenoblastic and roughly banded. The light bands in specimen 50/375 from Ntaragua are composed of a mixture of felspar and elongated quartz grains and the darker bands consist of granoblastic aggregates of biotite, quartz and felspar. In some specimens such as 50/374 from the river Ladooru muscovite is intimately associated with the biotite. Apart from the banding in these rocks foliation is often expressed by orientated biotite flakes. In thin section the rocks are seen to be composed of biotite, quartz and felspar. Accessories include muscovite, apatite and iron ore. Turbid twinned oligoclase is subordinate to microcline, the latter often displaying a replacive relationship towards the plagioclase. Muscovite is common in specimen 50/375, while in other specimens ragged flakes of muscovite are a product of replacement of the potash felspar. The biotite varies from yellow-brown to dirty green, is flaky or tabular in habit and exhibits strong pleochroism. The quartz occurs in irregular grains of variable size and is frequently replaced by microcline.

(*b*) *Migmatites*

A zone of intense migmatization coinciding with a structural culmination occurs about six miles due south of Naigara. The rocks in this area grade from typical granitized biotite-rich gneisses in which foliation is evident into rocks in which the fabric is almost obliterated. They differ from the granitoid gneisses in being more coarsely and distinctly injected *lit par lit* by granitic lenses, while in some sections soaking and permeation by granitic sheets is evident, many sub-parallel to the original foliation. Contorted and wavy foliation is common, indicating some degree of plasticity during the metamorphic history of this part of the area. Porphyroblasts and knots of felspar are present in the pink leucocratic bands and thin, ill-defined biotite streaks are more common than in the banded granitized gneisses. Other areas of migmatized rock are to be found within the granitized gneisses, typical exposures of which are seen in the river Orngaeenet particularly east of the Naigara track crossing. Here interesting minor structures are present which are described in the structural section of this report.

Linear structures are not clearly visible in hand-specimen; foliation, however, is marked by the segregation of the darker constituents.

(*c*) *Granitoid Gneisses*

Granitoid gneisses form few outcrops in the area and are restricted to a few bands within the granitized rocks of the south-western part of the area. A number of low but prominent ribs outcrop near the river Olodoaale, south of Naigara and a small band was mapped on the eastern bank of the river Parkereiya in the south-west. The last-named band is not shown on the coloured geological map.

These granitoid gneisses representing highly granitized biotite gneisses are medium-grained pink rocks with a weakly gneissose texture emphasized by mica flakes and elongated quartz grains. In thin sections (specimens 50/376, from the river Parkereiya) the rocks show a xenoblastic texture consisting of oligoclase, microcline, quartz and biotite. The microcline predominates over the plagioclase which it partly replaces, while pools of quartz are frequently enclosed within both felspars. Replacement of oligoclase by small, irregular flakes of muscovite is also seen. Both felspars are cloudy though the plagioclase is more so due to alteration products that include sericite. Quartz is present in clear, irregular-shaped crystals occasionally replacing the felspar along crystal margins. Small elongated flakes of dark greenish-brown biotite are scattered through the rock exhibiting a preferred orientation parallel to the larger grains in the thin section. Magnetite is accessory.

(*d*) *Felspar Porphyroblast and Augen Gneisses*

These rocks are developed locally east and north of Narosura and on the western border near Olosolan. Other examples were mapped in the river Ladooru. Near Olosolan they represent the northerly extension of the granitized area already described. The gneisses resemble the biotite-rich rocks in the same localities but contain white or pink felspar augen and porphyroblasts that give the rocks a distinctive appearance. The augen which are variably white or pink are usually small but in the river Orido the flaggy gneisses contain crystals as large as one inch across. They are strongly foliated rocks and are conspicuous in this locality where they form sharp ribs striking across the river, alternating and grading rapidly into more fissile biotite gneisses containing small augen. The groundmass of the gneisses look similar to those of the biotite gneisses, a granoblastic mosaic of quartz, twinned oligoclase and flakes of biotite. Both oligoclase and microcline are present the latter forming pink porphyroblasts and augen as in specimen 50/368 from the river Orido.

At Narosura granitic material has invaded the rocks in a zone in which *lit par lit* injections and discrete dykes and lenses have locally granitized the biotite gneisses. The porphyroblasts of felspar in these rocks tend to be white rather than pink. Some were identified as oligoclase.

(6) Pegmatites

Pegmatites and associated aplites are common in the area but are more frequently seen in the rocks outcropping west of the Loita Hills, where they are developed in a zone of granitized biotite gneisses and migmatites. Elsewhere they have invaded augen and porphyroblastic gneisses in the area north-west of Olosolan and north and east of Narosura.

The pegmatites form concordant *lit par lit* injections, lenticular bodies or cross-cutting dykes and are conspicuous in the area bounded by the Naigara-Morijo track and the Ririjoshoro ridge to the west. Here a centre of intense granitization contains migmatitic rocks with accompanying pegmatites many of which are composed of large, pink, potash felspars. Typical specimens are represented by 50/361 from four miles south of Naigara where felspathic pegmatites form cross-cutting bodies in kyanite schists. A number of other occurrences are seen on the Naigara-Morijo track south of the river Olkejuasur. Outcrops in the river Ladooru show numerous rock pavements invaded by cross-cutting pegmatitic intrusions with felspathic segregations. Magnetite, ilmenite and occasionally mica are developed in the pegmatites. Tourmaline is very characteristic of the area and though most is developed in quartzites and pelitic schists the mineral is also found in quartz pegmatites in the Naigara area.

(7) Metamorphism

The Basement System rocks in the Loita Hills area have been subject to intense regional metamorphism of the highest grade, probably accomplished after more than one period of orogenesis. The rocks are considered to be altered sediments that originally consisted of sandstones, grits and greywackes with interbedded shales and marls. Limestones were not involved in the processes and no evidence was found to suggest the presence of volcanic rocks, though some plagioclase amphibolites and associated amphibole schists may represent thin dykes or sills.

During metamorphism alumina-rich sediments are the most sensitive to change and in the present area metamorphosed argillaceous rocks were mapped where they are interstratified with quartzites and other rocks that show little response to metamorphism apart from recrystallization. The schists are characterized by the presence of kyanite and sillimanite and more rarely andalusite. All rocks are considered to fall into the kyanite-muscovite sub-facies of the amphibolite facies (Francis, 1956, p. 360). Kyanite, sillimanite and garnet have developed in pelitic rocks now characterized by muscovite and biotite schists, and these schists indicate less alumina rather than a different grade of metamorphism. The presence of common muscovite is in no way connected with the formation of the alumino-silicates but indicates an assemblage in which these minerals are in equilibrium.

Typical mineral assemblages in rocks of pelitic origin include:—

plagioclase-garnet-muscovite-biotite-quartz

plagioclase-muscovite-biotite-quartz

kyanite-plagioclase-garnet-muscovite-biotite-quartz

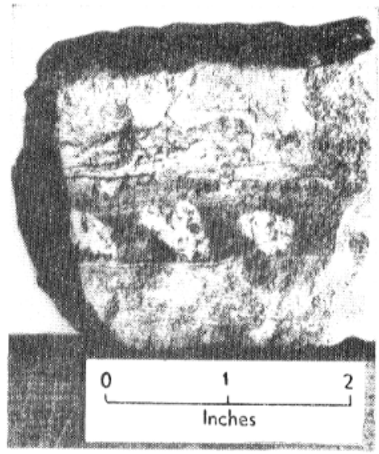
kyanite-sillimanite-plagioclase-garnet-muscovite-biotite-quartz

sillimanite-plagioclase-garnet-biotite-quartz.

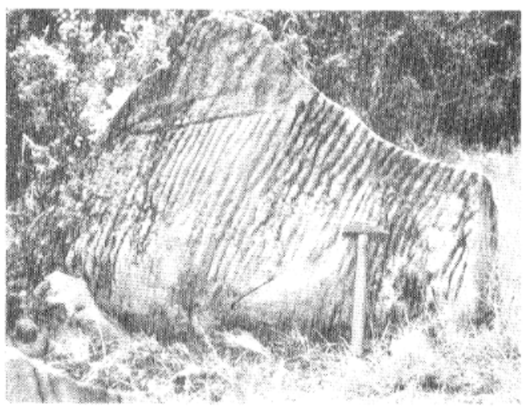
The distribution of alumino-silicates throughout the area, albeit in rocks of similar lithological type, indicates that the original composition of the rocks has exercised the principal control during metamorphism and that physical conditions although important were not primarily responsible. They appear to bear no relation to structural features. Kyanite is more typical of these high-grade assemblages, however, and its presence suggests that stress was a prevailing factor during metamorphism. There is little or no progressive increase in the intensity of metamorphism while the distribution of kyanite gives no reason for believing that load was an important factor. Sillimanite-muscovite is a stable assemblage in the area while the sillimanite-potash assemblage recorded by Wyckoff (1952, p. 49) is not recognized. The interesting feature is the persistence of kyanite in those rocks in which sillimanite is abundant. Wyckoff (*op. cit.*, p. 50) considers that rocks containing both minerals represents a state of disequilibrium, though a study of kyanite-sillimanite stability diagrams indicates that it is possible for the two minerals to occur together in equilibrium, a feature common in many of the pelitic gneisses and schists in Kenya. Francis (*op. cit.*, p. 364) cites a number of localities at which combinations of alumino-silicates occur. In the present area both kyanite and sillimanite and kyanite-andalusite combinations are present without any evidence of replacement, while pseudomorphs occurring within a few miles of one another suggest that crystallization took place under temperature-pressure conditions corresponding closely to point "a" on the diagram illustrated by Clifford (1958, p. 341). Although kyanite is the characteristic alumino-silicate in the rocks of the present area, slight variations in the temperature-pressure conditions during metamorphism would influence the production of andalusite and sillimanite. It is important to note that those rocks containing andalusite, which would normally correspond to slightly lower grades of metamorphism, are high in the stratigraphic sequence in the area, sillimanite-bearing rocks, however, occur within an area of great structural complexity where conditions are most likely to favour the growth of minerals developed during periods of high-grade metamorphism. The lack of sillimanite *faserkiesel* (which in Kenya frequently develop in areas of granitization and migmatization) and the absence of any alteration of alumino-silicates to muscovite, suggest that sillimanite did not develop as a result of metasomatic action. Pelitic rocks show little response to granitization and it is possible that the high-grade minerals did not develop until a late orogenic episode following a period of granitization that contributed to the heat of metamorphism and probably the formation of sillimanite. The sillimanite was produced at a later stage than the kyanite, due to the influence of migrating solutions during migmatization. Under these conditions Watson (1948, p. 161) considers that it is undesirable to use the minerals as an index of grade of regional metamorphism.

Further it is unlikely that any important change in chemical composition of the original sediments has taken place except for the introduction of boron and potash, though water must have been removed from pelitic sediments during metamorphism.

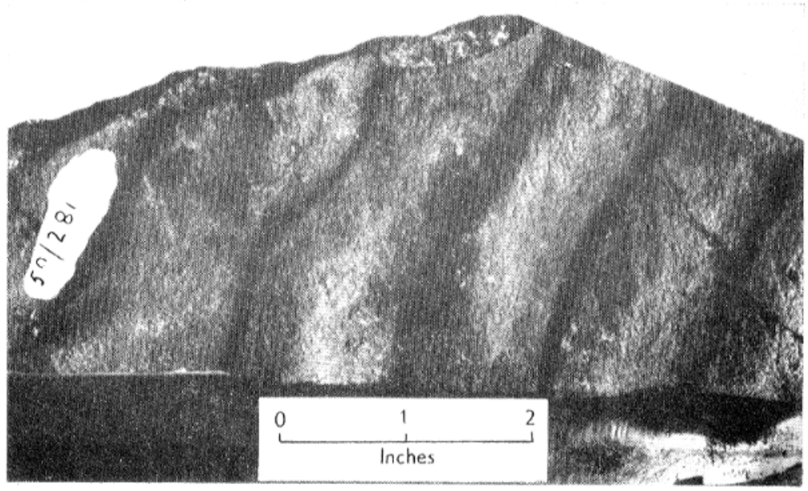
PLATE I



(a) Kaolinized muscovite schists from Usubugo. The rock consists of multi-coloured bands of clay-like material.

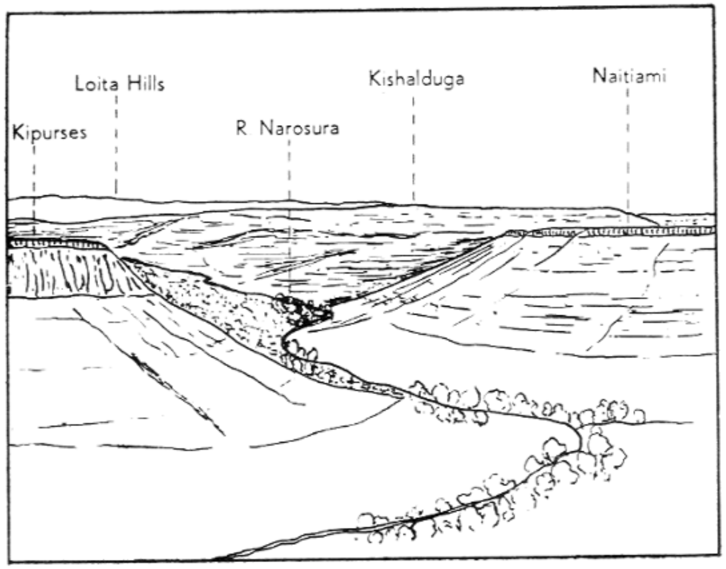


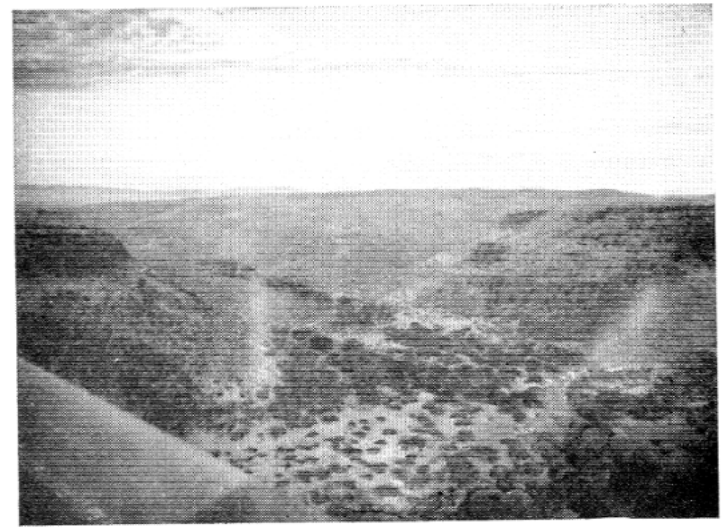
(b) Ripple-marks in quartzite south of Lengitoto.



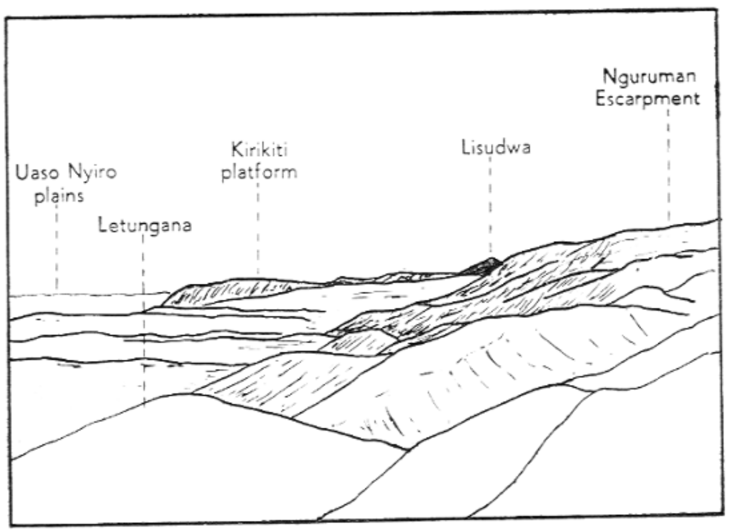
(c) Ripple-marks in felspathic quartzite from Runai.

PLATE II



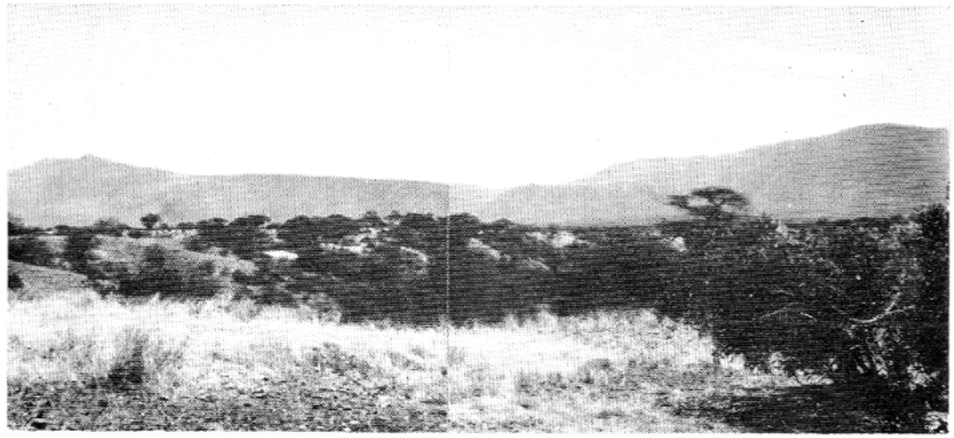


(a) Lengitoto trachytes forming Kipurses and Naitiami overlie tilted Kirikiti basalts of Kishalduga. The trachytes have been down-faulted and underlie the plain in the foreground.

