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COLONY AND PROTECTORATE OF KENYA

MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
GWASI AREA

DEGREE SHEET 41, SOUTH-WEST QUARTER
AND PART OF NORTH-WEST QUARTER
(with Coloured Maps)

by

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FOREWORD

The publication of the report on the Gwasi area completes the primary geological survey of South Nyanza, in the south-western corner of Kenya. It is a most important area as in its northern part there is a number of carbonatite centres, which include rocks of types that are generally found to be associated with deposits containing rare earth minerals and minerals containing the metal columbium. Various alkaline igneous rocks are found at the centres, and the mapping of that at Rangwa has proved the presence of the melilite-rich rock uncompahgrite, together with some turjaite—both rocks that are known at few places in the world.

The geology of the area is complex and, in the time available for the primary survey, it was not possible to map in as much detail as obviously will ultimately be required. Dr. McCall has produced, however, reasonably detailed maps that will be of immense use in the prospecting of the areas that are likely to be mineralized. His mapping has enabled him to evolve satisfactory accounts of the mode of origin of the carbonatite centres, the story being particularly clearly seen at Rangwa. Much of the early history of the area was one of volcanicity, in Precambrian times, which was followed by a long period of which there is no geological record, but which ended by the country being left almost as a plain after long-continued denudation. Then, in early Tertiary times, volcanicity was resumed, its first manifestation being a bulging upwards of the plain at places that are now exposed as the carbonatite centres. The centre at Rangwa became the focus of a central volcano, much of which is still preserved and when traced on the ground reveals itself as a mass of size comparable with that of Mt. Elgon.

A branch of the Kavirondo Gulf rift valley runs through the northern part of the area, and it is within it that the carbonatite centres lie. The mapping has proved, however, that the rifting occurred subsequently to the volcanicity, though there is evidence that some kind of depression must have existed there at an earlier date.

The Macalder gold-copper mine lies in the south-west part of the area, and a brief account is given of some aspects connected with it. Other possibly economic minerals within the area are also discussed.

Nairobi,
7th May, 1956.

WILLIAM PULFREY,
Chief Geologist.

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ABSTRACT

The report describes an area of about 1,400 square miles of South Nyanza, in western Kenya, on the shore of Lake Victoria. The land area is bounded by the parallel 1° 00′ S., by longitude 34° 30′ E., and by the shores of Lake Victoria and the Kavirondo Gulf, but also includes the islands in the lake. The total area of land is about 1,100 square miles. Physiographically the area includes the Gwasi massif, the Lambwe valley, Rusinga and Mfanganu Islands and the western half of the River Kuja drainage basin.

The rocks exposed include Precambrian volcanic rocks, meta-sediments and shallow intrusions of the Nyanzian System, with conglomerates and arkoses of the Kavirondian System. These rocks are mildly metamorphosed and have been invaded by granites and dykes of various types. There are no rocks representing the Paleozoic and Mesozoic eras, but intrusive, tectonic, volcanic and depositional activity occurred in the Tertiary era. After a number of ring complexes containing alkaline igneous rocks and carbonatites associated with explosion vents had been emplaced prior to the lower Miocene, volcanic activity commenced on a large scale, a vast volcanic cone being raised up in Kisingiri and great expanses being covered with nephelinitic lavas, melilitic lavas, and nephelinitic agglomerates.

Faulting in the upper Miocene or slightly later gave rise to a south-westerly-trending graben which enclosed the explosive diatremes and associated ring complexes. This normal gravity faulting was followed by outbursts of renewed volcanic activity, a series of phonolitic nephelinite plugs being emplaced along the major faults and along subsidiary fracture lines.

Two periods of sedimentary deposition can be recognized. Lake beds were first deposited in the Lake Victoria basin in the lower Miocene and have yielded a wealth of faunal remains. Later, during the Pleistocene pluvial periods thick sediments were deposited in the Lambwe valley, and less extensive deposits at Karungu and at Kaksingiri.

An account of the various rocks and the structures is given.

Pyrochlore, columbian perovskite, apatite and magnetite are present in the carbonatite complexes in such quantity as to suggest the possibility of mining development. Unusually radio-active ironstones are present at Ruri and Tuige and may overlie deposits of uranium-thorium minerals.

GEOLOGY OF THE GWASI AREA

I—INTRODUCTION

The Gwasi area as defined for this report comprises the land part of the south-west quarter of Degree Sheet 41 (Kenya), corresponding with the Directorate of Colonial Surveys Sheet No. 129, bounded by latitudes 0° 30′ S. and 1° 00′ S. and by longitude 34° 30′ E., together with the part of the coast of south Nyanza lying within the north-west quarter of Degree Sheet 41 (Directorate of Colonial Surveys sheet No. 115) and the islands of Mfanganu, Kimaboni, Takivere, Mbassa, and Rusinga (*see* Fig. 1). A small portion of Mfanganu Island lies in the degree sheet immediately to the west, which is otherwise occupied by the waters of Lake Victoria. The area surveyed lies entirely within the administrative district of South Nyanza, the District Office being at Kisii.

The area was surveyed in reconnaissance style as part of the programme of primary geological mapping of the Colony, between February and April, 1954, and from July to November, 1954. Volcanic centres at Kisingiri (Rangwa) and Ruri, where carbonatites are developed, were surveyed in some detail in view of the known association of apatite, monazite, pyrochlore, rare earth minerals and radio-active minerals with complexes of this type. Some of these minerals had already been found in rocks from Ruri and the survey confirmed their presence in the carbonatite centres of Rangwa, Ruri and Tuige.

Though considerable attention was paid to the carbonatite centres, and though as a whole the report may appear detailed, the period of about five and a half months spent on field-work was insufficient to allow the preparation of more than an outline of the diverse and unusual geological features that occur in the Gwasi area. Much valuable information would be revealed by further field-work, particularly in the case of the Rangwa and Ruri complexes.

Nature of the Country.—The country may be separated into four major divisions:—

(1) The Kuja basin
(2) The Lambwe valley
(3) The Gwasi hills
(4) The Islands

The *Kuja basin* forms an area of gently rolling, well populated country, sloping westwards from the Kanyamkago hills and down the dip-slope from the Kaniamwia escarpment on the eastern side of the Lambwe valley to the valley of the Kuja River, the largest river in South Nyanza, which drains along a sinuous course from the Kisii highlands between Kisii and Sotik to Lake Victoria near Karungu. The Kuja has numerous tributaries, many of which are permanent or semi-permanent, and with the high rainfall prevailing, a good livelihood can be won from small holdings growing millet, maize, finger millet, groundnuts, sugar and cotton. Cattle, however, do not fare too well owing to the prevalence of tsetse fly in the thick bush along the banks of the Kuja and its tributaries.

Bush clearance to remove the tsetse fly in the Oyani valley has met with only limited success, chiefly due to factors of an administrative nature.

The extensive flat-floored *Lambwe valley* (Plate VII, Fig. 2), formed by the westerly continuation of the Kavirondo fault-trough, lies between the Kaniamwia scarp which rises a thousand feet above it on its south-eastern flank and the Gwasi hills. The valley was at some time before the advent of the White Man completely depopulated. A number of reasons for this depopulation have been put forward, but in all probability the cause was sleeping sickness, as the areas concerned correspond closely to the pattern of tsetse fly infestation.

The valley is floored by alluvium and covered by bush and open grassland, and there is no doubt that ground-water can be obtained at a reasonable depth throughout its length. Buffalo are the only large game still residing. It is thus ideal for settlement provided the tsetse fly can be eradicated, and closely linked schemes are now being carried out by the East African Tsetse and Trypanosomiasis Organization and the African Land Development Board. Settlement is proceeding slowly in the north-east end of the valley.