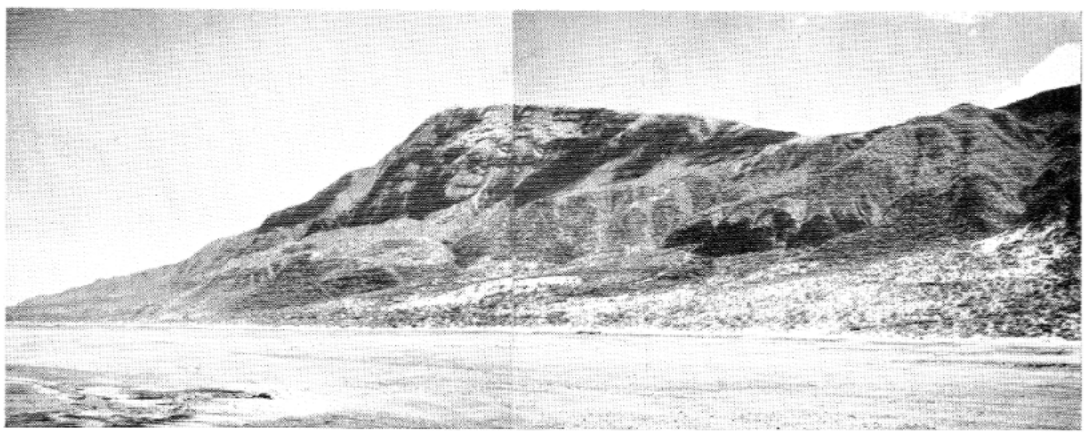


(b) The Nguruman escarpment at about latitude 1° 40′ S. looking south. A fault passes along the base of the face of the quartzite hills that form the escarpment while to the east the Kirikiti platform forms a marked step on which lie Kirikiti basalts that outcrop in the middle-distance.

PLATE III

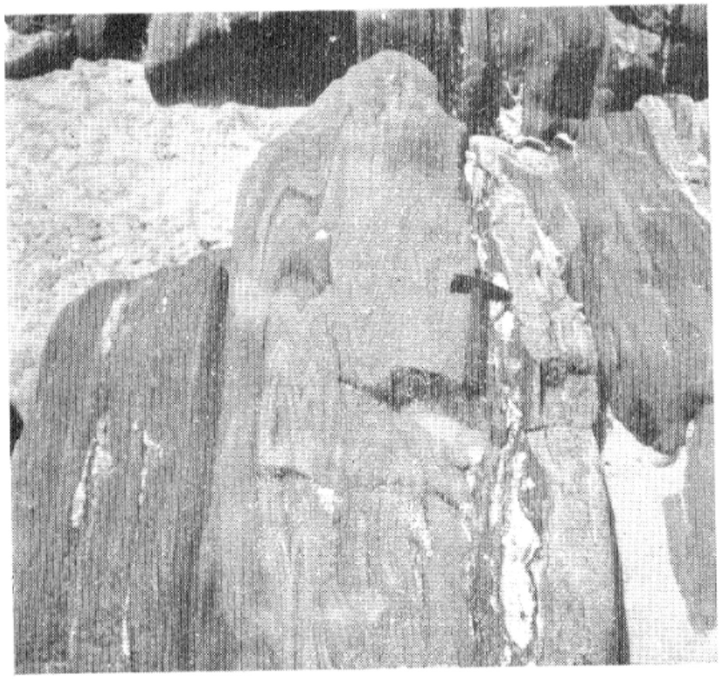


(a) Ol Doinyo Sambu and part of the Nguruman escarpment. The photo was taken from near the Pagasi river, outcrops of Pagasi beds occurring in the foreground.



(b) Ol Doinyo Sambu from the northern end of Lake Natron. This Pleistocene volcano has been bisected by faulting. In the foreground are alkaline springs.

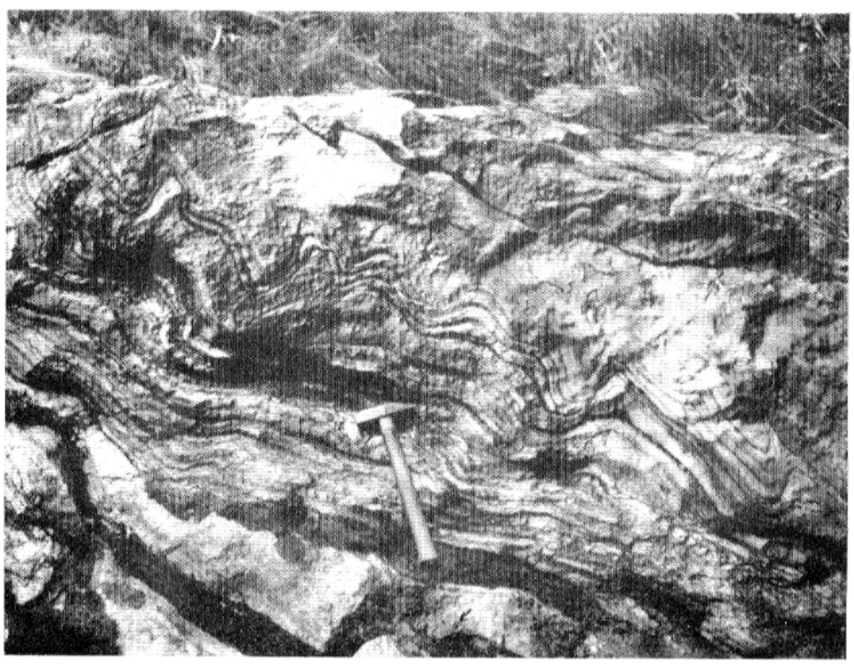
PLATE IV



Isoclinally folded migmatitic gneisses in the river Lepolosie, south-west of Naigara.

PLATE V

(a) Fissile muscovite schists in the river Rimeregele, three miles south of Naigara.

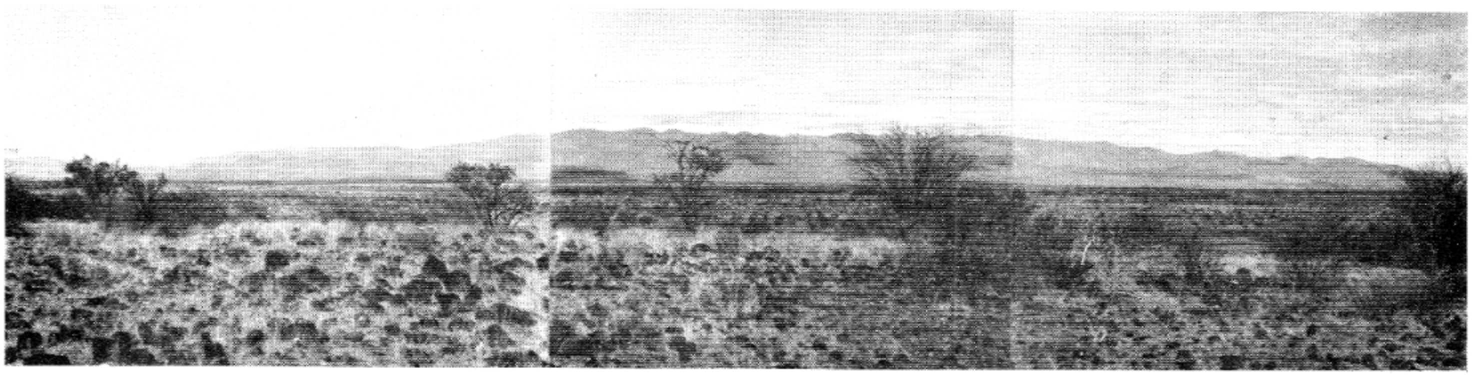


(b) Crumpled biotite gneisses in the river Lekuruki, north-west of Naigara.

PLATE VI

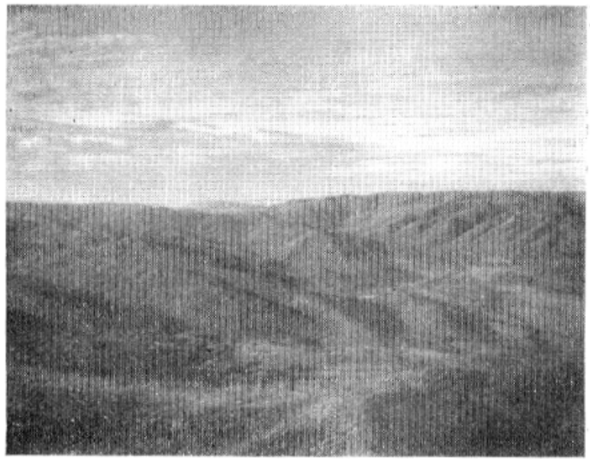
The Nguruman escarpment from the northern end of Lake Natron. Volcanic rocks of Ol Doinyo Sambu overlie the Basement System rocks exposed in the escarpment (in the background).

PLATE VII



The Nguruman escarpment from the Magadi area. The lower part of the escarpment is composed of Tertiary and Pleistocene volcanic rocks that rest against highly folded Basement System gneisses and quartzites exposed in the upper part of the escarpment. The even summit level of the Loita hills represents the end-Cretaceous bevel, the lower sub-Miocene bevel being represented by the spurs to the north and south of the main hill mass.

PLATE VIII



(a) The Loita Hills from Olibeshet. The break in the range of hills is due to erosion along the Morijo faults.

(b) Truncated spurs on the Nguruman escarpment north of Ol Doinyo Sambu.

(c) Highly folded quartzites plunging to the north on the Nguruman escarpment at Kilalafi. The folds plunge from left to right in the photograph and simulate dipping strata.

Granitization and *lit par lit* injections have been confined mainly to the south-western part of the area. Local areas of intense migmatization where evidence of plastic deformation was common were noted mainly south of Naigara. Alkali metasomatism accompanied the period of granitization and maximum migmatization, when rocks were permeated and veined. In thin sections this alteration is indicated by the introduction of potash felspar, chiefly microcline. This felspar displays a replacive relationship towards quartz and plagioclase which it embays, while isolated blebs of quartz and the occasional islands of myrmekite within potash felspar represent late-stage replacement by microcline. During the replacement not all the quartz was resorbed. The northern and eastern boundaries of the zone of granitization is marked by discrete injections and the development of augen and porphyroblasts of felspar in schistose rocks. A second area of permeated rocks occurs near Narosura.

The period of granitization was accompanied by a phase of boron metasomatism leading to the widespread crystallization of tourmaline. It has been shown that argillaceous sediments can contain sufficient boron to account for the presence of tourmaline in the metamorphic derivatives of these rocks (Turner, 1948, p. 127) and much of the tourmaline in the pelitic schists of the area can probably be attributed to the boron content of the parent rock. Many of the quartzites, however, contain small pockets of tourmaline which must be attributed to pegmatitic bodies associated with granitization.

2. Tertiary

Estimation of the age relationship of lavas and terrestrial deposits can be based on physiographic evidence, on their relationship to the sub-Miocene peneplain and to the overlying Pleistocene lavas, and on their association with younger rift faulting. Other evidence may be derived from neighbouring areas and in particular with the areas to the east (viz. Baker, 1958 and Matheson, 1965). The rocks of Tertiary age may be classified in the following chronological order:—

Pliocene	Kirikiti Basalts. Melanephelinites, olivine melanephelinites, ankaratrites and nephelinites of Kishalduga, Olomboneg, and Olduratolekarkoyo.
Miocene	Gravels, mudstones, clays and calcareous deposits overlying the sub-Miocene peneplain.
Early Tertiary	Gravels, mudstones, tuffs.

(1) Terrestrial Deposits

A number of separate deposits distributed throughout the western part of the area are considered to be of Tertiary age. Most of these are bedded gravels and orange-brown clays with gravels, that are exposed in stream sections and on interfluves in the Naigara area. The gravels probably represent hill-wash and alluvial fans that accumulated on the sub-Miocene peneplain and against the western slopes of the Loita Hills. In some sections over 30 ft. of conglomerates and gravels with sands are exposed in vertical-sided gullies, the deposits thinning and becoming less coarse towards the west. The finest material is represented by overlying iron-stained clays with gravels which are patchily developed over a wide area. Comparable in age are similar deposits exposed in the valleys of the rivers Orido, Lemisikio and Lekuruki, north of Olosolan, where the maximum thicknesses are slightly in excess of 15 ft. Grey, gravelly mudstones and calcareous soils occur with the gravels in the river Lekuruki, while thin kunkar sheets and calcareous deposits are exposed on the western bank of the river Idepes, south-west of Naigara. Bedded deposits of volcanic origin which are exposed in stream sections north of Ol Doinyo Loisekin in the north-western corner of the area, and boulders of grey tuff overlying iron-stained clays and gravels at Ol Doinyo Lemujai are ascribed to about the same age. The volcanic origin of these deposits suggests that they were formed at the same time as the tuffs of the Narosura area, which are brown gravels and tuffs containing numerous rounded pumice fragments probably laid down in shallow water on the sub-Miocene peneplain.

Other deposits of Tertiary age were mapped in the Ol Mesutie area where they are exposed in the upper reaches of many streams near the Tanganyika border at Ilgeri and seven miles south-west, in the river Olonkoiirienito. All the deposits are iron-stained indurated or semi-indurated gravels believed to have accumulated on bevels of Tertiary age. An early Tertiary deposit is probably represented by sediments exposed in a stream section at Osarara, on Usubugo, where bleached gravels overlying grey tuff rest on clayey gravels and coarse-grained mudstones. The deposits were probably laid down in a shallow lake as the mudstones display evidence of slumping. It is interesting to note that the mica schists in this area are highly altered and now represented by banded kaolin deposits. In the physiography section it was suggested that the deposits were formed on the end-Cretaceous peneplain, and it seems likely that deposition of the sediments and alteration of the mica schists took place in a lake that occupied a shallow valley formed during the early Tertiary period. Laterized gravels overlying Basement System schists at Lereteti, near Naigara, are considered to be of the same age.

(2) Melanephelinites, Olivine Melanephelinites, Ankaratrites and Nephelinites

Melanephelinites and olivine melanephelinites form a large proportion of the volcanic rocks in the north-eastern corner of the area where they overlie the sub-Miocene peneplain. These are highly eroded, gently tilted lava-flows erupted either from fissures or vents now concealed. A conical peak, situated three and a half miles south-east of Kishalduga and composed of melanephelinite, the weathered surface of which is strewn with small calcareous concretions, may represent the site of one of the old vents. Other vents may include those at Loisiumurto from which later lavas were extruded, an agglomerate cone, now exposed at the base of the lavas in the Narosura river near the eastern border of the area, and a well-preserved cone three miles east of Kipurses in the area to the east of the present one. The flows, forming a succession nearly 900 ft. thick, vary in thickness and have been worn back by denudation along the junctions of contiguous flows. The hard, relatively unaltered portions of the flows stand up as a steep slope at the back of each short terrace, a feature clearly visible on aerial photographs. Most of the flows are traceable for long distances and are seen to pass into the area to the north. Of the three principal lavas which were mapped on Kishalduga, the lower one is separated from the others by agglomerates and tuff beds, and is characteristic of the melanephelinites here, forming the greater part of the volcanic outcrop, occurring north and south of the Narosura river. Nearly 800 ft. of lower melanephelinites were measured and it can only be presumed that this represents a number of individual flows.

The characteristic lava type is a dense, black rock occasionally vesicular and markedly porphyritic, containing abundant pyroxene phenocrysts ranging up to 4 mm. in length that are conspicuous on weathered surfaces. The idiomorphic pyroxene is a pale-brown nearly colourless variety, exhibiting strong zoning and twinning. Inclusions of ore grains are common and are frequently confined to the rims of the phenocrysts. The matrix in specimen 50/298 from Kishalduga consists of prisms of augite and irregular grains of magnetite set in a brown, interstitial partly isotropic base, composed of nepheline and analcime. A little olivine showing alteration to antigorite is present and rare laths of felspar were determined as calcic labradorite (An_{66}).

The upper flows of olivine melanephelinite on Kishalduga are similar but not so fine-grained and contain a greater proportion of nepheline and euhedral olivine, the latter mineral being conspicuous in the hand-specimen of 50/297. The olivines are clear green crystals and frequently show alteration to "iddingsite". In specimen 50/296 the augite phenocrysts are long prismatic crystals with a crude preferred orientation (Fig. 5).

These rocks also differ from the lower lavas in that they are more vesicular and contain zeolites.

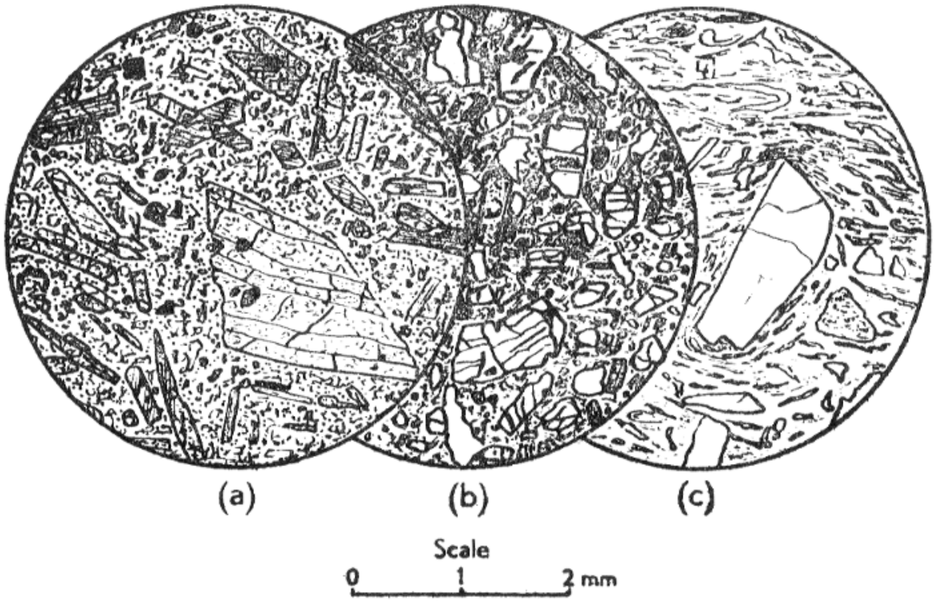


Fig. 5—Microscope drawings of thin sections of Tertiary and Pleistocene volcanic rocks.

(a) 50/296, melanephelinite from Kishalduga. A porphyritic rock containing phenocrysts of augite, crudely orientated, in a holocrystalline groundmass containing olivine and nepheline.

(b) 50/295, olivine melanephelinite from a vent at Loisiumurto. A porphyritic, nepheline-rich lava containing phenocrysts of olivine and augite.

(c) 50/271, ignimbrite from Goitigo. Phenocrysts of felspar exhibiting fluidal texture in a matrix of glass shards.

Ankaratrite (biotite-olivine melanephelinite) forms the summit of Olomboneg in the south-eastern corner of the area, where a lava flow 50 ft. thick overlies Basement System quartzites. A second patch of ankaratritic lava outcrops at Olduratolekarkoyo, two miles north-west of Olomboneg. These lavas are likely to be equivalent in age to the melanephelinites of Kishalduga which are considered to be older than the Kirikiti Basalts. The ankaratrite lava is more coarsely-grained than the melanephelinites of Kishalduga and contains abundant, closely-packed augite phenocrysts set in a holocrystalline matrix, with olivine crystals that are transformed to iddingsite and serpentine. Orange-brown to yellow-brown biotite frequently forms a discontinuous outer zone round the pseudomorphs. The augites form idiomorphic prisms frequently displaying ragged, magnetite-rich edges that locally enclose parts of the groundmass. Abundant pyroxene prisms in the groundmass are pale-brown and in parts of the rock show distinctive zoning, the pyroxene being rimmed by green aegirine or aegirine-augite. Specimen 57/4 from Olduratolekarkoyo is notable for the presence of anhedral to subhedral nepheline with a refractive index near 1.54. Frequently the nepheline assumes a poikilitic habit enclosing pyroxene and ore, indicating its early crystallization. Orange-brown biotite, markedly pleochroic, occurs in numerous ragged patches throughout the groundmass. The mica which is fresh and clear, encloses both pyroxene and ore indicating the primary nature of this mineral. Small vesicles of 57/4 contain zeolites one of which was identified as chabazite. An analysis of an ankaratrite, 51/731, from the base of the Nguruman Escarpment at the river Oloibortoto and similar to the Olomboneg rock is quoted on page 37.

Underlying Pleistocene agglomerates in the bed of the river Saengatuny, one mile north-east of Narosura, are outcrops of nephelinite that appear to form part of a dyke-like intrusion into Basement System rocks. Exposures are poor and in some instances consist only of rounded boulders. Outcrops of nephelinite similar to that described above occur a few miles north-east of Narosura in the adjacent area to the north. The nephelinite is a hard, dark, grey-green rock with abundant phenocrysts of nepheline up to 1.5 cm. in length set in a dull, aphanitic matrix. The phenocrysts are usually vitreous or greasy in appearance. Weathered surfaces are greenish with iron-stained hollows due to the weathering out of the nepheline. In thin sections of specimen 50/276 from the river Saengatuny, the phenocrysts are set in a fine-grained holocrystalline groundmass, coloured green due to abundant pyroxene. The nepheline which occurs in stout tabular crystals is marginally altered and dusty with inclusions. Rare laths of felspar, pale-green aegirine-augite and a little orange-brown cossyrite are associated in the matrix, together with tiny euhedra of nepheline and abundant grains of black iron ore.

(3) Kirikiti Basalts

Along the eastern border of the area, north of Ol Doinyo Sambu, a number of basalt flows have been mapped and described by Baker (1958, pp. 16-18). These basalts now rest against the lower part of an eroded fault scarp (Plate IIb) along which renewed faulting took place leaving a basalt ledge sloping gently southwards beneath the pebble-beds of Pagasi. Small boulders of vesicular basalt occurring about 100 yards east of the Entasekera police post probably represent the eroded remains of a small outlier of Kirikiti basalt that was extruded from the Entasekera fault.

The Kirikiti Basalts are thought to have been extruded from a number of north-south vents and rest against a pre-existing fault scarp of Basement System rocks as suggested by Baker (1958, p. 16). They were subsequently downfaulted and are now seen overlying the Kirikiti platform and again forming the floor of the Rift Valley. The author examined exposures of Kirikiti Basalt in sections exposed in the gorges of the east-flowing rivers near the River Oloibortoto at localities just east of the eastern border of the Loita Hills area. Faulted Kirikiti Basalts were seen to overlie sediments including mudstones and fossiliferous limestones (containing a tooth of a crocodile), that are probably Miocene or lower Pliocene in age. Miss Neilson (in Gregory, 1921, p. 405) also describes Kirikiti-type basalts, collected by Gregory (Nos. 640 and 641), their precise locality being unknown except that they were obtained from the Nguruman escarpment, west of Magadi. An analysis of specimen GN 640, an alkali basalt, which is re-quoted on page 37 is given by Campbell Smith (1931, p. 252).

(4) Age Relationship between Tertiary and Lower Pleistocene Volcanic Rocks

The occurrence of highly eroded, westerly dipping melanephelinites at Kishalduga and relatively uneroded, horizontal Kirikiti Basalts of the north-western corner of the Magadi area, separated by the Kipurses fault at Naitiami, suggests that the melanephelinites are older rocks. This is further supported by evidence to the south where a thick succession of Kirikiti Basalts are seen to rest against an eroded fault-scarp (Plate IIb) that formed as a result of north-south faulting prior to the extrusion of the basalt. The basalts flooded the floor of the Rift Valley to a depth of more than 1,000 ft. (Baker, 1958, p. 16) near the eastern border of the present area, thus concealing the fault-zone. The melanephelinites overlie the easterly sloping sub-Miocene peneplain, indicating that the formation of this part of the Rift Valley was preceded by warping of the sub-Miocene bevel and the outpourings of alkaline lavas. A period of faulting with the formation of the first major rift fault, possibly a branching fault, of which the Naitiami fault is part, down-throwing melanephelinites and Basement System rocks to the east, was followed by a period of erosion and the formation of what is now the upper part of the Nguruman Escarpment. Eruption of the Kirikiti Basalts, the lavas flowing up against this pre-existing fault scarp, was followed by further erosion. The relationships in the neighbouring and present areas between the melanephelinites and Kirikiti Basalts suggests the basalts were never down-faulted from the top of the Nguruman Escarpment and this is supported by the fact that there is no evidence of faulting at the western edge of the basalt outcrops where excellent exposures are to be seen in the river gorges such as the Oloibortoto. Here the lavas unconformably overlie the Basement System rocks, the main fault zones being more than two miles east of the eastern border of the Loita Hills area. During Pleistocene times the basalts in the north-western corner of the Magadi area were covered by the Lengitoto Trachytes, probably fissure eruptions from the Naitiami fault zone, to a maximum thickness of 500 ft. in the present area. Baker (1958, p. 18) mapped about 50-100 ft. of trachyte on the Lengitoto Plateau thus suggesting that the lavas thinned eastwards. Renewed faulting then took place along the Naitiami fault, followed by erosion and the subsequent development of the Naitiami-Kipurses scarp. Erosion in Pleistocene to Recent times exposed a succession (*see* Fig. 6) of melanephelinites overlain by Kirikiti Basalts which in turn were overlain by trachytes to be seen in the Magadi area (Baker, 1958). The melanephelinites of Kishalduga are, therefore, the possible equivalents of the Ol Keju Nero Basalts (or possibly contemporaneous with the Olorgesailie Volcanic Series) which in some instances are felspar-free rocks (*op. cit.*, p. 16). The melanephelinites of the Loita Hills area have therefore been assigned to the Miocene.

3. Pleistocene

The rocks of Pleistocene age are widely spread and include:—

Upper Pleistocene	Lake Beds
Middle Pleistocene	Ol Doinyo Sambu Volcanics Olivine melanephelinites of Loisiumurto Ignimbrites Tuffs
Lower Pleistocene to Upper Pliocene	Lengitoto Trachytes Kunkar limestones

The ages of Lower and Upper Pleistocene are based mainly on evidence established in the adjacent Magadi areas now confirmed in the Loita Hills area. Recent age determinations made on alkali-trachytes from the Magadi area indicate ages of 0.8 to 1.7 million years. In that area the true thickness of trachytes is unknown and it cannot be stated with any certainty where the Lengitoto Trachyte occurs within the succession, though evidence suggests it forms part of the lower flows. No positive age, on the other hand, can be given to rocks assigned to the Middle Pleistocene. The faulting that affected the volcano of Ol Doinyo Sambu has been tentatively dated as Middle Pleistocene, while the ignimbrites in the north-east corner of the area (that were extruded from vents at Loisiumurto) partly fill a valley excavated since the outpourings of the Lengitoto Trachytes. The alkaline lavas of Loisiumurto can possibly be correlated with similar rocks at Ol Doinyo Sambu. It is of interest to note that veins of calcite and ngurumanite have recently been discovered by the author and B. H. Baker in ankaratrites that are considered to form part of the Kirikiti Basalts outcropping in a tributary of the Oloibortoto river near the base of the Nguruman Escarpment in the Magadi area (Saggerson and Williams, 1964, p. 41). These veins and the presence of alkaline rocks suggest a close affinity and the possibility of alkaline plutonic rocks at depth in this part of the Rift Valley. Alkaline rocks with carbonatites have recently been described from the Rift Valley.

(1) Kunkar Limestones

Kunkar limestone is mainly confined to the area between Entasekera and Ol Mesutie where it overlies terraces along the valleys of the Orkejulesai and its tributaries. The terraces developed during end-Tertiary times and it is likely that the superficial limestones were formed at about the same time, or very early in the Pleistocene period. The kunkar forms impersistent sheets overlying calcareous, rubbly deposits and can best be examined in road cuttings at Nairotian. Kunkar limestone has been referred to in connexion with deposits overlying the sub-Miocene peneplain in the Naigara area, while small sheets and nodules of limestone have formed on the surface of Kirikiti Basalts in the north-east corner of the area. In the latter case it is possible that the limestones are similar in age to those at Ol Mesutie when conditions were favourable for their formation. There was no evidence of kunkar limestone covering the surface of later (Pleistocene) lava flows, nor where the older basalts are deeply eroded.

(2) Lengitoto Trachytes

At the north-eastern corner of the area is a dissected plateau standing at 6,000 ft., bounded on the eastern side by a scarp 500 ft. high and composed of a number of horizontal trachyte lava flows that on Kipurses can be seen to rest against and overlie the Kirikiti Basalts. The plateau, which includes Naitiami and Kipurses, is divided into three separate mesa-like hills that became isolated as a result of dissection in Pleistocene time (Plate IIa). At Kipurses the lavas, approximately 500 ft. thick, consist of at least four recognizable flows, each very vesicular at the top and forming a number of small but conspicuous terraces as a result of differential erosion on an east-facing scarp slope. The lavas have been downfaulted to the east, the upper portion of the downfaulted block being represented by the original Lengitoto Trachyte described by Baker (1958, p. 18). Fig. 6 is a diagrammatic section showing the presumed relationship between the Lengitoto trachytes and Kirikiti Basalts at latitude 1° 35′ S. No evidence of sediments separating the Kirikiti Basalts and overlying trachytes as described by Baker (*loc. cit.*, p. 18) was seen in the present area, so it is presumed that thinning of the sediments occurs westwards as indicated in Fig. 6. It is further suggested that the trachytes were fissure eruptions that were extruded probably along an early north-south rift fault, and that they thinned rapidly to the east where about 50 ft. only of lava was mapped on the Lengitoto Plateau. In his discussion on the age of the trachytes, Baker (ibid., p. 18) considers these Lengitoto lavas to represent the oldest of the Plateau Trachyte Series and evidence in the Loita Hills area substantiates his observations.

The trachytes are hard grey-green rocks that ring sonorously when hit, and bear a distinct megascopic resemblance to phonolites outcropping at Kisumu (Saggerson, 1952, p. 29). Both have a characteristic mottled appearance on fresh surfaces while the fissile nature of the lava is common to both rock-types. Some of the trachytes however are light weathering and distinctly vesicular on the upper parts of individual flows, a feature not seen in the Kisumu phonolites. Thin sections of various trachyte flows show little variation in the lavas except that the groundmass felspars vary from short, stubby crystals to fine laths in different specimens. Phenocrysts of sanidine twinned on the Carlsbad and Manebach laws are set in a fine-grained matrix consisting mainly of abundant lathy or prismatic orthoclase with interstitial micro-ophitic aegirine, kataphorite, cossyrite and magnetite. In specimen 50/393, the texture is typically trachytic. The kataphorite has strong pleochroism from yellow-green to brown or pinkish-brown while the cossyrite also displays pleochroic colours, chestnut brown to black. The rocks may be compared with the kataphorite-trachyte of Campbell Smith (1931, p. 225) and are identical with those described by Baker (1958, p. 18). The average of six analyses of alkali-trachytes from the neighbouring Magadi area is quoted on page 37.

(3) Pebble Beds and Sands

In the South-Magadi Area, Baker (1963, p. 14) has shown that unconsolidated pebble-beds and sands overlie the Kirikiti platform in the Pagasi area, five miles north-east of the north-west corner of Lake Natron (36° 02′ E., 2° 02′ S.). These pebble sheets extend westwards into the present area where they become indistinguishable from the hill-wash and alluvial fans that conceal the base of the Nguruman escarpment. The latter deposits have accumulated at the base of precipitous slopes as a result of rapid erosion of the escarpment. Good sections can be examined, however, in the Pagasi river to the east of the present area where boulders of quartzite (and occasionally Kirikiti Basalt) are seen to form the greater proportion of the deposits (Plate IIIa).

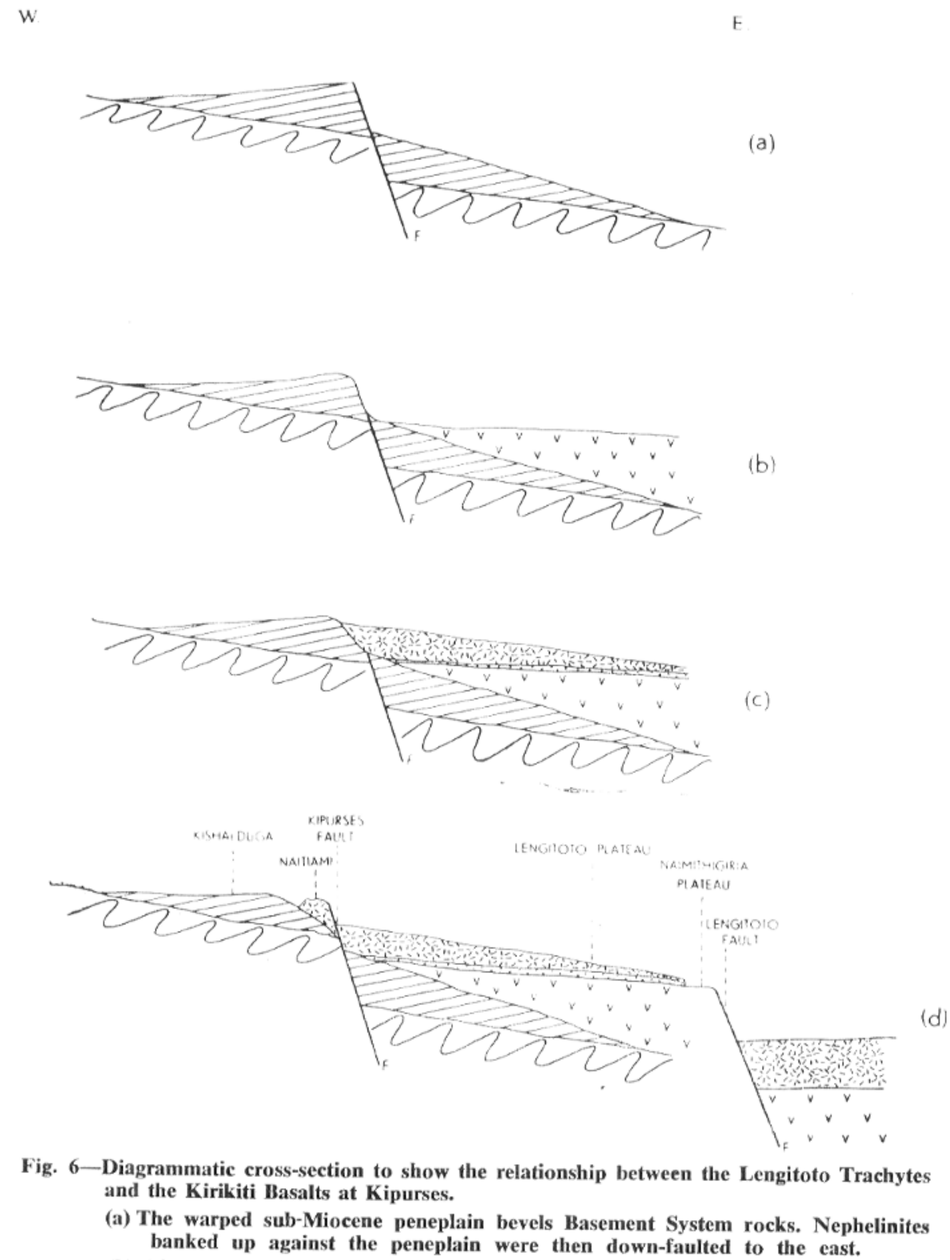


Fig. 6—Diagrammatic cross-section to show the relationship between the Lengitoto Trachytes and the Kirikiti Basalts at Kipurses.

(a) The warped sub-Miocene peneplain bevels Basement System rocks. Nephelinites banked up against the peneplain were then down-faulted to the east.

(b) After a period of erosion the nephelinites east of the fault were covered by Kirikiti Basalts.

(c) Further erosion and the laying down of sediments on the Kirikiti Basalts is followed by a period of extrusion of Lengitoto Trachytes.

(d) The section as seen at the present time. Renewed faulting along the Kipurses fault has downthrown Lengitoto Trachytes to the east.

Recent erosion has partly separated the nephelinites of Kishalduga from the upper trachytes of Naitiami.