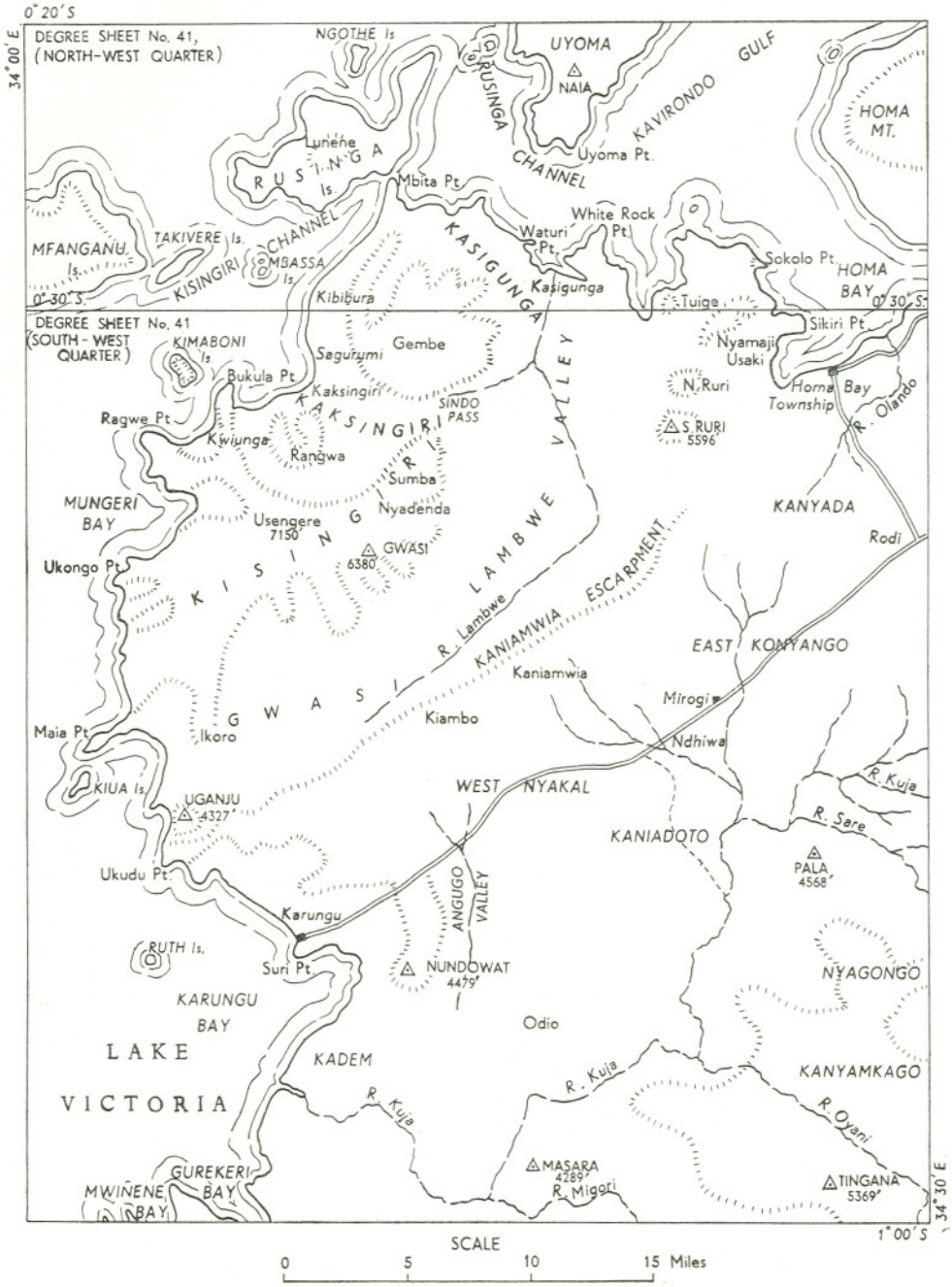


Fig. 1.—Topographical reference map of the Gwasi area.

The *Gwasi hills*, rising to seven thousand feet above sea-level, are part of an old dissected volcano, of even larger areal extent than Mount Elgon. The slopes are steep, traversed by numerous gullies, and in part forested. Permanent streams are completely absent; only the narrow coastal strip is populated, near to the water-supply provided by the lake.

The Islands Mfanganu and Rusinga are comparatively densely populated but, owing to the rocky nature of the terrain, the island people are little more than self-supporting, even with the supply of fish from the lake. Surprisingly, Mfanganu island has many small permanent rivulets.

The islands and the coastal fringe in Kaksingiri and Kasingunga locations are populated mainly by Suba, who originally came from Uganda. The rest of the area is populated by Luo (except for a few Kipsigis exiled near Gwasi and on Mfanganu for punitive reasons).

Soil erosion is developing alarmingly along the coastal fringe and in the islands, owing to the concentration of livestock near the lake shore.

Climate.—Rainfall figures, taken from the records of the East African Meteorological Department, are given in the table below:—

Station	Rainfall 1952	Rainfall 1953	Average Annual Rainfall	No. of years over which Average taken
	inches	*inches*	*inches*	
Mbita Dispensary	32·92	23·79*	35·22	4
Homa Ginnery	48·73	32·42	40·58	2
Lambwe (E.A.T.T.R.O. Camp)..	47·97	44·11	54·29	3
Lambwe (Sekka)	34·98	28·26	35·25	3
Lambwe (Aslu)	61·95	85·46	not recorded	not recorded
Lambwe (Sokoyamo)	40·86	47·04	46·28	3
Mirindi Trading Centre† ..	70·07	60·78	54·66	9
Uriri‡	73·22	record incomplete	57·41	8
Rapogi Mission	68·69	,,	53·94	9

*Excluding July.
†Two miles south-east of Rodi, in the adjoining area to the east.
‡About a mile outside the south-east corner of the area mapped.

The rainfall is heavy over the inland areas but the yearly average drops sharply on the edge of Lake Victoria. The climate on the whole is hot and oppressive, especially inland, though on the coast fresh and fairly strong winds spring from the lake in the afternoon making conditions much more pleasant. Thunder-storms are almost a daily occurrence over the Lambwe Valley and Gwasi.

Communications and Settlement.—The area is entirely occupied by native land units. There are no towns of any size; Homa Bay and Mirogi boast a handful of Asian shops, and small native markets are scattered throughout the locations.

There are no all-weather roads in the area and all the roads are closed during wet weather. The roads vary from narrow metalled murram roads to unmetalled tracks across black cotton soil. Homa Bay is served by a twice weekly tug-boat service from Kisumu and buses from Kisii serve Homa Bay, Mirogi, Karungu, Mbita and Gwasi.

The Kuja ferry between Kanyamkago and Kaniadoto is passable only to light motor traffic.

Maps.—The mapping was carried out on air photographs produced by the Aircraft Operating Company of South Africa for Kenya Consolidated Goldfields Limited (1937-1939) and on photographs taken by 82 Squadron, R.A.F. (1948-1952). A base map derived from the latter set of air photos covering a large part of the area was supplied by the East African

Tsetse and Trypanosomiasis Research Organization, and much of the survey was based on it. Names used on the map have in many cases been spelled as closely as possible to the phonetic rendering of the Luo names, obtained from illiterate local inhabitants.

The south-west corner of the geological map, comprising part of the Karungu area and the north-western end of the Migori gold-belt, was copied from a map by R. M. Shackleton (1946)*.

Acknowledgements.—The Provincial Commissioner, Nyanza Province, and the District Commissioner, Kisii, rendered considerable assistance which is acknowledged; also to the Settlement officer, African Land Development, Lambwe Valley, and the Assistant Agricultural Officer, Gulf Division, thanks are due for much valuable help during the course of the survey.

II.—PREVIOUS GEOLOGICAL WORK

The area lying to the south of the Kavirondo Gulf was apparently unknown from a geological viewpoint until the end of the first decade of this century. In 1907 K. H. B. Joll, Government Mining Expert, visited various parts of the district and collected specimens at Karungu and concentrates from gravels in the River Sare, but no record of the results of his work is available. The discovery of Miocene sediments at Karungu in 1909 by G. R. Chesnaye caused the British Museum to send out Dr. F. Oswald in 1911 to make a detailed investigation of the beds. Oswald (1914) gave a comprehensive account of his expedition and his classification of the sediments is reproduced in this report. His observations on the volcanic rocks, and other geological formations in South Nyanza had, however, no basis of close examination, and are inaccurate. An agglomerate (the Metamala agglomerate) discovered near the present site of the Kuja ferry was accepted by both Oswald and J. W. Gregory (1921, p. 130) as proof of pre-Miocene Tertiary volcanism; that eruption occurred in the Gwasi area before the lake beds were deposited has been demonstrated during the present work, but the so-called "Metamala agglomerate" is undoubtedly Kavirondian conglomerate of Precambrian age. Gregory did not visit the area but frequently refers to the Gwasi Plateau and the Karungu sediments.

E. J. Wayland (1931) carried out brief traverses in South Nyanza in 1930, when he discovered the Miocene lake beds of Rusinga, and noted that they contrast with the Karungu beds, in that they are dominantly of volcanic origin. He suggested lime absorption for the origin of the abundant melanite garnets in the nephelinite agglomerate of Rusinga.

P. E. Kent (1941, 1942 and 1944) visited Rusinga Island and the adjacent area in 1934 with the East African Archaeological Expedition. The last quoted work provides a comprehensive account of his conclusions. He deduced a Miocene age for the lake beds from fossil evidence, and also described reversed faulting which he ascribed to horizontal compression.