(4) Tuffs

Tuffs were mapped along the northern border of the area, north and west of Narosura and in stream sections south of this village. They generally lie north of the river Saengatuny valley in which they are seen to overlie the Kishalduga melanephelinite while a number of minor outcrops occur in valleys east of Narosura and as far south as the river Mbwageta. At the last-named locality thin agglomerate bands are interbedded in the tuffs. The tuffs attain their maximum development on the eastern side of the outcrop where it is estimated they are nearly 150 ft. thick (west of the confluence of the Saengatuny and Sugura rivers). Rapid thinning of the volcanic rocks occurs westwards and a little more than 10 ft. of tuff was measured near Narosura. West of the main Narok road the tuffs form only a thin covering over the Basement System rocks and rare boulders scattered over the surface particularly at Goitigo and Dasati suggest the nearly complete removal of volcanic rocks that probably covered a much greater area in the past. Four miles east of Goitigo, Basement System rocks now exposed in patches indicate where the tuffs have been stripped by erosion from the interfluves. A small tuff band outcropping in the river Irpoori, west of Naigara, is associated with iron-stained gravels of late Tertiary age.

The tuffs vary in colour, usually from light grey to blue-grey, though maroon-coloured rocks were noted in the southern part of the Lengitoto valley. Fragments which are small, the largest measuring less than an inch, are mostly elongated parallel to the bedding contacts. Some sections in the river Narosura show the tuffs to be more massive, enabling the rock to be quarried as building-stone. Thin sections disclose fragments up to 2.5 mm. embedded in an iron-stained matrix, while in specimen 50/290 from Narosura microscopic banding is visible. Light coloured fragments include pumice, ignimbrite and phenocrysts of orthoclase. Quartz is present though never abundant, although when occurring in silicified tuffs is of later origin. Many kinds of tuff are recognized, including vitric, lithic and crystallo-lithic varieties. A single exposure of ignimbrite (specimen 50/271) is associated with the tuffs at Goitigo. The tuffs, which are younger than the lavas at Kishalduga, are thought to be deposits derived from the Loisiumurto vents and are probably contemporary in age with the ignimbrites of that area.

(5) Ignimbrites

The Lengitoto valley section south-east of Narosura displays good outcrops of ignimbrite. The rocks are typically grey-blue, flinty and unbedded. Some surfaces show lighter streaks orientated approximately parallel to each other, suggesting fluidity during formation and simulating flow lineations in lava. Other specimens, such as those collected from the valley of the river Olkejulormungushi resemble dense basalts, while a small band interbedded in tuffs at Goitigo is grey and greasy in appearance. A thin section of the latter rock, 50/271, is typical of the ignimbrites and reveals fragments of large "phenocrysts" set in a fine matrix of glass shards and pumiceous material (Fig. 5 (*c*)). The groundmass has a fluidal texture due to contorted, curved and flattened wisps of clear glass and Y-shaped streaks. A characteristic feature of the rock is the discontinuity of these flattened shards. Scattered fragments of pumice and felspar crystals up to 2 mm. in length are the main lithic portions of the ignimbrites, though hornblende, olivine grains, quartz and trachyte chips, also flakes of biotite were noted in various specimens. In specimen 50/294 from Kipirtilo, microlites with a tendency to spherulitic texture are present in clumps in a nearly isotropic base. The ignimbrites are rarely silicified or calcified.

The ignimbrites are considered to be the products of explosive activity at the Loisiumurto vents and must have originated as a *nuée ardente* that avalanched down the north-eastern slopes of the volcanoes spreading north and south and inundating part of the eroded Lengitoto valley that developed long after the extrusion of the Lengitoto Trachytes, the base of which stands above the top of the ignimbrites. The deposits are over eight miles long and more than one mile wide, while the thickest section measured west of Ol Doinyo Leanda revealed over 150 feet of ignimbrite overlain by a thin tuff bed.

A number of other ignimbrites were mapped in the western part of the area, at Osarara on Usubugo, at Ririjoshoro and in the valleys of the rivers Orngaeenet, Lairaka and Orido. Their scattered but limited distribution and proximity to fault-zones suggest that they have been derived from explosive vents situated at cross-fractures. In all but the Usubugo occurrences they overlie the sub-Miocene peneplain while streams eroding the Miocene deposits near Naigara contain numerous boulders of ignimbrite in their courses. It is likely, therefore, that the deposits are relics of more extensive but isolated outcrops and are comparable in age with similar rocks at Loisiumurto. The specimens from these localities contain more fragmental material than those of Loisiumurto and in many instances are underlain by thin tuffaceous bands.

(6) Olivine Melanephelinites of Loisiumurto

Four ancient eroded vents aligned NE.-SW. were recognized at Loisiumurto. The tuffs and ignimbrites of the northern and north-eastern parts of the area are considered to have beeen derived from them, and it is not improbable that some of the Kishalduga flows were also products of earlier volcanic activity associated with the same volcanoes. The deposits and lavas overlie the sub-Miocene peneplain and are younger than the horizontal Pleistocene trachytes outcropping to the east. An estimate of age can also be based on physiographic evidence: The tilted lavas of Kishalduga are eroded forming rounded outlines on interfluves in the lower part of the Narosura river. Further the rivers in this region had cut through the Lengitoto Trachyte and the melanephelinites at Kishalduga before the ignimbrite flow filled part of the Lengitoto valley. The vents have been completely eroded thus revealing plugs of olivine melanephelinite. The olivine melanephelinites filling these necks are different from those found among the early lava flows. They present craggy and bouldery surfaces, the highest vent being situated at an altitude of about 6,600 feet. A typical specimen 50/295 is dark grey, slightly vesicular with scattered phenocrysts of olivine up to 2 mm. Examination of thin sections shows small olivine and pyroxene microphenocrysts set in a holocrystalline groundmass (Fig. 5 (*b*)). The sub-idiomorphic olivines are pale-brown or nearly colourless and are rarely fresh, showing evidence of resorption and alteration to orange-coloured iddingsite round the crystal margins. Pale augite is not so common as olivine. Rare plagioclase of the groundmass is a calcic-labradorite An_{70} associated with small olivines, greenish-brown pyroxene, nepheline and magnetite. The magnetite forms numerous small octahedra in the groundmass where it is frequently concentrated round the edges of altered olivines. Vesicles are commonly filled with calcite, sometimes spherulitic, which also occurs interstitially in the groundmass. This rock differs from the olivine melanephelinite of Kishalduga in its abundance of olivine, rare plagioclase, and its lack of large augite phenocrysts.

(7) Ol Doinyo Sambu Volcanics

The northern slopes of the impressive volcano of Ol Doinyo Sambu (Plate III), rising to about 6,600 feet in Tanganyika, form part of the south-eastern corner of the area. The mountain is a composite volcanic cone which consists of accumulations of well-stratified tuffs, agglomerates and lavas, the lavas being conspicuous due to their greater resistance to weathering. A deep gorge dissects the northern end of the volcano thus displaying a magnificent section showing the deposits rising gradually eastwards to the edge of the Rift Valley where a north-south fault has bisected the mountain, the eastern down-faulted portion now lying buried beneath the sediments of Lake Natron. The works of Bailey Willis (1936), and Uhlig and Jaeger (1942) both show illustrations of Ol Doinyo Sambu rising abruptly 4,600 feet from the Rift Valley floor. That part of the mountain which lies in the Loita Hills area is seen to overlie Basement System quartzites and is older than Upper Pleistocene deposits of the Pagasi area. The volcano erupted along an early rift fault, and was subsequently faulted, probably in the middle Pleistocene, and may be equivalent in age to the Ol Doinyo Nyegi volcanics of the Magadi area.

Descending the side of Ol Doinyo Sambu from Olomboneg a number of highly vesicular blue-black basaltic lavas are seen to comprise the upper flows including that forming the shelf at Mima. This succession of over 850 feet consists of olivine-andesine-basalts interbedded with light-coloured agglomerates and tuffs. Specimen 57/5 is typical of these lavas and comes from the uppermost flow at Mima. The rock is grey to purple, with a typical holocrystalline porphyritic texture and contains scattered phenocrysts of plagioclase, pale-brown augite and olivine (Fig. 7 (*c*)). Some phenocrysts over 3 cm. in

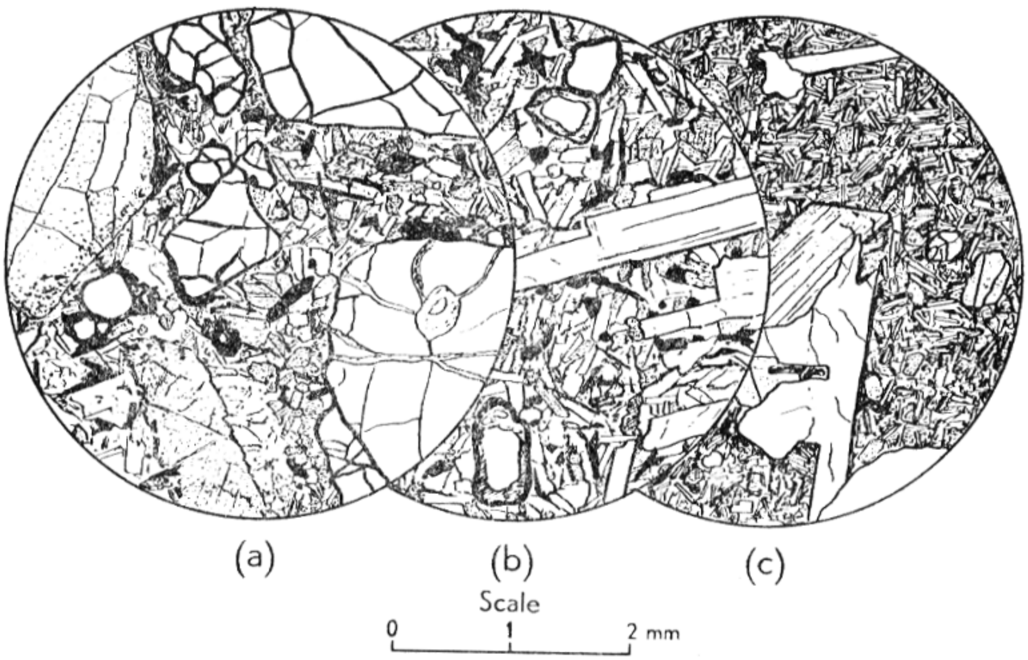


Fig. 7—Miscroscope drawings of thin sections of Ol Doinyo Sambu volcanics.

(a) 57/12. Olivine micro-gabbro. Phenocrysts of olivine and pyroxene in a matrix of plagioclase, augite, altered olivine and magnetite.

(b) 57/11. Olivine basalt. Microphenocrysts of olivine and plagioclase in a coarse matrix of felspar, pyroxene and magnetite.

(c) 57/5. Olivine-andesine basalt. Phenocrysts of pyroxene, plagioclase and small olivines in a matrix of the same minerals.

length were observed in hand-specimens. The plagioclase is andesine (An_{44}) in long tabular crystals measuring up to 2.5 mm., occasionally ophitically intergrown with the pyroxene. The olivine has beeen completely altered to orange-brown iddingsite. The groundmass is composed of laths of andesine (An_{36}), augite, serpentinized olivine and abundant magnetite. The felspar laths are sometimes disposed in radiating or branching groups though usually they are associated with the pyroxene in a sub-ophitic relationship. In specimen 57/6 the rock is finer-grained and some glass is present as mesostasis.

The lavas comprising the lower flows are mainly fissile, dark blue or grey olivine basalts, their textures suggesting the trachy-basalts of some authors. They are fine-grained rocks containing microphenocrysts of felspar, olivine and more rarely augite set in a very fine-grained base charged with felspar, pyroxene and magnetite (Fig. 7 (*b*)). The felspar varies in different thin sections (57/8, 57/10, 57/11, 57/13) from An_{53} to

An_{70} indicating a more calcic plagioclase than that in the upper flows. In the ground-mass felspar laths and microlites are fluxionally orientated and associated with titan-augite, magnetite and small olivines usually altered to pale-green or yellowish serpentine but occasionally to iddingsite and antigorite.

Early German writers refer to trachy-dolerites of Ol Doinyo Sambu, presumably the equivalent of the basalts described from the present area. An analysis of a trachy-dolerite given by Finckh (1903, p. 501) and quoted by Krenkel (1925, p. 252) is re-quoted together with an alkali basalt of Kirikiti type (Campbell Smith, 1931, p. 162) and other lavas. Early writers observed that many of the rocks from Ol Doinyo Sambu are similar to those found on Kilimanjaro where they are referred to as Mawenzi-type trachy-basalts and rhomb-porphyries.

	A	B	C	D
	%	%	%	%
SiO_2	39·24	44·25	60·88	48·47
Al_2O_3 ..	9·58	17·05	12·06	15·31
Fe_2O_3 ..	8·72	3·15	4·51	6·69
FeO	5·47	9·98	3·45	6·36
MgO ..	9·52	5·28	0·79	3·60
CaO	15·35	11·04	2·06	8·14
Na_2O ..	3·18	3·05	5·72	4·49
K_2O	1·07	1·16	4·64	1·67
H_2O	3·62	0·26	} 2·47	—
H_2O- ..	0·16	0·75		1·65
TiO_2	3·02	3·30	0·76	2·23
P_2O_5 ..	0·57	0·50	1·06	0·52
MnO	0·21	0·11	0·41	trace
CO_2	0·16	n.d.	0·58	0·26
S	—	n.d.	—	0·14
SO_3	—	—	0·12	—
Cl	—	—	0·023	—
TOTALS ..	100·32	99·88	99·533	99·53*

A. Ankaratrite, 51/731, from the base of the Nguruman Escarpment at the river Oloibortoto (Saggerson and Williams, 1964). *Anal.:* Min. Res. Div., Overseas Geological Surveys.

B. Alkali-basalt (GN 640) from the upper Nguruman escarpment west of Lake Magadi (Campbell Smith, 1931, p. 252). *Anal.:* W. H. Herdsman.

C. Average of six alkali trachytes from the Magadi area (Campbell Smith, 1931, p. 227 and Baker, 1958, p. 20).

D. Trachy-dolerite from Ol Doinyo Sambu, Krenkel, 1925, p. 252 (after Finckh, 1903, p. 501).

Kunzli (1901, p. 159) described an amygdaloidal picrite-porphyrite collected by Kaiser (1898) from the Nguruman escarpment. The specimen was probably obtained from Ol Doinyo Sambu. Similar rocks 57/9 and 57/12 identified as olivine micro-gabbros were obtained from 400 feet above the base of the volcano during the present survey. They are coarse-grained, heavy black rocks with phenocrysts of olivine and pyroxene in a matrix of felspar, pyroxene, magnetite and altered olivine (Fig. 7 (*a*)). The phenocrysts are large subhedral crystals up to 5 mm. in diameter. The olivine is colourless and fairly fresh but shows some alteration to serpentine, while the augite, which is partly chloritized, shows twinning and prominent zoning emphasized by

* This includes 0.07 oxygen for S which should be subtracted from the total.

granules of magnetite. The felspar is andesine (An_{51}) occurring in broad laths associated with brown augite, serpentinized olivine and linear magnetite granules. Limonite is present as an alteration product. The rock has affinities with masafuerite (Johannsen, 1938, Vol. III, p. 334).

An interesting specimen (57/15) was collected from a dry stream bed at the foot of Ol Doinyo Sambu. It is a grey-green pale weathering rock, characterized by abundant phenocrysts (1.5 mm.) of pale nepheline. The nepheline is altered to analcime and calcite and occurs in a dark, iron-stained groundmass in which aegirine-augite, nepheline and rare laths of plagioclase felpar were recognized. The rock is a nepheline tephrite close to nephelinite in composition. A tephrite described by Miss Neilson (in Gregory, 1921, p. 404) was collected by Gregory (specimen number 637) and also came from Ol Doinyo Sambu.

At the north-west tip of Lake Natron a number of small hills composed of blocks of lavas (Plate VI) similar to those found in the flows comprising Ol Doinyo Sambu, are thought to have originated in a small agglomerate vent that erupted along the line of the Old Doinyo Sambu fault. Saline springs emerge from beneath the agglomerate boulders at the southern end of the outcrops. (Plate III (*b*))

(8) Lake Beds

No actual outcrops of High Magadi Beds (Baker, 1958, p. 37) were seen during the survey but there is little doubt that lacustrine silts and clays underlie the wind-blown sands, fine-grained alluvial silts and grey-brown dusty soils of the Uaso Nyiro plain, north of Lake Natron. Baker (1963, p. 16) reports beach levels on Melil hill near the north shore of the lake while a survey of the plain north of Lake Natron revealed the presence of brown silts that are probably poorly exposed members of the High Magadi Beds. Pebble sheets and silts standing four feet above the levei of the Lake Natron flats and forming the edge of the lake in the present area probably represent an old beach level.

4. Recent Deposits

The Recent deposits may be classified as black-cotton soils, grey soils, red-brown soils and quartz sands, pebble sheets and alluvial deposits, forest loams, volcanic soils and alluvium. *Black cotton* soils are among the most extensive of the Recent deposits and cover large parts of the plains to the west of the Loita hills. The soils are found on most interfluves, in poorly drained areas and on top of Usubugo, they frequently contain numerous calcareous concretions and support a characteristic thorn-scrub vegetation. In many parts of Kenya black-cotton soils are generally associated with areas of poor drainage, but here they occur on westerly or southerly sloping plains that are dissected by numerous stream courses.

Related to the previous soils are the *grey soils* of Ol Mesutie, Morijo and the north-west Naigara area. They are better drained and consist of a mixture of black-cotton soil and sandy soil derived from hill slopes. In a stream section two miles east of Morijo Loita, gravels overlying 5-8 feet of grey-brown clay-like mudstones, are Quaternary deposits that may be Pleistocene in age.

Red-brown sandy soils cover small portions of the area and are derived mainly from the weathering of the quartzites. They occur in localities (such as hill tops) where drainage is good and rainfall is just sufficient to permit their formation under semi-arid conditions. With these may be classified the *quartz sands* that have accumulated in and around quartzite ridges and hills as a result of disintegration of metamorphosed grits. Such accumulations have a low humus content and support a sparse vegetation of grass and a few low bushes. Brown *loams* protected by dense forest cover the slopes of the central part of the Loita hills and the Nguruman escarpment.

The *volcanic soils* are found in the eastern parts of the area where they form a thick capping to some of the basalts and trachytes. These soils which are dark red-brown, laterized and well-drained earths support a thick scrub vegetation or good grassland. Although water-supplies are far distant in these areas the Masai prefer to graze their herds over volcanic country because of the better vegetation.