A. A. Fitch, C. D. Hallam and W. Edgeworth-Johnstone carried out a reconnaissance survey in 1937–9 for Kenya Consolidated Goldfields Ltd., producing a map on the 1/125,000 scale of the area south and east of the Lambwe Valley.

W. Pulfrey mapped in the Ruri and Homa mountain areas during 1943. He provided a preliminary note (1944) on the Ruri hills, suggesting that they are carbonatite ring complexes, and described (1949) the ijolite mass of Usaki, near Ruri, and the small syenite and syenodiorite bodies of Ruri (1954) in detailed petrological studies.

R. M. Shackleton (1951A, 1951B) visited Rusinga and Gwasi in 1947 under the auspices of the Royal Society, accompanied by I. E. Higginbottom. A detailed survey was carried out on Rusinga and proved that there are many local unconformities within the Miocene sedimentary formations, and that slumping structures are prevalent. Shackleton regarded compression structures described by Kent, and considered by him as conclusive evidence for a compressive origin of the Kavirondo rift valley, as non-existent, and concluded that the balance of evidence favours a tensional origin for the rifting. Shackleton visited Rangwa and identified it as a carbonatite complex; he also stressed the fact that the whole Gwasi (or Kisingiri) massif forms the eroded remnant of one vast central volcano.

*References are quoted on pp. 86–88.

T. Whitworth visited Gumba hill, Rusinga, in 1951 to amplify the work of the 1947 Royal Society expedition by means of a detailed study of the sedimentary succession in that locality. He advanced (1952) an interesting theory on the conditions under which the Rusinga beds formed. He considered that they were deposited in a series of intermittent shallow lakes, under alternating desiccation conditions and more favourable savannah conditions, while volcanic eruptions continued nearby. He also noted the coarsening of the volcanic detritus towards the west, indicating a source in Kisingiri. He recorded at least one well defined thrust dislocation, but considered that compression is of minor significance, with little bearing on the development of the Kavirondo rifting.

B. N. Temperley (1949) carried out a reconnaissance of the Ruri hills with a view to finding limestone of economic value. L. D. Sanders carried out a brief radiometric survey on Ruri in 1952, and samples from the soils on Ruri were the subject of a departmental report by L. M. Bear.

L. S. B. Leakey and D. G. MacInnes of the Coryndon Museum, Nairobi, have carried out detailed research of an archaeological and palaeontological nature both on Rusinga Island and Mfanganu Island over many years and the research is still continuing. Several papers have been published on the Miocene fauna by Leakey and MacInnes and other workers. A complete bibliography can be found in volume 8 of "Fossil Mammals of Africa" (Hopwood and Hollyfield, 1954).

III.—PHYSIOGRAPHY

1. Topography

The main topographical divisions of the Gwasi area are as follows:—

(1) The Kanyamkago hills
(2) The Kaniamwia escarpment
(3) The Lambwe valley
(4) The Ruri hills
(5) The Gwasi massif
(6) Mfanganu island
(7) Rusinga island

The south-eastern corner of the area is largely formed by ranges of rounded hills, the Kanyamkago hills, rising to something more than 5,000 feet in many places. These hills, lying between the Sare and Migori rivers, and divided longitudinally by the Oyani valley, have individually north-west to south-east orientation, following the strike of extremely resistant porphyritic andesites within the Nyanzian system. Nyagongo, a small mass of granite, forms a northerly spur projecting from this high ground.

The Kaniamwia escarpment is a north-facing fault-line scarp extending in a west-south-westerly direction from Kanyada to Uganju. The maximum height of the scarp is 1,500 feet, the highest point being Kiambo, standing about 5,650 feet above sea-level. The scarp is extremely steep, but negotiable at most points. On the dip-slope, south-east of the scarp, the country falls gently to the Kuja river, following the gentle dip of the Gwasi lavas outwards from the volcano of Kisingiri.

The Lambwe valley is a large area covered by completely flat alluvium lying between the Kaniamwia escarpment and the Gwasi massif. The valley is of tectonic origin and its flat floor reflects an earlier extension of the lake, comparable with the extension that gave rise to the Kano plains near Kisumu. Lake beds laid down at the time are now obscured by recent alluvial cover and black cotton soil.

The Ruri hills consist of two major hills and numerous neighbouring conical eminences between the northern part of the Lambwe valley and Homa Bay. The two main features, North Ruri and South Ruri, are carbonatite complexes with typical cliff margins. They stand 5,300 (approximately) and 5,596 feet above sea-level respectively. The smaller sharp conical hills surrounding them and the ridge of Nyamaji (*c.* 4,800 feet) to the north are formed by volcanic plugs composed of hard lava.

The outer part of the Gwasi massif is composed of a steep, deeply gullied outer ridge of volcanic rocks called Kisingiri with high points at Gembe (6,230 feet), Sumba (6,034 feet), Gwasi (6,384 feet) and Usengere, alternatively known as Kwirathia (7,454 feet). The last, the summit of this densely forested ridge, is the highest point in the area. The semi-circular outer ridge falls sharply to an alluvial-floored depression, in which low hills of granite and Nyanzian rocks are exposed, due to updoming during the formation of the Kisingiri volcano. In the centre of this hollow, which is partly covered by the waters of Lake Victoria, rises an almost circular eminence with nearly vertical bounding cliffs, the carbonatite complex of Rangwa. The summit of Rangwa is 5,690 feet above sea-level.

To the north of the Gwasi massif, four large islands rise from Lake Victoria, which is 3,726 feet above sea-level. Kimaboni is formed by the continuation of the Kisingiri ridge. Takivere, a low island of granite, is part of the updomed ancient foundation of the volcanic rocks, raised up relative to the Gwasi massif by a west-south-west to east-north-east fault. Mfanganu, over nine miles in length, is composed mainly of volcanic rocks identical with those of Gwasi and lower Miocene sediments upthrown, relatively, by the fault referred to above. The southern coast of Mfanganu is a sheer cliff rising 1,800 feet from the lake and is clearly a fault-line scarp. The other large island, Rusinga, contrasts with Mfanganu by being made up of several comparatively low disconnected hillocks with a central summit on Lunene (4,790 feet). The contrast is due to the dominance of easily eroded soft sediments on Rusinga. Rusinga is also relatively upthrown in relation to Gwasi, the Mfanganu fault continuing through the Mbita passage and being clearly recognised in the scarp of Naia hill on Uyoma in Central Nyanza, to the north-east and on the north side of the Kavirondo Gulf. The throw of the fault is, however, small at its north-east end.

2. Drainage

The largest single drainage system in the area is formed by the River Kuja and its tributaries. The Kuja flows from the Kisii hills east of Kisii township down to the lake through the southern half of the area. Except in the coastal strip near Karungu it passes through areas of high rainfall throughout its course and increments from numerous permanent or semi-permanent tributaries flowing off the Kanyamkago hills in the south, and the Kaniamwia dip-slope in the north, accrue to it.

In contrast to the Kuja system, there is only one permanent stream flowing northward to the Kavirondo Gulf, the Olando, which rises in Kanyada and flows north-eastwards, entering the lake east of Homa Bay township. The deeply gullied water-courses of the Gwasi massif flow only as storm torrents for a few hours after heavy rain. To the north and east of the massif the streams sink underground immediately their courses strike the deep alluvium of the Lambwe valley. The water-courses on the Ruri hills are similar to those on Gwasi. Mfanganu boasts several short permanent streams, falling gently to the cliff edges of the central plateau. Kent (1942, p. 26) has noted the presence of significant wind-gaps in the great southern cliff of Mfanganu that extend the line of the valleys, indicating that in spite of its knife-sharp profile, the cliff is a fault-line scarp of considerable age, which has retreated to some distance from the plane of the fault.

On Rusinga island which is mainly made up of porous lower Miocene sediments, the streams are of short length, and only flow as storm-torrents of brief duration.

The vast flat expanse of the Lambwe valley is an area of subsurface drainage and it is certain that a water-table continuous with the surface of Lake Victoria, and rising gently away from the lake, underlies the valley.