Along a number of river courses are dark soils classified as *alluvium*. These are accumulations of black earths and sands in the Olngakualala swamp and on small alluvial flats flanking the larger valleys near Ol Mesutie. Occasionally these areas are subject to flooding. In many of the river courses, in particular those to the west of the Loita hills, are accumulations of sands, gravel and boulders which occasionally are cemented giving the appearance of a Recent conglomerate. Many of the beds of loose sand show excellent current-bedding and other features of sedimentary deposition and are a result of seasonal flooding. Alluvial boulder fans, hill wash and screes occur at the base of the Nguruman escarpment. They include coarse fluviatile deposits, found where rivers and streams with steep gradients and heavy loads descend the escarpment and debouch upon the relatively flat-floored plains. River courses at the foot of Ol Doinyo Sambu and Olomboneg expose boulder and gravel beds without reaching bedrock and some difficulty is found in separating these deposits from conglomerates of Pleistocene age. Most quartzite ridges have accumulations of soils and boulders forming their lower slopes. The screes are composed of débris from the weathering of quartzite ridges, the steeper talus slopes occurring where material is coarsest. This talus belt is of variable width, ranging from a few score feet on small hills to over a mile wide at the base of the Naigara range.

Laterite is widespread throughout the area occurring at all levels mainly along river and stream courses and at volcanic boundaries. The iron-stones are a product of leaching of iron-rich soils. No large deposits were seen, the iron-stone forming a bed usually a few inches thick within the soil over Basement System rocks.

During the survey numerous obsidian implements and chippings fashioned by prehistoric man were found widely scattered throughout the area, on the highest ridges as well as along river courses. Flakes were most frequently discovered in the north-eastern part of the area near Narosura at the foot of the Loita range. No obsidian flows were mapped in the area so it is presumed the rock from which the implements were derived came from the north-east where similar tools occur abundantly. Prehistoric man presumably made excursions into the hills or formed small settlements where abundant supplies of fresh meat were available.

VI—STRUCTURE

1. Structures in the Basement System Rocks

(1) Folding

The rocks of the Basement System in the Loita hills area have been intensely folded and deformed, migmatization and granitization which affected some of the rocks probably taking place during the early stages in the tectonic history of the area. The pattern produced by folding in the Basement System rocks indicates that they have been subjected to two phases of deformation, new folds being superimposed upon previously folded rocks. The recognition and interpretation of these structures correspond very closely with the areas to the west and north-west (Williams, 1964) and the overall picture is more easily understood when both areas are considered together. A summary of the structural history of this part of south-west Kenya has been given by Saggerson *et al.* (1960). The principal structural features of the present area are shown in Fig. 18 (at end) while Fig. 4 is a simplified geological map that indicates how the principal rock units have been intricately folded.

The structural data collected from different parts of the area indicate great structural complexity which will be better understood after more detailed mapping, beyond the scope of the present report, has been undertaken. Due to the relatively short period of mapping and the large area that had to be covered the detailed study of small areas was impossible and the data collected therefore limited. Nevertheless some of the interference patterns produced by the two phases of folding are typical of many described in the literature and in particular those referred to by Ramsay, 1962, pp. 466-481. In many parts of the area the structural data collected only discloses information concerning the second phase of folding and little about the earlier folds. Because the interference pattern produced, however, indicates two phases of folding it is necessary to treat each structural unit as a whole rather than analyse first-fold movements and second-fold movements separately. Indeed in order to understand the form of the first structures it is essential to analyse first the effects of the later phase of folding. Because of the lack of detailed information in numerous small areas it is not convenient to treat the structures into two distinct generations though structures of similar style and with similar patterns of preferred orientation are assumed to be of the same generation (cf. Weiss and McIntyre, 1957, p. 578).

(*a*) *Naigara Syncline*

The most important structure is the Naigara syncline and its interpretation is essential as a key to the solution of the structure of the area as a whole. During the first of these fold-movements the rocks were recumbently folded about NE-SW. axes while a second period of folding with approximately NW.-SE. trending axes was superposed upon the older folds. The syncline plunges to the north-west and has moderately dipping limbs. Both upper and lower limbs of the first structure are involved

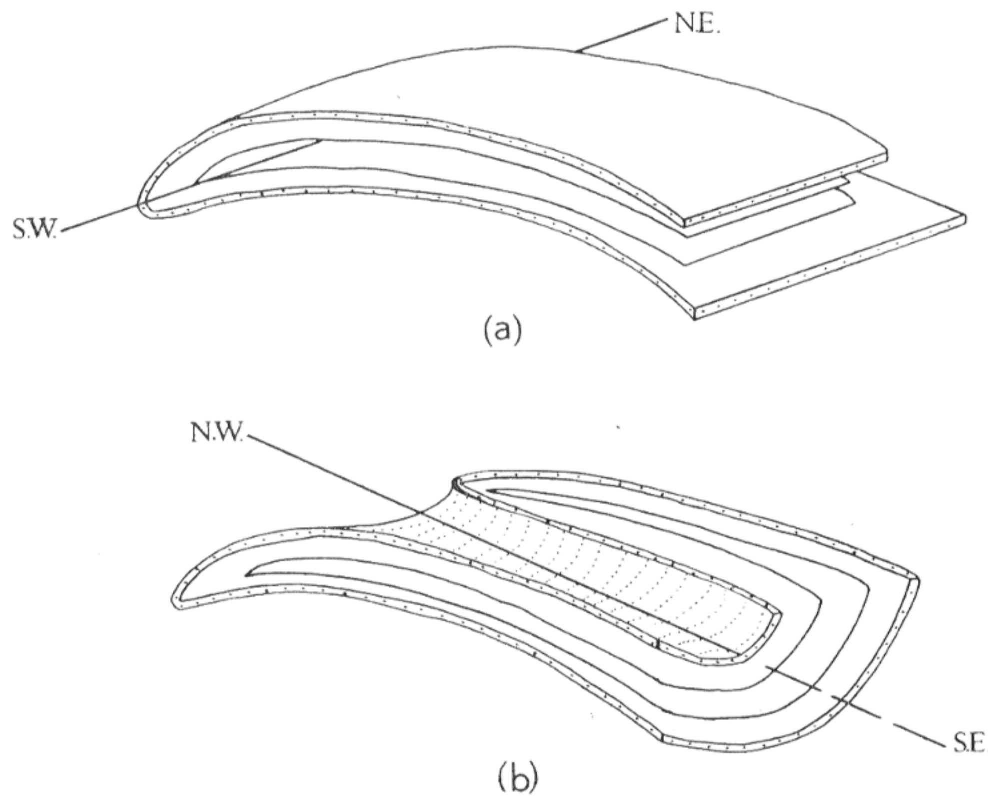


Fig. 8—The formation of the Naigara syncline.

(a) Pelitic schists recumbently folded about a NE.-SW. axis, the fold structure closing to the north-west.

(b) The recumbent fold is refolded about a NW.-SE. axis resulting in the formation of a syncline plunging gently to the north-west.

and the outcrop pattern as displayed by pelitic gneisses at Naigara is distinctive and results from the superposition of open synclinal folding on the nose of the original recumbent fold. Fig. 8 illustrates the type of structure created.

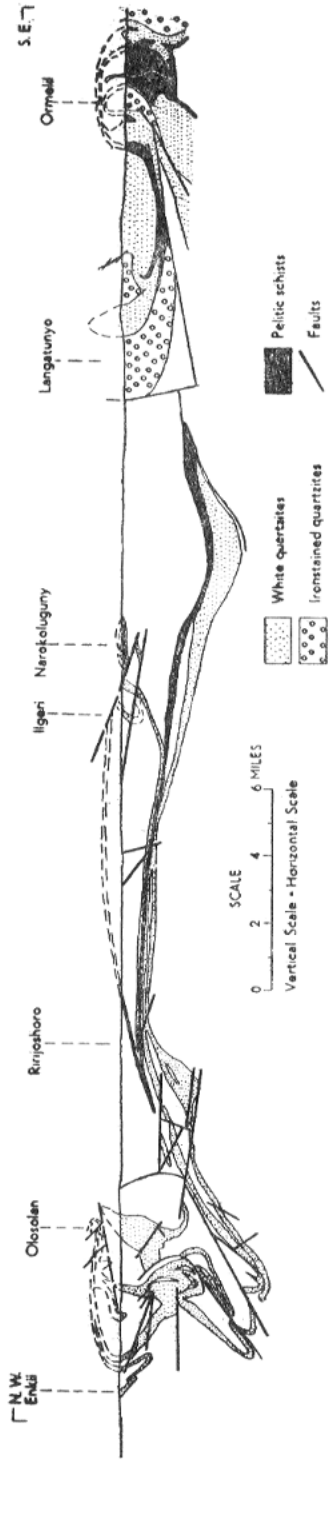


Fig. 9—Cross-section of the Naigara Syncline and adjacent areas

Folding of the sub-horizontal axial surface of the early recumbent structure is suggested by the fact that lineations formed as a result of first-folding plunge towards the axis of the Naigara syncline. The pelitic schists involved in the structure were traced southwards to the neighbourhood of Entasekera and Ol Mesutie where, despite the lack of good outcrops, it is concluded that the southerly extension of the inverted limb of the fold is missing and probably faulted out against the Entasekera fault. The recumbent fold closes downwards at its northern end near Naigara, and part of the upper limb is still preserved as a remnant at Narokoluguny. The form of the recumbent fold is shown in longitudinal cross-section in Fig. 9.

A number of minor folds within the Naigara syncline were seen in quartzites exposed in the gorge of the Lepolosie river at Ririjoshoro. At the eastern end of the gorge the folds in hard white quartzite are overturned to the west, the limbs dipping to the east while a few hundred yards west of this point less competent beds are vertical. Here and at other localities, the minor folding suggests that the direction of dominant pressure acted from the east during the second period of folding. Geometrical analysis of the attitude of foliation indicates apparently simple structures, whereas the spread of lineations and minor fold-axes on a stereographic plot can be accounted for in part by the complexity of the structures due to superimposed folding. Fig. 10 shows stereograms prepared for an area that includes the Naigara syncline and the

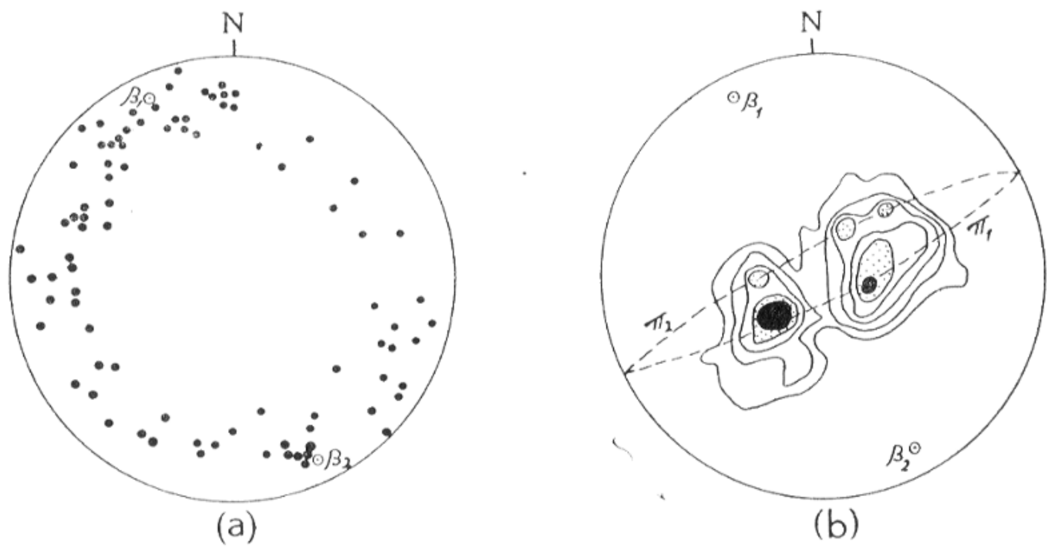


Fig. 10—Stereograms showing attitude of lineations and foliations in the Naigara-Usubugo sub-area.

(a) Stereographic projection of 73 lineations. The poles β_1 and β_2 from (b) are shown.

(b) Stereographic projection of 500 poles to foliation planes contoured at:—2, 3, 4, 5, 6 per cent per 1 per cent area. The great circles Π_1 and Π_2 passing through the poles and the poles β_1 and β_2 to these great circles are also shown.

Usubugo anticline as far south as a line, Ol Mesutie-Entasekera. The stereograms indicate that the axes of the fold trend at 15° west of north and plunge variably north and south indicating culminations and depressions in a simple fold system. Stereograms (Fig. 11) prepared for the Usubugooirobi area to east of Usubugo and as far south as latitude 1° 45′ S., also indicate that Basement System rocks in the north-east corner of the area have been folded about the same generally NNW.-SSE. axes. A swing in the axis of second folding from NNW.-SSE. to north-south, however, has modified the folds and is suggested in the stereograms.

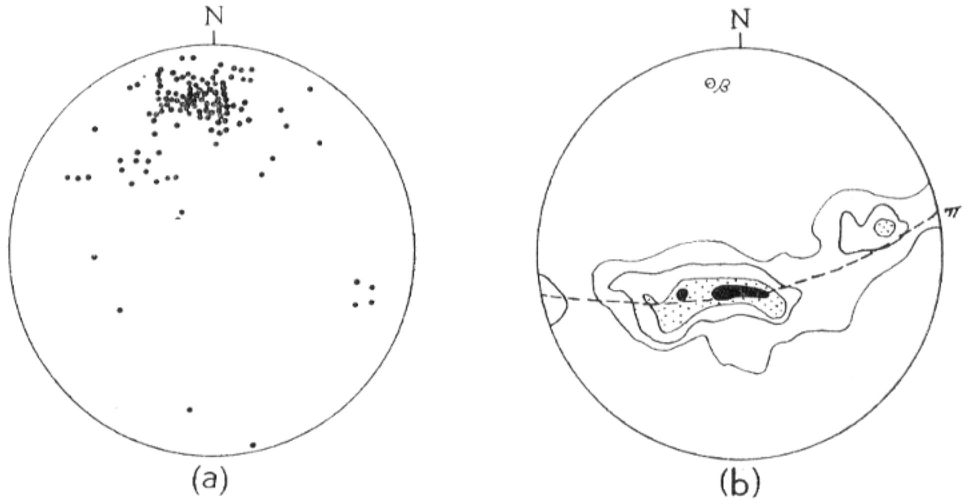


Fig. 11—Stereograms showing attitude of lineations and foliations in the Usubugooirobi sub-area.

(a) Stereographic projection of 108 lineations.

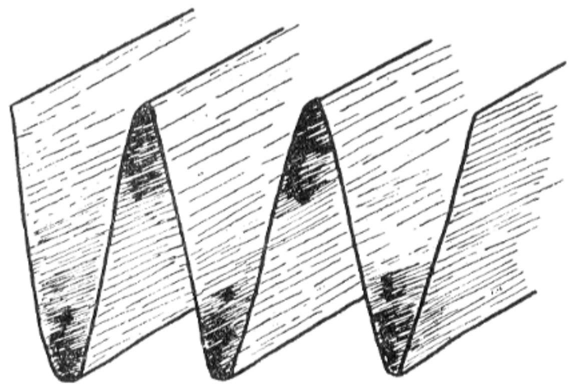
(b) Stereographic projection of 320 poles to foliation planes; contours 2, 4, 6, 8 per cent per 1 per cent area. The great circle Π passing through the poles and the pole β to this great circle are also shown.

(*b*) *Usubugo Anticline*

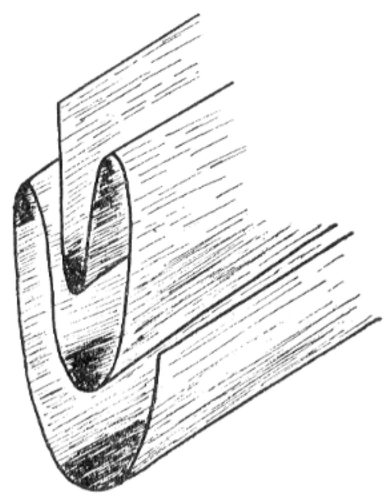
A second major structure of the second episode is the Usubugo anticline. The structure extending from the north-west to the Entasekera fault in the south-east is a large closed fold with its axis parallel to the neighbouring Naigara Syncline and plunging likewise to the north-west. Deformation has been sufficiently intense to cause beds to thicken and thin, while the nose of the fold has been considerably disrupted by faulting. Here the axial traces of first-folds can be correlated with counterparts on the opposite side of the anticline. Although the rocks forming the limbs of this anticline are relatively uncomplicated in the Usubugo area, north-west of Naigara between latitudes 1° 30′ S. and 1° 40′ S. the structures in the nose of the fold are complicated and the pattern again suggests folding about a NW.-SE. axis superimposed upon an early recumbent anticline with a NE.-SW. axis. As was noted in the earlier structure the limbs of the fold when traced in a south-easterly direction are cut out by the Entasekera fault. At Limoroki about one mile south of Morijo Loita small folds disturb the normal NNW.-SSE. foliation pattern and is a relic of the early recumbent folds with NE.-SW. axis. Faulting along axial planes of folds in the quartzites represents movement along shear planes developed in the apices of the folds. South of Ol Mesutie on the Tanganyika border folding in quartzites on the hills at Sukudie, Olorbukoi and Nairebuk was also accompanied by sliding and possibly thrusting. (*See* Fig. 9.)

(*c*) *Ol Koroi* (*involute*) *folds*

In the north-west corner of the area quartzites and associated rocks have been folded about NNE.-SSW. axes. A single white quartzite band provides an excellent marker horizon and the outcrop pattern indicates the involutions due to continuation of folding on the trend of the original NE.-SW. fold axis of a first-formed isocline. The Ol Koroi synform closes to the west outside the present area. (Fig. 12.) The synform now plunges to the NNE. though at Enkii, the axial surfaces of first-formed folds have been modified by the later NW.-SE. folding, resulting in the formation of arcuate axial-fold traces at that locality and a plunge depression shown by the older lineations along the axis of the Naigara syncline. Within the synform a single synclinal fold exhibits a folded axial surface and at Lengarani now gives an impression of an overturned anticline plunging north. Since folding of the axial surface is coaxial with the original fold axis the lineation pattern remains homogeneous and only the form taken by the quartzite outcrop suggests the complexity of the major structure. The trend of the folds is indicated in a stereographic plot of poles to foliation planes and



(a)



(b)

Fig. 12—The formation of the Ol Koroi synform.