3. Peneplanation

The only erosion bevel recognizable in the area is the sub-Miocene peneplain (Fig. 2). The peneplain here has a gentle tilt downward, at a rate of about 43 feet per mile, in a west-north-westerly direction towards Lake Victoria (Shackleton 1951B, plate XXIV). At Homa Bay and Karungu the Gwasi volcanics and Miocene lake beds lie on surfaces of ancient rocks (Nyanzian and Kavirondian) below 4,000 feet above sea-level. The surface of the ancient rocks underlying the volcanics near Mirogi is 4,350 feet and they rise to over 5,000 feet in the Kanyamkago hills in the south-east corner of the area, where there is no evidence of residuals of an earlier peneplain. The tilt on the peneplain indicates considerable disturbance since the maturation of the bevel, presumably in early Tertiary times. Sagging in the region now occupied by Lake Victoria caused the surface, which must originally have been almost horizontal or perhaps with a gentle slope to the east, to slope towards that area.

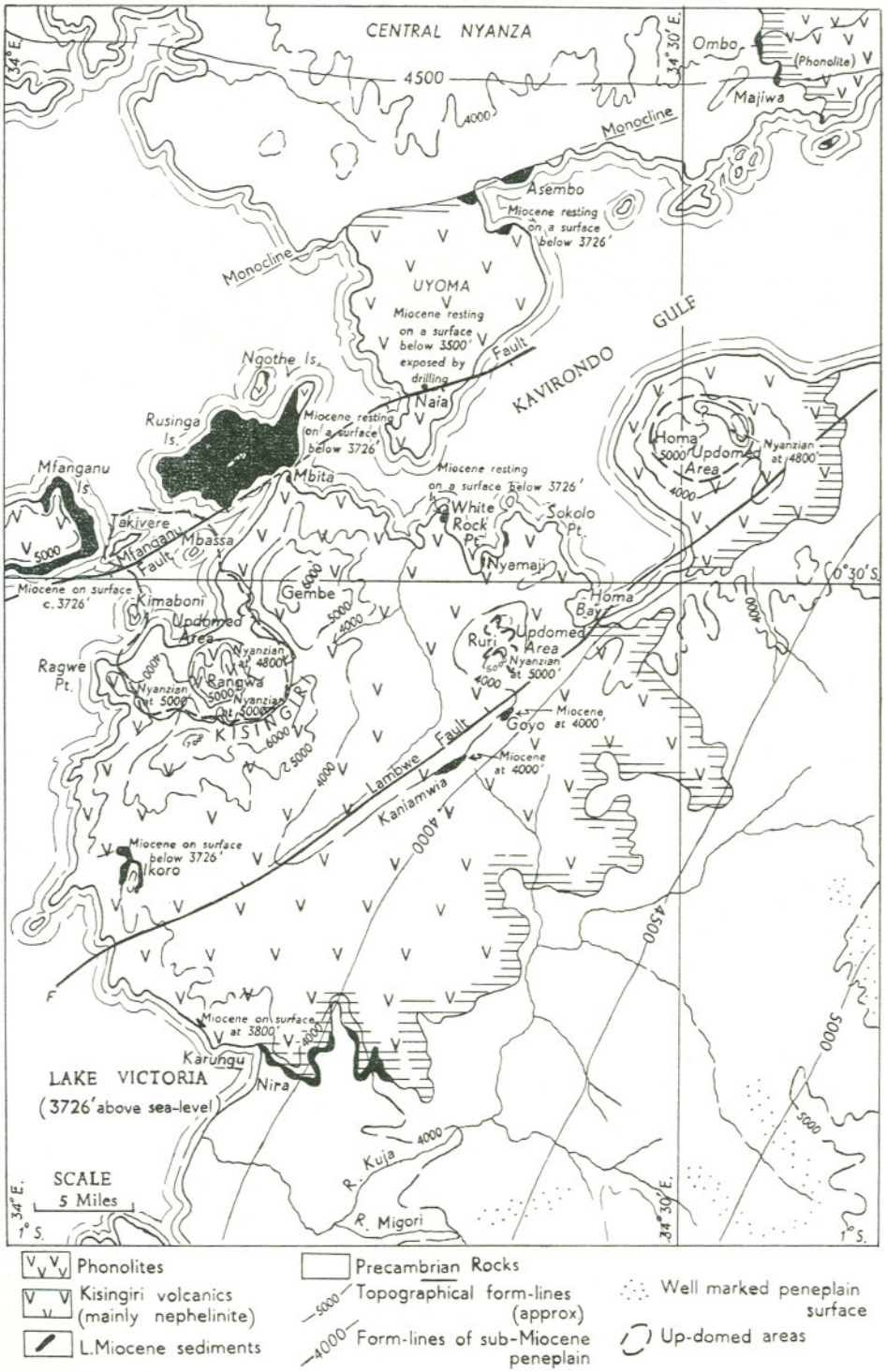


Fig. 2.—Sketch map illustrating the deformation of the sub-Miocene peneplain in the Gwasi area by down-warping towards Lake Victoria, in the Lambwe graben, and by up-doming at the alkaline and carbonatite ring complexes. Adapted from a map of the erosion surfaces of Nyanza Province by R. M. Shackleton (1951B) with added information.

The sub-Miocene peneplain was pushed up to above 5,000 feet consequent on later movement in the centre of the Kisingiri volcano. Such doming under an alkaline and carbonatite complex has also been described by B. C. King (1948) from Napak, Uganda. The uplift around Rangwa has even more vertical component than at first appears evident, for the sub-Miocene peneplain is depressed about 1,000 feet under Kisingiri, owing to the downthrow in the post-Miocene trough lying between the Lambwe and Mfanganu faults. The up-doming probably exceeds 2,000 feet in vertical extent. On Takivere the domed-up sub-Miocene surface is seen on the upthrow side north of the Mfanganu fault. Similar doming is evident in the Ruri and Tuige complexes.

A similar doming process might well be present in the great nephelinite volcano of Mount Elgon and should be considered as a possible origin of some of the anomalous surfaces noted in that area by Gibson (1954, p. 9).

IV—SUMMARY OF THE GEOLOGY AND GEOLOGICAL HISTORY OF THE AREA

The rocks of the Gwasi area comprise Precambrian lavas and sediments belonging to two systems, an extensive series of volcanic and intrusive rocks as well as sediments of Tertiary age, and various sediments of Pleistocene and Recent age. During the Palaeozoic and Mesozoic eras stable continental conditions prevailed, and there is no evidence of sedimentation, volcanic activity, or of igneous intrusions. The systems represented are indicated in the following table:—

Era	System	Rock types	Absolute age
			(*millions of years*)
Recent ..	—	sediments	$<\frac{1}{40}$
Pleistocene ..	—	sediments	1 or less
Tertiary ..	—	sediments, lavas and other volcanic rocks, igneous intrusions, carbonatites.	*c.* 25 or less
Precambrian ..	Bukoban ..	dykes (?)..	?
	Kavirondian ..	sediments	>2,000
	Nyanzian ..	lavas and sediments	>2,000

The succession of geological events was as follows:—

Recent	Alluvial deposits, talus, cemented talus breccias, black cotton soil, murram and lateritic earths
	Recession of Lake Victoria, leaving raised beaches
Pleistocene (Pluvial periods)	Deep gravels of Kaksingiri deposited
	Over 300 ft. thickness of lake beds deposited in an arm of the more extensive lake in the Lambwe Valley. Limestone deposits at Kaksingiri (lacustrine ?)
Tertiary	Late carbonatite dykes and cone-sheets emplaced on Ruri
	Late explosion breccia and pumice tuff erupted on Ruri and Nyamaji
	Plugs and dykes of phonolitic nephelinite (Gotjope type) and phonolitic nephelinite (Ruri and Nyamaji types) erupted from lines of weakness related to the rift faulting
	Faulting down of the Lambwe graben along two parallel and antithetic normal gravity faults (Kaniamwia fault, Mfanganu fault)
	Upper Kisingiri mela-nephelinite and subsidiary melilitite lavas extruded from fissures radiating from Kisingiri
	——Disconformity——
	Late melanite nephelinite (Kiahera type) dykes, radiating from Rangwa