(a) Tight folding about NE.-SW. axis.

(b) Continuation of folding about NE.-SW. axis. An original syncline has been refolded about the axis of the synform and on the NW.-SE. side takes the form of an anticline.

lineations (Fig. 13). The trend of lineation is approximately N25° E. and plunging between 10° and 20° to the NNE. The traces of the axial planes of folds between Enkii and the Lepolosie river suggest they had axes that trend more nearly east-west in this part of the area.

The scatter shown by the lineation is attributed to later NW.-SE. folding, the Naigara syncline having affected the rocks of this area as suggested by opposing directions of lineations near Ol Doinyo Lemujai.

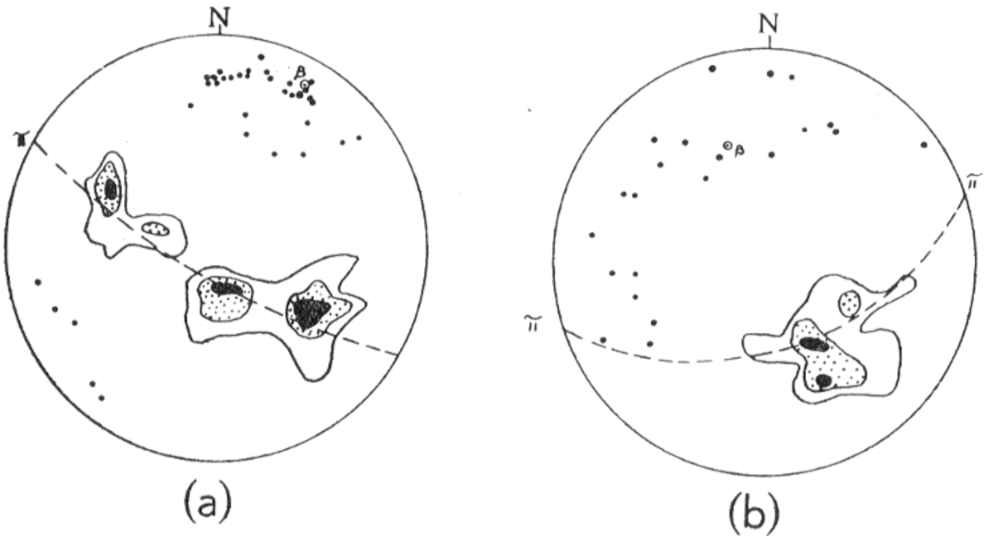


Fig. 13—Stereograms of lineation, poles to foliation planes and axes of minor folds in two sub-areas of the Loita Hills area. The lineations are shown as dots while the poles to foliation planes have been contoured. The great circles passing through the poles and the poles to these great circles are also shown.

(a) NW. corner of the Loita Hills area. Contours, 3, 5, 15 per cent per 1 per cent area.

(b) SE. corner of the Loita Hills area. Contours, 5, 10, 15 per cent per 1 per cent area.

(*d*) *Folds south-east of Entasekera*

Between Entasekera and the southern border a similar style of folding with involutions similar to that seen in the north-west corner of the area can be demonstrated, continued folding occurred on both limbs of a recumbent fold with a NE. to SW. axis closing to the north-west. As the axial planes of the smaller folds are inclined to the north-west it is probable that the axial plane of the recumbent fold was similarly inclined in this locality (Fig. 14). If both limbs of the recumbent fold have been affected by subsequent folding about the same axis, the axial plane of the recumbent fold must, if it plunges, have a sinuous trace. This is seen in Fig. 4, the quartzites forming both limbs of the fold having been intricately folded in the area east of Entasekera. The sinuous trace of the recumbent fold can be traced from Emburkutia to the south-east where it passes beneath the Tertiary volcanic rocks. West of Olomboneg lineations associated with the first period of folding plunge towards the axis of the Naigara syncline, the southerly continuation of which is indicated by a narrow zone of north-westerly plunging lineations between Langatunyo and Olomboneg. A stereogram of poles to foliation (Fig. 13) and the attitude of lineations indicate the complex nature of the structure.

(e) Folds at Enemisikio

The zone of NE.-SW. folds is continued southwards and at Enemisikio in the south-west corner of the area, a system of simple folds on NE.-SW.-trending axial planes with moderately steep south-westerly plunging axes was recognized in granitized rocks. The fold-axes appear to terminate sharply near the quartzite ridge at Ilgeri suggesting a discordance between the granitized rocks and those to the east. The effect of later

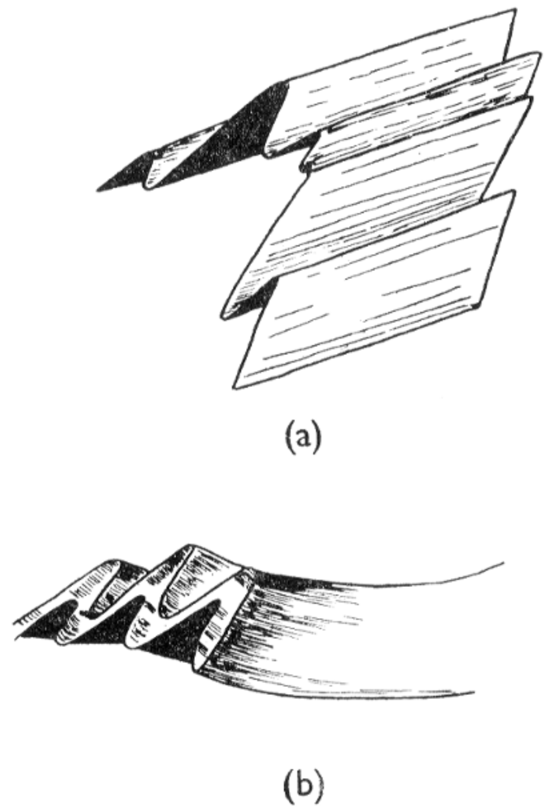


Fig. 14—The formation of the complex folds near Entasekera.

(a) Overturned folds on both limbs of a recumbent first-fold were formed first, all folds having NE.-SW. axes. The limbs of the overturned folds dip to the NW.

(b) The recumbent fold (the overturned folds affecting both limbs) is synclinally folded about a NW.-SE. axis.

folding on these first-fold axial traces is indicated by opposing first lineations in the limbs of the Ngama anticline (*see* Williams, 1964, p. 38), and by the sinuous axial traces of first-folds. Near Ol Mesutie muscovite-rich schists outcrop within an area of granitized rocks due to the arching of first-folds about the axis of the Ngama anticline. A swing in lineation near Paraiko and by minor structures throughout the western and north-western part of the area, are attributed to the effect of a second-fold period on older linear structures, a zone of second NW.-SE.-trending folds being present in Tanganyika, south of the border, as evidenced by air photographs. A great variety of minor structures are associated with this second episode and occur in rocks that were incompetent or show evidence of granitization and migmatization. The migmatites show small-scale slip-folds and puckered folds in numerous outcrops (Plates IV and V). The development of axial plane foliation parallel to the NE.-SW. folds accompanied by minor sliding indicates that many of the minor structures are of the shear-folding type.

In exposures along the river Lemisikio the axial plane foliation is marked by aplitic patches elongated in the axial direction and pegmatitic lenses occupy shear-planes. In the valley of the Orngaeenet and its tributaries are frequent occurrences of minor structures trending approximately parallel to the major folds as shown in Fig. 18. Quartz-felspar rich material introduced into rocks during the period of migmatization has itself been subject to deformation (Fig. 15).

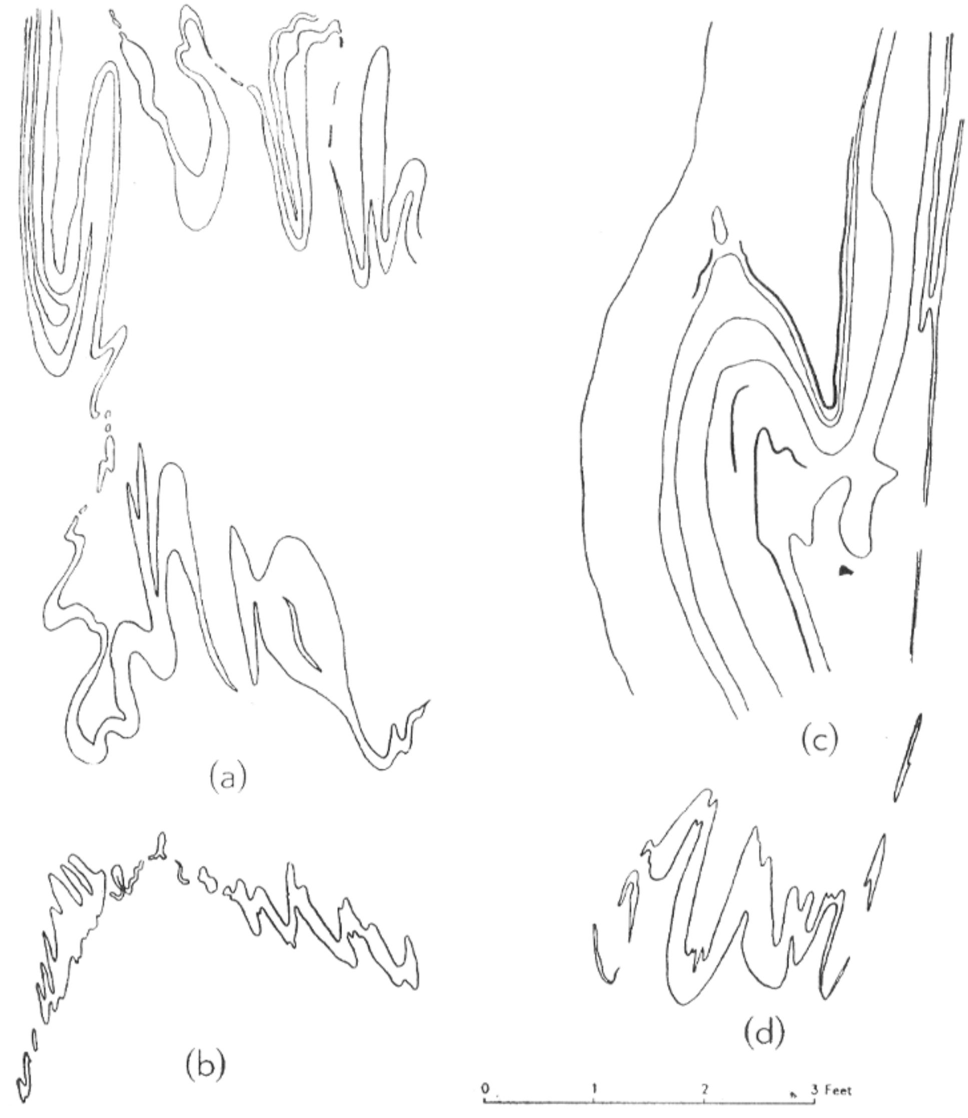


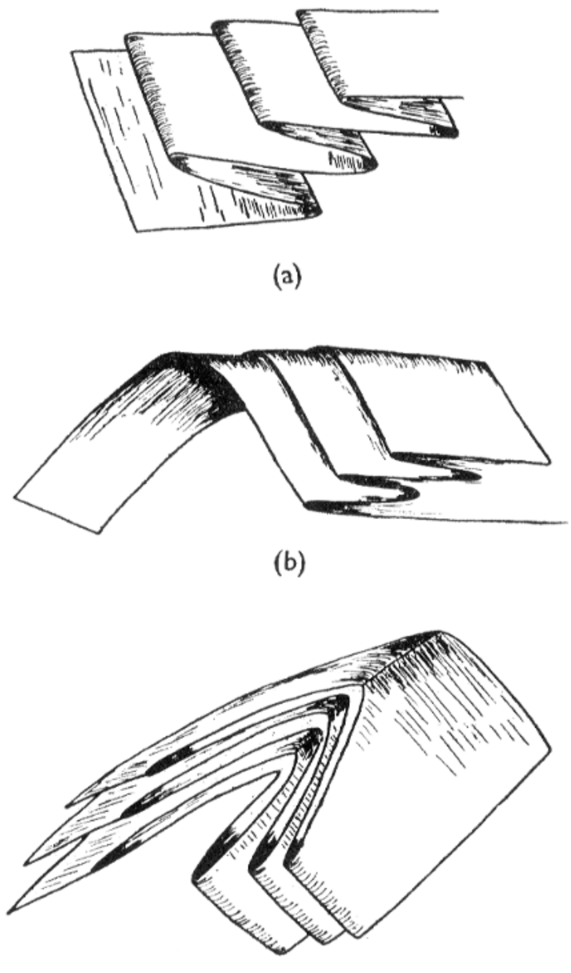
Fig. 15—Contortions in Migmatites.

(a) and (b) Contorted quartz-rich bodies in semi-pelitic migmatites in the river Orngaeenet.

(c) Contortions in banded hornblendic migmatite in the river Enenkoiireroi. The bands represent thin streaks of amphibolite in a biotite-rich host.

(d) A contorted quartzite band in hornblendic migmatite in the river Enenkoiireroi.

The quartz lenses, streaks, and bands or injections have been contorted producing bodies of differing widths and irregular shapes in biotite schists and gneisses. The foliation in the host rock is often obliterated, but the form of the included quartz bodies suggests that the deformation was not entirely haphazard, for the trend of the migmatitic (minor) fold axes is approximately parallel to lineations in major structures produced during the NE.-SW. folding. In all instances the host-rock has been folded with the veins. It is also to be seen that extreme thickening and thinning of bands occurs in any section examined, though generally the same asymmetry is preserved in cross-section, a feature connected with overturning to the west. The form of the minor structures in these rocks suggests that granitization was contemporary with or slightly earlier than the period of NE.-SW. first-folding.



(a)

(b)

(c)

Fig. 16—The formation of the Lengitoto Anticline.

(a) Overturned folds on the limb of a recumbent first-fold, all folds having NE.-SW. axes. The limbs of the overturned folds originally dipped to the SE.

(b) All folds arched about an anticlinal north-south axis.

(c) Later erosion has removed the crest of the anticline, so the trace of the axial planes of the first-folds are now lying sub-parallel to the north-south axis of the second-fold. As the structure plunges north, that is into the plane of the paper, the outcrop on the ground thus simulates a synclinal fold.

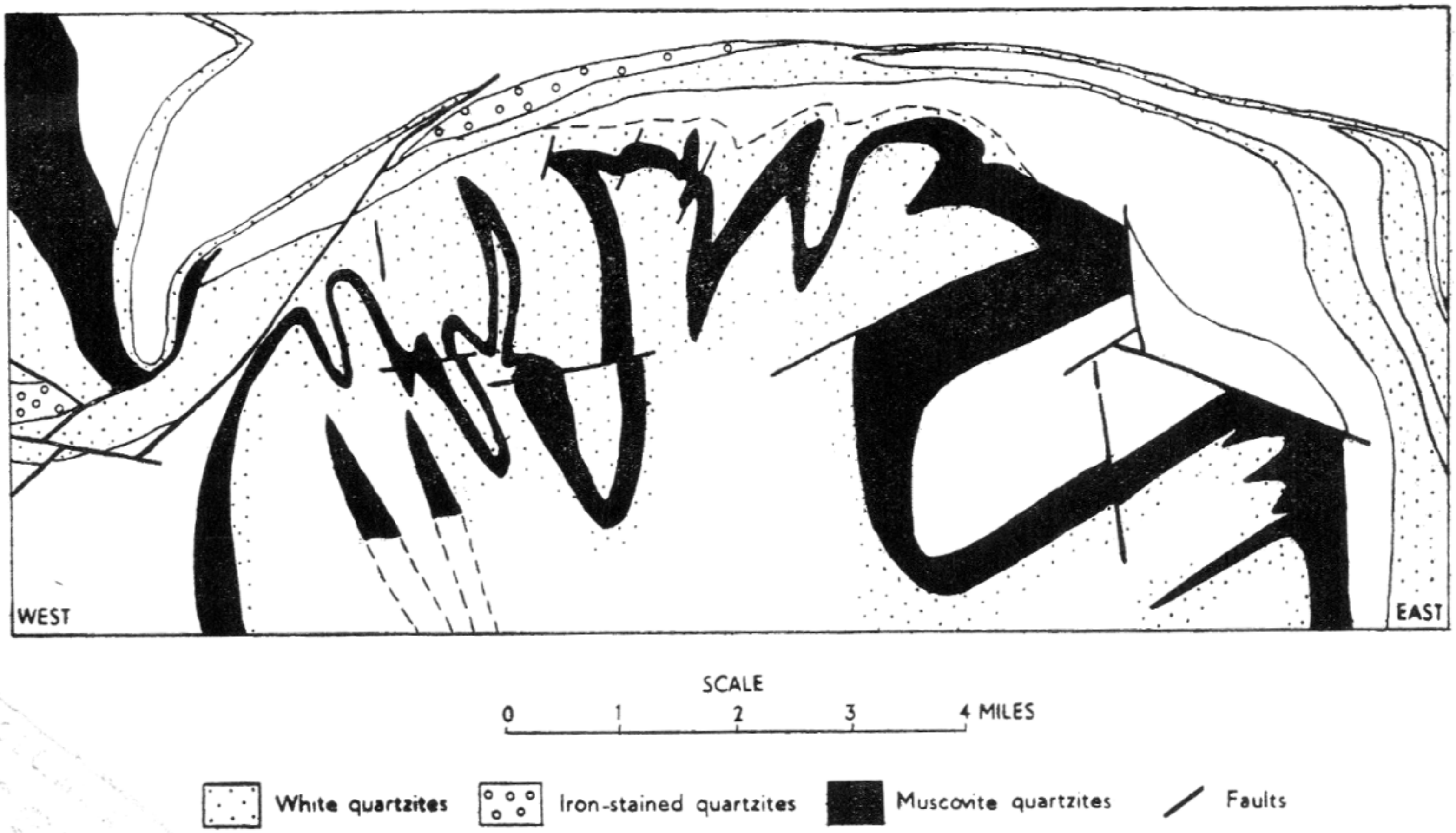


Fig. 17—Tectonic profile of the north-east corner of the Loita Hills area at Usubugooirobi.

(*f*) *Folds at Usubugooirobi. Lengitoto Anticline*

At Usubugooirobi a quartzite succession is characterized by the presence of cross-bedded muscovite quartzites. Mapping in the area and a consideration of the stratigraphy indicates that the junction between core and envelope is discordant. For example at latitude 1° 40′ S. on the eastern border of the area the NE.-SW. trending folds that plunge steeply to the NE. are transected sharply by the north-south trending bands of Ol Doinyo Leanda. This discordance appears as far south as the Oloibortoto River and a similar relationship is seen at the northern end of the Usubugooirobi block between Kipirtilo and Loisiumurto. During the second period of folding the axial traces of first-folds were arched about the Lengitoto anticline (Fig. 16) so that at the northern end of Usubugooirobi the first-fold traces are fan-shaped about the new fold axis, the folds now having steeply dipping limbs.

Such a structure has been figured by Ramsay (1962, p. 474) and results from superposed folds in which the *a* direction of the second fold (Lengitoto anticline) makes a high angle with the axial planes of the first-folds and the axes of the first-folds lie at moderate to high angles with the axial plane of the second-fold. The resulting interference pattern at Usubugooirobi shows similarities to that figured by Ramsay (*op. cit.*, p. 480) and probably represents an area of mutual antiformal culmination between two sets of folds at a wide angle to one another. Thus the quartzite succession at Usubugooirobi probably occurs southwards at least as far as Emburkutia and the Lengitoto anticline passes into the Ormelil antiform, a first-fold structure.

The envelope of rocks passing from Olibeshet through Kipirtilo to Ol Doinyo Leanda on the east side of Usubugooirobi are arched forming the Lengitoto anticline, that plunges northwards. A reversal in plunge direction at the southern end of Usubugooirobi indicates that the rocks are domed, the structure being due to the interference of two fold directions approximately at right angles. A tectonic profile of this part of the area is shown in Fig. 17.

Associated folds that affected rocks of the area between Usubugo and Narosura are attributed to the same fold-movements. To the east of Morijo Loita, however, the quartzites between Naeningujet and Alturato also appear to be discordant because at various localities the quartzites are in contact with different members of the Usubugo anticline. The effects of erosion have been most severe along this line of discordance, as indicated for example on the north-west side of the block near Enkoirie where there occurs a marked gap in the Loita Hills (Plate VIIIa).

(*g*) *Other Folds*

Between the Usubugo anticline and the Naigara syncline occurs a complicated zone of highly folded rocks overturned to the east. Involutions such as those at Ol Doinyo Lormongi, tight synclines south and west of Naigara hill and yet another anticlinal structure at Ol Doinyo Lomru all occur within this zone. Here the direction of axes of minor folds and lineations are not uniform and the presence of small-scale slides, particularly in crumples, together with minor folds in schists and the widespread development of axial plane foliation, suggests that this part of the area has undergone intense deformation, accompanied by irregular movements. The strongly deformed mica schists frequently show structures that are seemingly without any geometrical regularity and are found locally where the structures of both generations of folding are in juxtaposition, notably at Naigara. Away from this zone the second period of folding has generally deformed, and in many instances obliterated earlier structures, though the attitude of a number of lineations are the result of the older movement.

Near Naigara trigonometrical station, disharmonic folding has occurred between adjacent members of the stratigraphic succession and original bedding surfaces between differing lithological types were planes of sliding. The small folds that have affected these rocks represent detached portions of the main Usubugo fold.

(2) Faulting

The Basement System rocks of the Loita Hills have been considerably disturbed and faulting has occurred throughout the various phases of folding. Some faults have small throws and represent minor adjustments, slickensiding and some brecciation being associated with them. Many are probably major joints along which movement has taken place and examples can be seen in the quartzite escarpment at Morijo Loita. Other faults, however, are major fractures that have affected large blocks of country, the most important being the NE.-SW. trending Entasekera and Enkoriga faults. Both occur near major structural discordances though the former is probably a high angle fault down-throwing to the south-east bounding the high line of hills between Entasekera and Emboornarok. It coincides with a major break in the fold pattern near the eastern border of the area, and an apparent culmination in the lineation pattern separating the northerly plunging Lengitoto structure from the south-westerly plunging structures at Emburkutia and Entasekera, and probably slices right through the mountain range, making a large angle with the newer north-south direction of rift-faulting. Renewed movement along the Enkoriga fault is suggested by a thick brecciated pegmatite that occupies large sections of the fault-zone. During folding and faulting tectonic thinning of beds has occurred, for example the Morijo faults that cut the quartzites of the hill range north-east of Morijo Loita (Plate VIII (*a*)). At Emboornarok, near the Tanganyika border, quartzite slices have or are thought to have moved against one another along low-angle slides. It is possible that one of these has cut the quartzites along the Orpusare river, and has controlled erosion so that a deep gorge now transects the Nguruman escarpment at latitude 1° 58′ S. The north-westerly continuation of the slide is represented by the discordance between NE.-SW. structures of Enemisikio and the NNW.-SSE. trending bands that form the western limb of the Naigara syncline. Another prominent fault, the Naigara fault, downthrowing rocks to the east, which may partly represent a dislocation between adjacent fold belts, bounds the western edge of the Naigara range, crushed rocks and disturbed beds exposed in river-courses marking the line of the fault. At its northern end it is displaced by the Enkoriga fault, its continuation being represented by fault zones between Olenalangitomon and Ol Doinyo Loloponi. Many of the faults are clearly visible on air photographs and undoubtedly numerous others occur in these more poorly exposed parts of the area. Blocks of breccia in the valley of the Narosura river suggest that they were derived from the Narosura fault to the west, which probably extends further north than is shown on the map but is concealed by a thick soil cover. A highly brecciated rock was found *in situ* two miles north-east of Pololet and although indicating a fault of considerable magnitude it could not be traced for more than a few yards.

(3) Tectonic Synthesis

The structural data collected from different parts of the area indicate great structural complexity, which will be better understood after more detailed mapping beyond the scope of this present report has been undertaken. It is possible to come to some general conclusions and to propose a sequence of tectonic events that affected the rocks of the Loita Hills area. Any tectonic interpretation must be valid when applied to neighbouring areas and possibly over the greater part of western Kenya, already a considerabe measure of assessment has been reached in a recent synthesis (Saggerson *et al.*, 1960).

It has been pointed out that migmatization of Basement System rocks of the Loita Hills area took place during the earlier movement period. Metamorphism was probably long-continued, however, and culminated in granitization. Pelitic rocks involved in the deformation have reached a high grade of metamorphism with few or no retrogressive stages being recognized, which suggests that regional metamorphism occurred throughout the periods of folding and was not wholly an earlier phenomenon.

Towards a better understanding of the structure of the area the following simplified stratigraphical succession is recognized and is shown in more detail on Fig. 4.

Olosolan quartzite.
Usubugo (gritty) quartzite.
Olibeshet quartzite.
Naigara pelitic and semi-pelitic group.
Muscovite quartzites of Usubugooirobi.
Morijo quartzite.
Olemasher (gritty) quartzite.

Consideration of the structure and local succession in different parts of the area suggest that despite variations in thickness of the original sediments some beds are now separated by tectonic rather than lithologic breaks. Further, because of the interference of superposed deformations, beds in one locality are not yet exposed or have been removed by erosion. Pelitic schists forming part of the limbs of the Naigara syncline have only been noted at Bitin on the eastern side of the Usubugo anticline and at this locality mapping strongly suggests discontinuities between adjacent beds due to strong shearing movements or slip. Elsewhere the pelitic rocks of the Naigara area are probably the lateral equivalents to similar rocks exposed west of Olomboneg near the Tanganyika border.

In the south-western part of the area the semi-pelitic rocks of Enemisikio are considered to be equivalent to those within the pelitic schist envelope at Naigara and are here associated with quartzites exposed at Pololet and south of Ol Mesutie which are equivalent to the Morijo quartzite band.

The sequence of events that affected the crystalline rocks of the area may be summarized as follows:—

(1) Recumbent folding about NE.-SW. axes. Granitization culminating in migmatization which was most intense south of Naigara. The principal structure was probably a single recumbent fold the limbs of which were similarly folded. The upper limb of the fold is represented by the majority of the rocks of the area but those outcropping between Pololet and Olomboneg form the lower limb of the recumbent structure.

(2) Open folding about approximately NW.-SE. axes affected the greater part of the Loita Hills area. Major structures include the Naigara syncline, the Usubugo anticline and the complex fold-system that affected the whole of the Usubugooirobi-Emburkutia-Ormelil range. Rotation of the direction of folding and the development of N.-S. trending folds that include the Narosura syncline, and the Lengitoto anticline. The formation of the Morijo, Olosolan and Olibeshet slides. The slight change in direction of the folds from NW.-SE. to N.-S., i.e. non-parallel folds, is similar to that reported from other orogenic zones where intersection of fold belts are described.

It should be pointed out at this stage that more detailed work is required to prove whether the north-westerly closing recumbent folds are synclinal or anticlinal, for if the axial plane of a recumbent anticline is arched about an axis parallel to the axis of that fold the nose of the recumbent fold will appear to be synclinal. The structural history suggests that major discordances have resulted from sliding during (disharmonic) folding while the effects of refolding have been locally intense and in some parts have obscured the earlier structures. Recumbent folding has been recognized in the neighbouring area to the west (Williams, 1964) and similar structures have recently been mapped in north-west and south-east Kenya.

Throughout this area and the Mara River-Sianna area to the north-west (Williams, 1964), zones of dominant first-folds with approximately NE.-SW. axes with alternate zones of dominant second-folds with approximately NW.-SE. axes result in typical interference patterns produced by two successive foldings. The presence of numerous quartzite bands that can be traced for large distances despite the intricacy of the folding, have greatly assisted the mapping and subsequent structural interpretation of the Loita Hills area. The interfering fold-system can have been produced either by a single strain or by superimposed unrelated strains. The presence of more than one structure does not mean that they have been necessarily produced during separate orogenies for they may have been produced simultaneously or represent separate phases of the same orogeny. Ramsay (1962, p. 473) gives the criteria that might be used to separate fold patterns produced by one deformation from those produced by two and it is considered that the structures in the present area are due to the superposition of independent deformations that were widely separated in time.

Though refolding and cross-folds have been described from other parts of Kenya and while the trends of fold axes in the Loita Hills area are approximately parallel to fold axes both in Basement System rocks in areas to the east of the Rift Valley in north-west Kenya and in rocks of the Nyanzian-Kavirondian System (to the north-west of the present area) (e.g. Shackleton, 1946, p. 42) the style of folding and its complexity is dissimilar from other parts of the country. Further metamorphic rocks characterized by a thick succession of quartzites is probably unique in Kenya and though comparisons may be made between similar rocks in north-west Kenya and the Namanga-Bissel area of Southern Kenya (Joubert, 1957) it is possible that the metamorphic rocks of the present area form a separate series within the Precambrian of Kenya. Whether deformations that affected the rocks of the Loita Hills area are of similar age to those that affected other Precambrian rocks elsewhere must for the present remain unsolved.

2. Tertiary and Quaternary Structures

West of Lake Magadi the Gregory or Great Rift Valley is flanked by the Nguruman escarpment, a superb fault-scarp part which comprises the eastern border of the Loita Hills area (Plate VII). The escarpment has formed as a result of movement along north-south trending faults, the evidence suggesting that these are normal faults down-throwing to the east. Uhlig (1907, p. 489) considered that at its southern end, near Ol Doinyo Sambu, the main fault passed into an overthrust, and cited as evidence quartz-mica schists overlying volcanics, the schists having been metamorphosed during the period of thrusting. Bailey Willis (1936, p. 263) discounted the time of metamorphism of the Basement System rocks, and considered that Uhlig's evidence concerning the presence of an overthrust "admits of no doubt". The present author is not in agreement, and although the exact locality was not visited suggests that the occurrence of schists $2\frac{1}{2}$ km. to the south-east of the main outcrop at Olomboneg indicates an inlier of Basement System rocks surrounded by volcanics, or that volcanics have been intruded along bedding planes in volcanics or Basement System rocks that exhibit shearing and foliation typical of the rocks of this area, thus giving the impression of schists overlying lavas in what looks like a thrust zone.

Regional uplift and peneplanation in Mesozoic and Tertiary times led to the formation of the end-Cretaceous and sub-Miocene peneplains that were subsequently warped along an approximately north-south axis from Naigara in the north to Emboornarok in the south (Fig. 2). The arching probably represents the first movement that led to the creation of the Rift Valley in this part of Kenya, and is comparable with similar movements that affected the sub-Miocene peneplain along the shoulders of the Rift in other parts of the Colony. This arching was followed by a period of volcanic activity when melanephelinites of Kishalduga and ankaratrites of Olomboneg, probably of Pliocene age, were extruded from vents and fissures aligned along north-south fractures and faults. No evidence was seen to indicate that these lavas poured down an old escarpment as suggested by Dixey (1956, p. 25). This volcanicity was followed by the first stage of faulting of the Nguruman escarpment, and was probably contemporaneous with the formation of the first Rift faults in southern Kenya. The major fault that forms the escarpment was named the Sonjo fault by Uhlig (1907), and trends approximately north-south along the eastern border of the area, where it is concealed by Kirikiti Basalts, and swings to a south-westerly direction west of Ol Doinyo Sambu (Plate III (*a*)) to continue into Tanganyika where it bounds the Sonjo scarp. This Sonjo fault has a maximum throw to the east of nearly 4,000 feet in the south-east corner of the area, but the throw probably diminishes northwards. It has been noted in an earlier section (page 30) that the Kipurses fault is a branch of this first major fault and movement along it was responsible for the westerly dip of the nephelinites at Kishalduga. A later period (Pliocene) of volcanic activity resulted in the extrusion of Kirikiti Basalts that covered the lower part of the pre-existing fault scarp (cf. Baker, 1958, p. 16).

In early Pleistocene times a renewal of volcanic activity led to the eruption of the Lengitoto Trachytes, fissure eruptions that poured out probably along pre-established north-south fractures and the associated Kipurses fault, the lavas overlapping onto the gently tilted nephelinites. A later movement along this fault threw down the trachytes 500 feet to the east, so forming the scarp that bounds Naitiami and Kipurses (Plate II (*a*)). The extravasation of ignimbrites, tuffs and lavas from scattered vents in the northern part of the area coincided with the period of most violent volcanic activity, the vents being situated at intersections of old faults and fractures in those parts of the area not immediately adjacent to the Rift Valley. The Naitiami fault probably pre-dated the main Kirikiti fault (Baker, *op. cit.*, p. 62), easterly branches of which further down-faulted the trachytes east of the Lengitoto plateau (six miles east of Kipurses). Displacement along this fault-zone may have been accomplished in two distinct movements for Baker (ibid., p. 62) has shown that a later movement on the second (Kirikiti-Nguruman) fault east of the Sonjo fault but parallel to it gave rise to the Kirikiti platform (Plate II (*b*)). The lavas of the platform slope gently southwards beneath the Pagasi pebble-beds, which lie at an altitude of about 2,300 feet, and it is possible that part of the movement on this second fault tilted the lavas thus exaggerating the throw of the Sonjo fault. That a renewed movement occurred on this fault is shown by the preservation of triangular facets on truncated spurs of the highly dissected Nguruman escarpment between Ol Doinyo Sambu and Lisudwa, a hill just north of latitude 2° 00′ S. (Plate VIII (*b*)). The Nguruman fault passes to the east of the present area where it probably dies out near Lake Natron.

A third period of volcanic activity in middle Pleistocene times resulted in the formation of Ol Doinyo Sambu, a composite volcanic cone that rises majestically from the floor of the Rift Valley west of Lake Natron (Plate III). A fault has sliced through the volcano down-throwing its eastern half to a level beneath Lake Natron (altitude 2,067 feet) (Plate III (*b*)). The topmost lava of Ol Doinyo Sambu occurs at a height of about 4,250 feet at Mima, indicating a minimum throw of 2,150 feet on the Ol Doinyo Sambu fault. The Basement System rocks which comprise the sub-volcanic metamorphic foundation must, therefore, lie at least 2,200 feet beneath the lake, though southwards near the centre of the lake, is probably at a much deeper level. The Ol Doinyo Sambu fault, named the *Ostafrikanische Bruchstufe* by Uhlig (1907), dies rapidly to the north at about latitude 2° 00′ S. Rejuvenation of faulting along the Ol Doinyo Sambu fault or associated north-south faults not exposed is probably responsible for truncation of spurs along this part of the Nguruman Escarpment (Plate VIII (*b*)). Both Uhlig (*op. cit.*, p. 487 *et seq.*) and Bailey Willis (1946, p. 260) comment on this striking fault-scarp, the latter author correctly describing and illustrating (Plate LI) the faulting west of Lake Natron to be offset *en echelon* stepping westwards from north to south.

Although the Rift Valley generally follows the Precambrian structures of the Nguruman escarpment the warping of the sub-Miocene peneplain and the presence of overlying lavas on hill summits that formed part of the pre-rift topography indicates the initiation of rifting probably in Miocene or lower Pliocene times.

Gregory on the other hand considered the rift faulting to have commenced in pre-Miocene times (Gregory, 1921, p. 364). It has now been shown that the Miocene Kapiti Phonolite is affected by the east rift fault, while in the Kisumu area the faults bounding the Kavirondo Rift Valley were considered by Shackleton (1952, p. 387) to be of post-sub-Miocene age (Saggerson, 1952, p. 75). The period of rifting was intermittent, therefore, and faulting with extrusion of lavas took place at intervals from Miocene times to the present day.

VII—MINERAL DEPOSITS

The inaccessibility of the area and its remoteness from the principal centres of population precludes the area from being of any immediate economic importance for mineral production for many years to come. Although a number of different minerals and rocks were observed they are of scientific interest only. Mineral occurrences are indicated on the coloured geological map.