Tertiary—(*Contd.*)	Alnöitic suite of dykes radiating from Rangwa Carbonatite plugs, radial dykes and cone-sheets emplaced within and adjacent to the Rangwa vent Upper agglomerate of the Middle Kisingiri group ejected from the Rangwa vent
Lower Miocene	Fine pyroclasts ejected from the Rangwa vent re-deposited as Miocene lake beds of Rusinga, Mfanganu and Ikoro. Lower nephelinite and melanite nephelinite agglomerates of the Middle Kisingiri group of Kisingiri ejected from Rangwa and intercalated in the lake beds Explosive diatreme of Rangwa emplaced in the centre of the earlier alkaline ring complex Miocene lake beds of Karungu, Goyo, and Kaniamwia deposited Lower Kisingiri nephelinite and mela-nephelinite lavas extruded from fissures radiating from the Rangwa centre Prolonged erosion on Rangwa, Ruri, and Tuige Massive carbonatite ring dykes emplaced in the Ruri and Tuige vents Explosion vents, diatremes of North Ruri, South Ruri, Tuige, and (?) Sokolo emplaced, boring through an earlier alkaline complex Intrusion of uncompahgrite at Rangwa Intrusion of alkaline igneous rocks at Rangwa, Usaki, Sokolo Point and Ruri; up-doming and fenitization of the country-rock
Mesozoic Palaeozoic	Stable continental conditions. Repeated cycles of erosion and peneplanation. No evidence of deposition, or of intrusive or extrusive activity
Precambrian	*Bukoban System* Not represented. Some late unmetamorphosed dykes may be of Bukoban age.
	Leucogranites emplaced (Nyagongo, Muhoro, Angugo, Kaksingiri-Takivere, and possibly part of the Kitere granite) Dolerite dykes (Augite hornblende porphyry, diorite, porphyrite, dacite porphyrite dykes) Post-Kavirondian orogeny Faulting on north-south trends
	Kavirondian System Conglomerates and subordinate arkosic grits deposited
	Angular unconformity Granites (Migori granite and part of Kitere granite emplaced) Post-Nyanzian orogeny
	Nyanzian System Rhyolite lavas extruded (quartz porphyries and felsite porphyries emplaced as shallow intrusions) Andesitic lavas mainly deposited in or under water forming pillow lavas; tuffs ("dioritic porphyrite" hypabyssal intrusion of Sare-Oyani emplaced) Slate and shale group deposited Greywackés deposited Dolerites. Basalt lavas extruded partly into water (as pillow lavas)

The Nyanzian System.—The oldest rocks exposed in the area are the weakly metamorphosed members of the Nyanzian System which, in contrast to the rocks of the Basement System long considered as the oldest rocks in Kenya, have undergone only low-grade "phyllite" metamorphism. In the southern part of the area they consist of metabasalts with banded ironstones, and well-defined pillow lavas; greywackés, andesitic tuffs and conglomerates again with banded ironstone horizons; and tuffaceous and silty slates together with andesites, and banded ironstones. Further north they consist of andesites with well-defined pillow structures, andesitic tuffs and basalts: they also include the possibly intrusive "porphyritic andesites" of Sare-Oyani. A wide belt of rhyolites and banded ironstones make up the succession south of the Kaniamwia fault.

Further outcrops of Nyanzian rocks occur near Homa Bay where rhyolites and banded ironstones outcrop together with matabasalts and felsite porphyries. A group of rocks that cannot be firmly allocated to systems, but which is thought to consist of sediments of Kavirondian age together with Nyanzian volcanics, has a limited occurrence within the Kaksingiri granite. It comprises rocks that are more highly metamorphosed than any others in the area and includes mica schists, tremolite schists, hornblende schists, amphibolite schists, and banded ironstones.

Most of the Nyanzian rocks are of extrusive volcanic origin but they are closely associated with analogous hypabyssal intrusions.

The Nyanzian rocks are tightly folded along west-north-west to east-south-east axes and dips are usually steep.

Kavirondian System.—The Kavirondian rocks in South Nyanza are an unrelieved series of conglomerates and arkosic grits. Numerous outcrops are found both north and south of the Kuja river, and a small outcrop occurs near Homa Bay in the north-east corner of the area. They rest unconformably on the Nyanzian, but have themselves been strongly folded, and dips are invariably steep though less than those of the Nyanzian (viz. of the order 50° to 65°).

The Granites and associated rocks.—Granites of two ages are known in the south-west corner of the area and north-east of Nundowat hill, near Karungu. The western termination of the Kitere granite, which is probably partly pre-Kavirondian and partly post-Kavirondian, lies within the area. It is poorly exposed, however, lying in boggy ground near the confluence of the Kuja and Sare rivers. A small body of post-Kavirondian leucogranite, in places forming tors, outcrops on Nyagongo. A further expanse of leucogranite, up-domed during the Tertiary epoch and underlying the volcano of Kisingiri, is exposed in an annular chain of outcrops surrounding the Rangwa carbonatite complex and also on Takivere Island.

The Minor Intrusives.—Granite porphyries, porphyrites, quartz porphyries, diorites, felsite porphyries, dacite porphyrites, augite-hornblende porphyrites and dolerites cut the Precambrian rocks. In distinction from the shallow intrusions within the Nyanzian these have dyke form and are post-Kavirondian in age. Some of the later dolerites possibly formed feeders to the Bukoban basalts which once overlay the older rocks, but have been removed by erosion.

The Tertiary Rocks.—The Tertiary rocks consist of nephelinitic lavas and agglomerates of various ages, with intercalated sediments of lower Miocene age and lacustrine origin, together with shallow intrusive bodies of ijolite, uncompahgrite and nepheline syenite, and six separate carbonatite diatremes. The extreme complexity of the Tertiary formations, which cover more than half of the area, is probably unparalleled in any area of similar size in East Africa.

Quaternary and Recent.—These include a thick series of diatomitic lake beds of presumably Pleistocene age that underlie the black cotton soil of the Lambwe Valley. Raised beach deposits and thick alluvial gravels near Kaksingiri and Karungu are also attributed to the Pleistocene Pluvial periods.

The superficial deposits include black cotton soil, murram, laterite, and talus (in the form of breccias with calcareous cement and as unconsolidated talus).

V—DETAILS OF THE GEOLOGY

1. Precambrian

(1) The Nyanzian System

The rocks of the Nyanzian System are the oldest exposed in the area. Comparable rocks in the Kakamega area have a minimum absolute age of 2,200 ± 150 million years, as was recently determined by Prof. J. T. Wilson of Toronto University by the determination of lead isotopes in galena from a vein in the Risks Mine (Mines and Geological Department, 1953, p. 13)*.

The original nature of the Nyanzian rocks is often in doubt in the present area, even with the assistance of microscope examination of thin sections. Variations in composition are rapid and alteration consequent on shearing and decomposition often makes positive identification difficult or impossible. Nonetheless it can be determined that most of the rocks of the system are of extrusive volcanic origin. Some of the lavas, however, are associated with contemporaneous or pene-contemporaneous intrusions. For example the basalts of the system were invaded by dolerites, and it is the writer's opinion that the Sare-Oyani porphyritic andesite (the "dioritic porphyrite" of Shackleton, 1946, p. 27) is a near-surface intrusion with marginal extrusive phases. The felsite porphyries of the Wire series, which have a substantial outcrop east of Homa Bay township, are also near-surface intrusions. The association of extrusive volcanic rocks and near-surface intrusions is, in fact, one that is seen throughout the Nyanzian system.

(*a*) *Succession*

The rocks of the Nyanzian system from the south-western section of the area, which is part of the Migori gold-belt, were described by Shackleton (1946, p. 9). This south-west corner of the area was not, therefore, resurveyed by the writer and Shackleton's descriptions are repeated in this report. He described the occurrence of clastic sediments—greywackés and shales—but no clastic sediments have been noted elsewhere in the area within the Nyanzian formations.

Huddleston (1951, p. 9) described the Nyanzian succession within the Kisii area immediately to the east of the Gwasi area. The Nyanzian rocks exposed north of the Sare-Oyani porphyritic andesite form a continuation of his succession, and pass under the Tertiary nephelinites of Kisingiri on the north side of the Kuja river. The Nyanzian rocks north of the Kitere granite also continue along a north-westerly strike from the Kisii area, passing under the nephelinites at Homa Bay. An inlier of Nyanzian rocks occurs on Ruri, and is believed to owe its existence to up-doming in Tertiary times.

Shackleton and Huddleston are in agreement as to the general succession but their succession conflicts with that used by Pulfrey (1946, p. 9) in North Nyanza. A detailed comparison of the successions in Nyanza Province has been given by Huddleston (*op. cit.* pp. 6 to 7). The succession in the present area is mainly a continuation of the successions established by Shackleton and Huddleston, though there are some slight divergences of opinion. For instance, Huddleston places his Sare-Oyani andesites above the rhyolite group, but in the opinion of the present writer the Sare-Oyani porphyritic andesite is in part a shallow intrusion with associated marginal surface manifestations including the lavas and tuffs near Sare (Huddleston 1951, p. 10) and Nyagongo. The presence amongst the pillow lavas, north of Nyagongo, of porphyritic bands identical in appearance with the "diorite porphyrite" is sufficiently conclusive evidence of the close association of the porphyritic andesite and the lavas. No reason to assume a later age than the rhyolitic group for these andesites can be discovered, however, in the Gwasi area, and as Huddleston's succession was deduced solely from an interpretation of fold structures, it is considered that the andesites should not be separated into an earlier and later group.