1. Quartzite

A large proportion of the Basement System rocks of the area are composed of quartzites many of which are heavily iron-stained or contain impurities that render them unsuitable for ceramic purposes. Some bands, however, consisting of dense white quartz of low iron content, might prove suitable for the manufacture of glass and refractories but such bands tend to be exceedingly hard and uneconomical to crush. Crushed quartzite can also be used as an abrasive, road-metal, fill or base-course for heavy-duty roads, aggregate for concrete, building-stone and grinding-mill pebbles, for which purpose it can easily be obtained at many localities.

2. Building-stone

Grey tuff of pleasing appearance is being extracted from a number of quarries along the river Narosura, east of the main Narok road. The tuff, which is easy to work, occurs in bands approximately 10 ft. to 30 ft. thick and after rough dressing is transported by road to Narok and Entasekera where it is used for building. At present the demand is small though the reserves of rock are considerable and will meet the local needs for many years.

3. Sand

No extensive concentrations of sand are available in the area but numerous small rivers contain deposits of clean sand suitable for building. These sands originate from the quartzites of the Loita Hills and are most easily obtainable from those streams that cross the Narok-Tanganyika road near Narosura. These reserves were noted in the Report on the Development Committee for 1946 (Vol. 2, p. 67). Sand for building in Narok is being extracted from these rivers at the present time.

4. Crushed Stone

Supplies of crushed stone suitable for road metal, lightweight aggregate and as aggregate for insulation of buildings can be readily obtained from the outcrops of tuff and lava in the north-eastern part of the area.

5. Kyanite and Sillimanite

Kyanite and sillimanite occur in numerous bands in the western half of the area, also four miles south-east of Narosura and in the south-eastern corner of the area. Although kyanite is occasionally concentrated in lenses, often forming more than 30 per cent of the rock, the deposits have no economic significance on account of their remoteness and low kyanite content.

6. Other Minerals

A single occurrence of *copper* was seen in a breccia outcropping seven miles north-west of Ol Mesutie in the south-western corner of the area. The copper mineral, bright green malachite, is sparsely disseminated in the rock and therefore of academic interest only.

Magnetite occurs in thin streaks and lenses in the quartzites and quartz-muscovite schists, and forms a major constituent in a thin band of magnetite schist outcropping in the river Lepolosie south-west of Naigara. The mineral also occurs as small aggregates in pegmatites. The presence of *ilmenite* was confirmed in a number of localities and it is possible that this mineral may be intergrown with the magnetite as well as occurring independently.

Tourmaline frequently occurs in schists and gneisses of pelitic origin, a quartz-muscovite schist in the river Lairaka near Ririjoshoro being notable. Tourmaline "suns" and aggregates, with crystals often measuring up to 2 in., are found in *quartzites* and pegmatites. All the tourmaline examined in the area was the black variety (schorl) and therefore of no economic importance.

Asbestiform amphibole occurs in hornblende-rich gneisses two miles south of Naigara. The poor quality of the fibre and restricted occurrence preclude the mineral from being of economic interest.

Felspar and *mica* are frequently concentrated in pegmatites, particularly in the western part of the area. Usually the mica occurs in small books and rarely of sufficient size or purity to warrant detailed prospecting.

A single lens of *wollastonite* was discovered in the river Olkejuasur two miles south of Naigara. The mineral forms more than 50 per cent of the rock.

Garnet is present in small quantities in a few isolated occurrences. Large boulders of garnetiferous rock 9 in. in diameter were seen in the bed of the river Lekuruki, two miles north-east of Olosolan. The boulders, which are massive, probably represent portions of eroded garnetiferous *boudins*.

Lateritic ironstone (murram) forms a capping to Basement System rocks near stream courses where movement of surface and groundwater is at a maximum. No deposits of sufficient size suitable for quarrying as road-metal were seen during the survey.

Altered mica-schists at Osarara on Usubugo and kyanite schists and gneisses in the river Orpusare are altered to multi-coloured soft, friable rock and clay that contain well-developed crystals of *kaolin*. Little use can be made of these deposits due to their relative inaccessibility.

No radio-active minerals were discovered during the survey but a slight increase in radio-activity was noticed generally over the granitized rocks between Naigara and Ririjoshoro.

7. Water-supplies

Unlike many other parts of Kenya, the Loita Hills area has few water-supply problems. Many streams and rivers have a permanent or near-permanent flow and only where these discharge onto the plains do they become seasonal water-courses.

The few hundreds of Masai present in the area maintain themselves and their cattle without moving great distances even during periods of drought. Thick forests on steep slopes prevent a rapid run-off thereby regulating the discharge of water at springs and providing a constant supply of water to streams rising in the forests. A number of softer muscovite quartzites and pelitic rocks interbanded in the harder quartzites also provide good aquifers. The quartzites are broken by numerous faults, fractures and joints that freely transmit water, so providing a nearly constant flow as at Narosura, Naigara and Entasekera. Another excellent aquifer is the junction of the volcanic with the underlying Basement System rocks, which were considerably weathered before the deposition of the tuffs and lavas. This is best developed at Narosura. Streams and rivers are constantly replenished by water leakage from the underground reservoir through numerous springs and seepages. Ground-water leaving the forest region of Usubugooirobi emerges in large streams that flow east and west either down the Nguruman escarpment or into the Olngakualala swamp. Those streams flowing eastwards to the Rift Valley include the rivers Narosura, Orkejulengitoto (and neighbouring streams), Endosapia, Oloibortoto and Endooma, with a plentiful water-supply in their upper reaches, but become dry river-courses a few hundred yards from the foot of the escarpment. The flow of the river Narosura where the main road crosses the river was measured as 3.2 cusecs during a dry period in 1959. The lack of water in the lower parts of the river-courses suggests that the rivers replenish the groundwater in the alluvial cover at the base of the hills. A large proportion of water discharging into the Olngakualala swamp either as ground-water or as surface water is lost by evapo-transpiration, though groundwater leakage probably recharges the headwaters of the east-flowing Oloibortoto and Orkejuasur rivers, the latter being a principal tributary of the Orkejulesai near Entasekera. The flow from the springs feeding the Orkejuasur river during a dry period in 1959 was measured as 0.5 cusecs. The swamp has the appearance of a small area of inland drainage but the absence of salts indicates a sub-surface loss of water.

The heavy rains during the months of April and May cause the permanent rivers such as the Orido and Orngaeenet and their tributaries to flood westwards. This seasonal flooding diminishes rapidly and is completely absorbed within a few miles of the hill regions where it disappears beneath the alluvium. Many rivers have a constant flow except during the monsoon periods when the flow becomes variable. Only after long periods of exceptionally dry weather, such as during 1952-54, do these rivers become almost dry.

The absence of boreholes in the area is due to the adequacy of surface waters, and even in the driest years it is possible to obtain supplies in the larger rivers. A borehole (C1751) was drilled at Morijo Loita by the African Land Utilization Survey. A seepage of water was struck at 75 ft., and further drilling to a depth of 302 ft. without success necessitated abandonment of the borehole. A near-by spring now provides the needs for a school and is a cattle-watering centre for the surrounding area.

Many springs were seen during the survey and without doubt others exist, particularly along the bases of hills or in close proximity to fault-zones. Water-holes on the plains and small, natural rock-catchments in the hills serve the needs of Masai cattle and the indigenous animals for limited periods of the year. Two large water-holes at Alturato, south-east of Morijo Loita, the largest one 1,000 ft. in length, provide more permanent supplies.

A number of tepid and nearly cold saline spring seepages near the line of the Ol Doinyo Sambu fault occur at the north-west end of Lake Natron where the water from these springs forms saline efflorescences on the barren mud flats (Plate III (*b*)). The waters of these springs are clear at their point of emergence but are alkaline judging from their taste and smell. Like those in the Magadi area (Baker, 1958, pp. 51-55), coloured algae are common around the small pools at the spring sources.

Most of the river waters of the area were found to be suitable for drinking and pleasing in appearance. In a few cases the water is discoloured and of these (e.g. Morijo Loita) some are slightly iron-stained, which does not affect the potability. No reports of undrinkable saline water in the area have been received except for the temporary stream near the north-western corner of Lake Natron. Even the waters from the hot-springs situated in the river Orkejulesai near Emboornarok have a pleasing taste, suggesting the presence of small quantities of carbon dioxide. The strong and excellent appearance of the teeth, even in the older members of the Masai tribe, suggests that the waters have no deleterious effect.

An analysis of water taken from the river Orkejuasur at Entasekera gave:—

	Parts per 100,000, *except the fluorine figures which are parts per million*
Alkalinity (as $CaCo_3$)	
Carbonate	Nil
Bicarbonate	3·4
Ammonia (saline)	trace
Chlorides as Cl	0·3
Sulphates as SO_4	trace
Nitrites	present
Nitrates	Nil
Iron	0·16
Silica	2·0
Total hardness	2·0
Carbon dioxide	present
Total solids	12·0
Fluorides	0·7
pH	6·5

Analyst: Government Chemist, Kenya.

This analysis indicates a water highly suitable for drinking purposes.

Schemes for irrigating the land or damming streams to give a ready and constant water-supply have not been found necessary. A number of small vegetable plots sited along permanent river-courses are to be seen at Narosura and near Emboornarok but these are in partial disuse mainly due to the lack of sufficient local demands for vegetables and maize.

The area appears to have agricultural potential and would be particularly suited to ranching, while close to certain river-courses crops could be grown to provide food. The generally poor soil, however, would hinder any large-scale projects. More widespread water-supplies would be necessary, but if required little difficulty is envisaged in providing these.

VIII—REFERENCES

Baker, B. H., 1958.—"The Geology of the Magadi Area." Report No. 42, Geol. Surv., Kenya.

——— 1963.—"The Geology of the South-Magadi Area." Report No. 61, Geol. Surv., Kenya.

Behrend, F., 1918.—"Die stratigraphie des östlichen Zentralafrika." Beiträge zur geologischen Erforschung der Deutschen Schutzgebiete, Vol. 15.

Bullard, E. C., 1936.—"Gravity Measurements in East Africa." *Phil. Trans. Roy. Soc. Lond.*, Vol. 235, Series A, pp. 445-531.

Clifford, T.N., 1958.—"A note on Kyanite in the Moine Series of Southern Ross-shire and a review of related rocks in the Northern Highlands of Scotland." *Geol. Mag.*, Vol. XCV, pp. 333-346.

Dixey, F., 1956.—"The East African Rift System." Bulletin Supplement No. 1, *Col. Geol. Min. Res.* Supplement Series, Vol. 235, pp. 445-531.

Edwards, D. C., 1940.—"A Vegetation Map of Kenya with particular reference to Grassland Types." *Journ. Ecol.*, Vol. XXVIII, pp. 377-385.

Exley, C. S., 1959.—"Magmatic Differentiation and Alteration in the St. Austell Granite." *Quart. Journ. Geol. Surv.,* Vol. CXIV, pp. 197-230.

Fischer, G. A., 1884.—"Bericht über die in Auftrage der Geographischen Gesellschaft in Hamburg unternommene Reise in das Masai-Land." *Mitt. Geogr. Ges.,* Hamburg, 1882-1883, Pt. 1, Allgemeiner Bericht, pp. 36-99.

——— 1885.—"Ibid Pt. 2, Begleitworte zur Original-Routenkarte." pp. 189-237.

——— 1895.—"Am Ostufer des Victoria-Njanse." Petermanns Geogr. Mitteilungen, Vol. 1.

Finckh, L., 1903.—"Die Trachydolerite des Kibo und die Kenya." Zeitscher. d. Deutsch, Geol. Ges. Bd. 55, Mon. Ber S. 14.

Francis, G. H., 1956.—"Facies Boundaries in Pelites at the Middle Grades of Regional Metamorphism." *Geol. Mag.,* Vol. XCIII, pp. 353-368.

Gregory, J. W., 1894.—"Contributions to the Physical Geography of British East Africa." *Geogr. Journ.,* Vol. IV, pp. 505-514.

——— 1896.—"The Great Rift Valley."

——— 1920.—"The African Rift Valleys." *Geogr. Journ.,* Vol. 56, pp. 13-47 and 327-328.

——— 1921. "The Rift Valleys and Geology of East Africa."

Johannsen, A., 1938.—"A Descriptive Petrography of the Igneous Rocks."

Joubert, P., 1957.—"Geology of the Namanga-Bissel Area." Report No. 39, Geol. Surv., Kenya.

Kaiser, A., 1898.—"Die Schöllersche Expedition in Aequatorial-Ost-Afrika." *Bericht. St. Gall Naturwiss Ges.,* 1896-1897, pp. 314-342.

Kohlschütter, E., 1911.—"Uber den Bau der Erdkruste in Deutsch-Ostafrika." Vorlaufige Mitteilungen Nachr. delk. Ges. der Wiss zu Göttingen.

Krenkel, E., 1922.—"Die Bruchzonen Ostafrikas."

——— 1925.—"Geologie Afrikas."

Kunzli, E., 1901.—"Die petrographische Ausbeute der Schöllerschen Expedition in Aequatorial-Ostafrika (Masailand)." *Viertel jahr. naturf. Ges. Zurich,* XLVI, pp. 128-172.

Matheson, F., 1965.—"Geology of the Kajiado Area." Report No. 70, Geol. Surv., Kenya.

Mügge, O., 1885.—"Untersuchung der von Dr. G. A. Gischer gesammelten Gesteine." *Mitt. Geogr. Ges.* Hamburg, 1882-1883, pp. 238-264.

Parkinson, J., 1913.—"On a group of Metamorphosed Sediments situated between Machakos and Lake Magadi in British East Africa." *Quart. Journ. Geol. Soc.,* Vol. LXIX, pp. 534-539.

Pugh, J. C., 1955.—"Isostatic Readjustment and Pediplanation." *Quart. Journ. Geol. Soc.,* Vol. CXI, pp. 361-369.

Ramsay, J. G., 1962.—"Interference Patterns produced by Superposition of Folds." *J. of Geol.,* Vol. 70, pp. 466-481.

Saggerson, E. P., 1952.—"Geology of the Kisumu District." Report No. 21, Geol. Surv., Kenya.

——— *et al.,* 1960.—"Cross-folding and Refolding in the Basement System of Kenya Colony." Proceedings of the 21st Int. Geol. Congr. 1960, Part XVIII, pp. 335-346.

——— 1962.—"Geology of the Kasigau-Kurase Area." Report No. 51, Geol. Surv., Kenya.

——— and Williams, L. A. J., 1964.—"Ngurumanite from Southern Kenya and its bearing on the Origin of Rocks in the Northern Tanganyika Alkaline District." *J. of Petrol.,* Vol. V, pp. 40-81.

Schoeman, J. J., 1949.—"Geology of the Sotik Area." Report No. 16, Geol. Surv., Kenya.

Shackleton, R. M., 1946.—"Geology of the Migori Gold Belt and Adjoining Areas." Report No. 10, Geol. Surv., Kenya.

——— 1951.—"A Contribution to the Geology of the Kavirondo Rift Valley." *Quart. Journ. Geol. Soc.,* Vol. CVI, pp. 345-392.

Smith, G. E., 1907.—"From the Victoria Nyanza to Kilimanjaro." *Geogr. Journ.,* Vol. XXIX, pp. 249-272.

Smith, W. Campbell, 1931.—"A Classification of some Rhyolites, Trachytes and Phonolites from part of Kenya Colony, with a note on some Associated Basaltic Rocks." *Quart. Journ. Geol. Soc.,* Vol. LXXXVII, pp. 212-258.

Spink, P. C. and J. A. Stevens, 1946.—"Notes on the Magadi Section of the Eastern Rift Valley." *Geogr. Journ.,* Vol. CVII, pp. 236-241.

Stamp, L. D., 1953.—"Africa. A study in Tropical Development."

Turner, F. J., 1948.—"Mineralogical and Structural Evolution of the Metamorphic Rocks." Geol. Soc. Amer., Mem. 30.

Uhlig, C., 1907.—"Der sogennante Grosse Ostafrikanische Graben zwishchen Magad (Natron-See) und Laua ya Mueri (Manyara-See)." *Geog. Zeit,* Leipzig, Vol. XIII, pp. 478-505.

——— 1909.—"Mitteilungen aus den Deutschen Schutzgebieten." Erganzungsheft No. 2. Die Ostafrikanische Bruchstufe. Vol. 1.

——— 1912.—"Beitrage zur Kenntis der Geologie und Petrographie Ostafrikas." pp. 559-568.

Uhlig, C. and F. Jaeger, 1942.—"Die Ostafrikanische Bruchstufe und die angrenzenden Gebiete zwischen den Seen Magad und Lawa ya Meuri sowie den Westfuss den Meru." Wissenschaftliche Veröffentlichungen des Deutschen Institutes fur Länderkunde, Vol. 10.

Vogt, T., 1930.—"On the Chronological Order of Deposition of the Highland Schists." *Geol. Mag.,* Vol. LXVII, pp. 68-73.

von Trotha, Th., 1897.—"Meine Bereisung von Deutsch-Ostafrika." Vortrag, gehalten in der Gesellschaft för Erdkunde. Berlin.

Watson. J., 1948.—"Late Sillimanite in the Migmatites of Kildonan, Sutherland." *Geol. Mag.,* Vol. LXXXV, pp. 149-162.

Weiss, L. E., 1959.—"Structural Analysis of the Basement System at Turoka, Kenya." *Overseas Geol. and Min. Res.,* Vol. 7, pp. 3-35 and 123-153.

——— and D. B. McIntyre, 1957.—"Structural Geometry of Dalradian Rocks at Loch Leven, Scottish Highlands." *Journ. Geol.,* Vol. 65, pp. 575-602.

Williams, L. A. J., 1964.—"Geology of the Mara River—Sianna Area." Report No. 66, Geol. Surv., Kenya.

Willis, B., 1936.—"East African Plateaus and Rift Valleys."

Wyckoff, D., 1952.—"Metamorphic Facies in the Wissahickon Schist near Philadelphia, Pennsylvania." *Bull. Geol. Soc. Amer.,* Vol. 63, pp. 25-57.

G.P.K. 258—1m—1/65