The succession suggested by the writer is:—

(4) Rhyolitic Group (porphyritic felsite of the Wire group)

(3) Slaty and andesitic group of Migori
Andesitic group of Nyagongo } Sare-Oyani porphyritic andesites

*A. Holmes and L. Cahen (African Geochronology, *Col. Geol. and Min. Res.*, Vol. 5, No. 1, 1955, p. 30) have recently adopted an age of 2,800 million years based on the same determinations.

(2) Greywacké group of Migori

(1) Basic volcanic Group: including (*a*) Basalts of the Migori Belt (D_1 Dolerites)
(*b*) Metabasalts of Ruri
(*c*) Metabasalts of Homa Bay

The formations in brackets are the analogous hypabyssal intrusions associated with each group.

Some members of the Kaksingiri schists (*see* p. 20) are believed to be of Nyanzian age, but they are so intimately infolded with Kavirondian sediments that they cannot be adequately separated at the present stage of mapping. Their position in the proposed succession of Nyanzian rocks is not certain.

(*b*) *The Basic Volcanic Group*

(i) *Basalts of the Migori Gold Belt.*—The majority of the rocks of this sub-group are pillow lavas, the pillow structures showing that the lavas flowed into or under water. Typical exposures occur near the Akala-Karungu road immediately north of the alluvial plain and at Adiel hill. The pillow structure is clearly seen in some of the Macalder Mine drill-cores. Outcrops show a characteristic irregular lumpy weathering. The pillows vary in length from less than a foot to five or six feet but are seldom more than a foot or two thick. The bigger ones bulge irregularly. The spaces between the pillows are filled with chlorite or calcite but not, as is often the case elsewhere, by chert. Their edges, being chilled, are often slightly harder than the interior, and are marked by a concentration of varioles, paler green spherical structures about an eighth of an inch in diameter, due to a radial growth of fibrous felspar crystals in the glassy lava. They are easily distinguished from vesicles (which also occur) by their characteristic dirty green colour, and by the fact that they are often in contact or appear to have coalesced. The vesicles are about the same size as the varioles and are usually filled with dark green chlorite or with calcite, which has dissolved out on weathered surfaces leaving holes. Unlike the varioles they are discrete and do not touch one another.

The pillow lavas are usually sheared. For this reason the method of using the shape of the pillows for distinguishing whether flows have been overturned or not, which has proved successful as a "way-up" technique in many parts of the world, has not been applied in the Migori belt.

Thin sections of the pillow lavas are unsatisfactory because of the fine grain and alteration. The varioles are seen as more opaque patches and the groundmass is a dirty chloritic, calcitic and leucoxene-dusted material, with criss-cross or stellate arrangements of narrow prisms of altered plagioclase about 0·3 to 0·5 mm. long. In some slides minute sheaves of actinolite reflect the former presence of interstitial augite. The original composition of the felspars is uncertain; they are now oligoclase. The evidence of the microscope slides such as it is suggests that the basalts were normal basalts; no evidence was seen of original sodic composition, implying spilitic affinites.

Fine-grained blocky basalts devoid of pillow structures outcrop at Nira near Karungu, but exposures are few. Huddleston (1951, p. 17) has described similar blocky basalts in detail.

(ii) *Metabasalts of Ruri.*—The metabasalts which comprise the up-domed inliers in the North Ruri, South Ruri and Tuige carbonatite complexes are compact bluish green rocks with textures varying from extremely fine-grained to slightly coarser and sugary, when they are rough to the touch. They are apparently not vesicular, and variolitic or spherulitic textures are absent.

In thin section the coarser and fresher specimens show a relic intergranular texture with a decussate arrangement of plagioclase prisms overriding a base of pale green ragged aggregates of a pale actinolitic hornblende. Colourless pyroxenes are present in the cores of some amphibole individuals. Specimen 41/1653* is an example in which the original intergranular texture of the rock can be traced. The felspars range from andesine-labradorite (An_{50}) to andesine (An_{42}) in composition.

*Numbers prefixed by 41/ refer to specimens in the regional collections of the Geological Survey.

Magnetite is present as dusty aggregates in the less altered specimens; the more altered specimens show little or no iron ore but are dusted with leucoxene. Epidote granules are also common. Quartz is sometimes present in very minor quantity (41/1663): it is of secondary origin. A finely microgranular light-coloured base, possibly derived from interstitial glassy material, is present in all these basalts, and is now composed mainly of recrystallized felspar and chlorite.

In one specimen (41/1663) the amphibole aggregates make up about 80 per cent of the rock, the felspars lying in irregular patches of microgranular base in a felt of amphibole which covers the greater part of the slide.

These basalts often contain calcite and in some cases it is abundant. The greater part of the calcite is probably due to secondary calcification associated with brecciation by carbonate-iron-ore veinlets, contemporary with the intrusion of the Tertiary carbonatites.

(iii) *Metabasalts East of Homa Bay.*—In the triangular area of Nyanzian rocks in the north-east corner of the area a series of greenish blue massive rocks, commonly coarse textured and rough to the touch, alternate with rhyolites, banded ironstones or porphyritic felsites. The presence of vesicles in most specimens examined suggests that the basic rocks are lavas rather than minor intrusions in the rhyolites. It is possible that both basalt flows and dolerites are represented but no field differentiation was attempted. The textures vary from coarsely crystalline, showing glistening augites on fresh surfaces, to very fine dense textures.

The thin sections show these lavas to be dominantly basaltic in composition. They typically show a decussate arrangement of rather broad felspar laths and patches of actinolitic hornblende. Epidote, leucoxene and calcite are aggregated in the interstices. Quartz is almost absent or present as appreciable interstitial pools. There is usually a certain amount of microgranular base. Vesicles, of rounded form and infilled with chlorite or calcite, are characteristic.

The above description refers to the typical heavily altered lavas; occasionally bands that have escaped alteration are found and two specimens from fresh relatively undecomposed outcrops show the original nature of the lavas.

Specimen 41/1480 from Simenya shows a decussate arrangement of saussuritized prisms of plagioclase, together with narrow prisms of a colourless augite. The interstices are infilled with pools of chlorite and colourless microgranular base. Titaniferous magnetite altering to leucoxene is an accessory. Prominent rounded and irregular vesicles are infilled with chlorite or with chalcedony with a rim of chlorite. Specimen 41/1507, which from its coarse texture and fresh appearance might be taken for a diorite or dolerite dyke, is thought to be a very coarse patch in the same lava series. Broad prisms of colourless augite are intercrystallized with coarse prisms of highly saussuritized plagioclase. Pools of chlorite are also present and patches of secondary quartz. Titaniferous magnetite in large skeletal crystals is an accessory, altering marginally to leucoxene.

The composition of these lavas is very variable; some contain appreciable quartz, some of which may represent an original mesostasis. The plagioclase is seldom easily identified, though calcic andesine appears to be the most common.

(*c*) *Greywacké Group*

This group is only represented in the Migori gold-belt and comprises greywackés, gritty andesitic tuffs, conglomerates, and banded ironstones. No conglomerates or banded ironstones are exposed within the greywacké group in the Gwasi area. The group is believed to be the equivalent of the group of rocks containing andesitic tuffs and argillaceous felspathic sandstones in the south-west part of the Kisii area.

(i) *Greywackés.*—"Probably the most widespread rock type in the Migori belt is a cleaved and usually indistinctly bedded rock consisting of quartz grains and angular or subangular bits of felspar scattered through dirty greenish matrix, which itself forms a considerable proportion of the rock. The quartz grains are nearly always visible to the naked eye" (Shackleton, 1946, p. 14).

"In thin sections they are seen to consist of angular to sub-angular, but very rarely rounded quartz grains, and sub-angular altered felspars (usually now oligoclase), occasional chloritized flakes of biotite and very rarely a few flakes of muscovite" (*ibid.*). Grains of microcrystalline quartzose material may represent acid lava or chert. The matrix is composed of sericite, and occasionally chlorite, in minute flakes with a parallel arrangement throughout the rock, formed during the low-grade metamorphism that the Nyanzian rocks have undergone. Quartz, rutile, calcite and rarely biotite are also variably present in the base.

(ii) *Gritty Andesitic Tuffs.*—These are distinguished from the greywackés by the presence of more abundant felspar and the yellowish rather than greenish chloritic colour of the matrix. They are thought to be derived from air-borne increments of andesitic volcanic material or from similar ashes washed by rivers into the locality where the greywackés were being deposited.

"Microscopically, these rocks consist of an unsorted mixture of angular fragments and whole crystals of turbid altered plagioclase with fewer angular grains of quartz and numerous fragments of altered andesitic lavas" (Shackleton, 1946, p. 14). Many if not all the quartz crystals may have been derived from dacite lavas, and rather than "gritty andesitic tuffs" the term "dacitic tuffs" might be more appropriate.

(*d*) *Slaty and Andesitic Group of Migori*

This group includes tuffaceous, silty and ferruginous slates, banded ironstones, the Masara andesitic rocks and shales.

The tuffaceous silty and ferruginous slates are hard sheared greenish to grey flinty rocks, hornfelsed near the granite and passing outwards into sericitic schists. These rocks have only a small area of outcrop in the Gwasi area, south of Masara. Ferruginous slates predominate in the band on the north side of the Masara andesitic group. They "are rusty weathering argillites, soft and with a flasery, rather poor cleavage" (Shackleton, 1946, p. 16). Banded ironstones occur within this group among the ferruginous slates, the more iron-poor varieties being grey in colour and cherty.

The Masara andesitic rocks, which include both andesites and tuffs, have a thickness of over 1,500 feet at Akala. In the vicinity of Masara they include andesitic crystal tuffs, andesitic lapilli tuffs and contemporaneous porphyrite intrusions.

The shales are grey blue in colour and surprisingly free from admixed tuff and silty material. Graphite is occasionally present.

(*e*) *The Andesitic Group* (*North of the Migori Belt*)

The andesitic rocks which form the high ground south of Rapogi are part of an extensive mass running south-eastwards towards Lolgorien. Shackleton (1946, p. 27) considered the mass to be intrusive and called it "dioritic porphyrite", but Huddleston (1951, p. 10) found tuff horizons and called the whole body "porphyritic andesite". It seems worthy of note that the area mapped by Huddleston included only part of the margin of the mass, whilst Shackleton mapped almost the whole of it. No tuff horizons were seen in the mass during the present survey, and immediately the margin is left behind, a pronounced flow-banding structure is seen to be developed. The original interpretation of Shackleton is accordingly preferred by the writer, and the mass is considered as an intrusion of porphyritic andesite (or dioritic porphyrite), comparable in mode of origin with the Nyamaji Tertiary mass (p. 69) in the north of the area, i.e. as a near-surface elongated stock of lava that underlay a chain of volcanoes. The presence of monotonously uniform non-vesicular porphyritic andesites with a microcrystalline base characteristic of a rapidly cooled shallow intrusion, together with some tuffs and surface flows along the margins is most satisfactorily explained in this way.

The mapping of the continuation of Huddleston's succession near Nyagongo has presented considerable difficulties. Huddleston took a broad band of andesites, marked N△ and including porphyrites of Sare-Oyani type, up to his western boundary both north and south of Nyagongo. In the present area sharp breaks between interdigitations of the Sare-Oyani porphyritic rock, and what is clearly a lava formation composed of andesites, dacites, basalts and dellenites, and including pillow lavas can be recognized. The rocks of the lava

group are so altered and so variable in composition that during the present reconnaissance survey no attempt could be made to map individual types, and the map shows only a separation of the Sare-Oyani porphyritic andesite from the andesitic lava group.

The porphyritic andesite symbol (Nap) has been used on the map only for the typical porphyritic blue Sare-Oyani type, and for coarsely porphyritic bands in the lava group. The remainder of the rocks between the Sare-Oyani mass and the rhyolite-ironstone group (Nr) were mapped as aphanatic lavas (Na), and as tuffs (Nat) where a fragmental character could be recognized.

(i) *The Sare-Oyani Porphyritic Andesites.*—The Nyanzian age of the porphyritic andesites is indicated by their inclusion as boulders in the overlying Kavirondian conglomerates. The narrow interdigitations of the porphyritic intrusions among the conglomerates mapped near Rapogi indicate the strong infolding that the two formations have subsequently undergone.

The porphyritic andesites are a characteristic blue colour, abundant small white plagioclase crystals and hornblende or augite phenocrysts being set in a bluish base. Occasionally a purplish coloration is seen due to finely desseminated hematite. The felspars are well shaped, oblong, and range up to three or four mm. in length. The rocks weather with a pale and very thin skin, and tend to break into cuboidal blocks that weather with a rusty colour. Under the microscope the felspars are seen to be zoned oligoclase and more rarely andesine. The augite is usually a colourless variety altered marginally to actinolite. Phenocrysts of green hornblende with brown cores, and biotite, altering to chlorite, are also usually present. Quartz is sometimes present as small rounded crystals interstitial to the phenocrysts, or as secondary patches. It is frequently absent altogether. The base is cherty and microcrystalline. A little iron ore is sometimes present as an accessory. A micro-brecciation of the phenocrysts is a common feature of the porphyritic andesites and a streaky, lenticular, dark-coloured flow banding that is rather vaguely defined is characteristic of the whole Sare-Oyani mass. The rocks are uncleaved, but have a regularly spaced system of clean joints.

(ii) *The Nyagongo Andesitic Lavas.*—Outside the Migori belt the only andesitic lavas of note within the area (besides these included in the metabasalt group near Homa Bay) are flows exposed on either side of the Nyagongo granite. These lavas are all dark in colour and vary greatly both in texture and in composition. The distinction between basalts and andesites is not easy but, from the ratio of mafic minerals to felsic minerals, the greater part of the lavas are thought to have originally had andesitic, dacitic or dellenitic composition. To the north-west of Nyagongo, however, mafic minerals predominate and the rocks were probably originally basaltic. A band of metabasalt has been shown on the map—but it is probably in part a dolerite (D_1).

The chief rock types in this group are:—

(*a*) Dark bluish coarse-textured rocks, apparently metabasalts (and metadolerites ?).

(*b*) Compact black tuffs, occurring as subordinate horizons north and south of Nyagongo.

(*c*) Light greenish heavily chloritized and epidotized pillow lavas (dacitic ?); the pillows are up to a foot long, and their form suggests younging of the formation towards the north-east (Plate I, Fig. 1).

(*d*) Coarse porphyritic andesites similar to the rocks of the Sare-Oyani mass. These are only found in a small band on the north side of Nyagongo.

Orthoclase is present in some of the lavas suggesting a dellenitic rather than an andesitic or dacitic composition. These andesitic lavas have already been described in detail by Huddleston (1951, p. 15).

(*f*) *The Rhyolitic Group*

The Rhyolitic Group forms a broad band in the Nyanzian from the Sare River to Ongeng; it also has a considerable development east of Homa Bay. The Wire porphyritic felsites which form a mass of high ground on the north-east margin of the area are considered to be a shallow intrusion which probably was the source of some of the surface flows of the rhyolitic group. No distinct flows can be found in this very uniform mass, tuff horizons are absent, there are no vesicles, and even more conclusive evidence of intrusion is seen north-east of Simenya where a dyke of diorite porphyrite, similar to some rocks of this mass, cuts Nyanzian metabasalt. The porphyritic felsites map like a body of granite.

The Rhyolitic Group is thus divided into the Wire Porphyritic Felsites which are shallow intrusions, and the Rhyolitic Lava Group which consists of rhyolitic lava flows, rhyolitic tuffs, and banded ironstones derived by the alteration of rhyolites.

(i) *The Wire Porphyritic Felsite Group.*—Huddleston (1951, p. 13) refers to these rocks as type (*b*) of the Nyanzian rhyolites of the Kisii area and states "The type (*b*) rhyolites might easily be confused with quartz-porphyries in the field except that no intrusive relations can be detected, and banded cherts, ironstones and pyroclastics are associated with them". No such association was seen in the Gwasi area and on the evidence available it is considered that they are near-surface contemporaneous intrusions.

They are pink, whitish grey, or green porphyrites, with quartz and felspar phenocrysts up to about 3 mm. maximum dimension set in a fine-grained flinty base. In thin sections most specimens are seen to be felsitic porphyries with rounded resorbed quartz phenocrysts and felspar phenocrysts set in a microgranular base composed mainly of quartz, felspar, and iron ore. The felspars are mostly oligoclase. Some of the pink varieties contain very altered relics after pyroxene phenocrysts and are of composition nearer to diorite porphyrite. The narrow intrusive dyke referred to above, is identical with rocks of the main body seen in exposures immediately south of the tongue of Tertiary lava in the north-east corner of the area, east-south-east of Asego. One specimen of quartz porphyry devoid of felspar phenocrysts was collected. This and the pyroxene-bearing specimens represent the limits of the composition variation of the mass. The felsites are not cleaved, but show well-developed jointing.

(ii) *The Rhyolitic Lava Group.*—The extensive series of Nyanzian rhyolite flows in the Kisii area, of which the rhyolites of the present area are a continuation, have been described by Huddleston (1951, pp. 12-13). Only a brief description of those in the Gwasi area is given here, as no further petrological examination has been made. The rhyolites are fine-textured highly siliceous-looking rocks, only rarely porphyritic and showing great variations in colour from dark greyish black through putty colour to shades of pink, white, cream and pale green. Streaky banded textures are common, a good example being specimen 41/1758 which shows banding in most of the colours mentioned. Vesicles and spherulitic textures are common, the vesicles often being infilled with chalcedony. Bands of a dirty mauve pink slaggy rock are intercalated in the rhyolites and are thought to be rhyolitic tuff.

The ironstones in the northern part of the Gwasi area are all considered to have been derived by the secondary alteration of rhyolites. They show the same fine wavy jasper-like banding as is seen in the associated rhyolites, and they also contain rounded cavities or ferruginous aggregates that are presumed to be secondary after phenocrysts or vesicles. These ironstones are of different type from the classical rhythmically banded sedimentary ironstones of the Migori belt.

The banded ironstones are well developed east of Homa Bay, in a large area south of Ongeng, and near Pala — in the last area they make up the greater part of the Rhyolitic Group.

(2) The Kavirondian System

The Kavirondian rocks form small infolded outliers resting unconformably on the Nyanzian in the Migori belt and near Rapogi. Large areas of Kavirondian occur in East Konyango and between the Kuja ferry and Rapogi. Another outcrop extends from near Homa Bay township to the eastern margin of the area. The Kavirondian in the Gwasi area consists entirely of conglomerates and subordinate arkosic grits; there are no shales and mudstones as there are in the system in North and Central Nyanza. The overstepping of the Kavirondian over the Nyanzian near Nyagongo demonstrates the unconformity between the two formations. Huddleston (1951, p. 17) has noted further indications of this angular unconformity east of the Gwasi area.

The conglomerates (Plate I, Fig. 2) consist of well-rounded boulders, sometimes as much as three feet in diameter: conspicuous among the boulders are granodiorites of various types, red jasper, and the porphyritic andesite of Sare-Oyani type. These boulders are set in a felspathic, gritty matrix which forms a variable proportion of the rock, ranging from a filling between closely packed boulders to a gritty base carrying a few and widely separated boulders. Normally the conglomerates are not bedded, but a faint stratification can be seen in the more gritty conglomerates. Cleavage is seldom apparent.

Plate I



Fig. 1.—Pillow structures in Nyanzian andesitic lava north of the Nyagongo granite.



Fig. 2.—Kavirondian conglomerate carrying well-rounded included boulders of granites of typically Nyanzian character. One mile west of Rapogi.

Plate II



Fig. 1.—Granite tor, Nyagongo.



Fig. 2.—Lower Miocene lake beds in the hundred-foot section at Nira, Karungu.

Shackleton (1946, p. 19) has identified boulders of the following types in conglomerates in the Migori area:—

Granodiorite (older granites)

Porphyritic hornblende granite, foliated hornblende granite (or granodiorite), foliated porphyritic hornblende granite (or granodiorite) (all of the older granite suite)

Diorite

Aplite

Dolerite (fine-grained mottled type) (older dolerites)

Basic volcanic rocks (some vesicular) (Nyanzian basalts)

Greenish greywacké or grit (Nyanzian)

Andesite (or porphyrite)

Dacite

Quartz porphyry

Fine-grained hornblende schist (hornfels of contact zone)

Hornblende porphyrite or andesite (Kavirondian of Shackleton)

Dioritic porphyrite (Nyanzian intrusions of Shackleton and the present report; Nyanzian andesites of Huddleston)

Red jasper

Black and grey chert

White vein quartz

Bluish grey vitreous vein quartz

The rock groups from which these boulders are believed to be derived are shown in parenthesis. It is clear that the older "granites" in this area and the Sare-Oyani andesites are older than the conglomerates, and of pre-Kavirondian age.

Shackleton has suggested that the large size of the granite boulders indicates local derivation; in fact on the southern margin of the Kitere granite, in a Kavirondian outcrop on the north bank of the Sare river, there is a conglomerate consisting almost entirely of closely packed granite boulders which can be matched megascopically and microscopically with the nearby Kitere granite and were presumably derived from it. Huddleston (1951, p. 18) has noted a similar occurrence further east, and also identified boulders of Nyagongo granite. If this is correct the Nyagongo granite must consist of two phases, one pre-Kavirondian conglomerate in age and one post-Kavirondian conglomerate in age, for microgranite veins from the Nyagongo granite cut the Kavirondian conglomerate north-west of Rapogi. There is, however, some doubt of the validity of such purely lithological correlations. On the same basis granites of proved post-Kavirondian age in North Nyanza could be correlated with pre-Kavirondian granites in South Nyanza.

Rhyolitic boulders are present in the conglomerates north of the Oyani river, and are clearly, as suggested by Huddleston, derived from the adjacent Nyanzian rhyolitic group.

The infolding of the conglomerate outliers with the porphyritic andesite of Sare-Oyani at Rapogi is pronounced, thin bands of conglomerate and associated grits alternating rapidly with bands of andesite. The conglomerate rests directly on the andesite, the contact being exposed at several points.

The matrix of the conglomerates is seen under the microscope to be similar to the grits described below. It is felspathic and coarse grained. Orthoclase and oligoclase predominate among the felspars, and occur together with rarer andesine and microcline. Sub-rounded quartz grains are common and calcite forms relatively abundant interstitial pools. Chloritization is often intense, particularly when the matrix has a fine-grained microgranular quartz-felspar base. Black iron ore and pyrite are common accessories.

The *grits* are bluish grey rocks, with white felspars and dark quartz grains easily visible in the hand-specimen. They grade through grits with scattered pebbles into conglomerates, from which they are separated on the map. They are well developed at Rapogi near the road between the mission and the Kuja ferry, and also on a roadside exposure one mile south of Homa Bay. In the latter exposure faint current bedding can be detected.

Under the microscope the grits are found to consist of angular and sub-angular grains of quartz and felspar set in a sparse highly chloritized, microgranular, quartzose base, in which occasional tiny felspars can be distinguished, together with epidote, sphene, rare brown biotite and apatite. Some sericitization of the felspars is seen but they are, in general, fresh. Fragmental volcanic material of larger than the average grain size is also sometimes present. Huddleston (1951, p. 19) has matched this volcanic material with Nyanzian lava types. Pale green augite and deep-green-brown hornblende are also present in some of the grits.

On the south bank at the Kuja ferry brown silty grits are exposed. They are composed of angular and subangular grains of quartz and felspar, the felspar predominating, set in a sericitic matrix. Many iron-stained relic fragments after amphiboles or pyroxenes are also present in them (specimen 41/1781). The rocks have a slightly schistose texture, and are probably the almost unmetamorphosed equivalent of the contact metamorphosed biotite-quartz schists and knotenschiefer at Kaksingiri.

(3) The Kaksingiri Schists

A series of schists is exposed within the Kaksingiri granite, with strike parallel to that of the Nyanzian-Kavirondian rocks further south. Their degree of metamorphism is, however, much greater than that of the Nyanzian rocks elsewhere in South Nyanza, and the presence of sedimentary banding and the mineral assemblage indicates that some of the schists were derived from clastic sediments. The series consists of amphibolite schists alternating with light-coloured quartz-biotite schists and tremolite schists. The amphibolites are probably metamorphosed basaltic lavas or dolerite sills. Ironstones are present, but their fine regular banding indicates derivation from stratified sediments and not from rhyolites.

The metasediments in the Kaksingiri schists are possibly derived from Kavirondian sediments like those of Central and North Nyanza and the silty grits at Kuja ferry. They have undergone considerable thermal metamorphism. It is considered that the schists represent interfolded members of the Nyanzian and Kavirondian systems, but highly detailed work would probably be required to map them as separate systems. They have accordingly been grouped on the present map as Nyanzian and Kavirondian combined, and are discussed here with the Kavirondian sediments for convenience.

The main occurrences of the schists are on Kasasa, Rukungu, and the Kwiunga-Bukula ridge. On Kasasa the apparent succession from north to south is:—

Tremolite schists

Biotite-quartz schists with bands of "knotenschiefer"

Amphibolite schists.

There is a considerable interdigitation of the various schist types, and it is evident from rapid changes in the dip of the stratification and schistosity and from the intense shearing that the rocks are strongly contorted.

On Rukungu only finely banded ironstones showing sedimentary banding are exposed.

On the Kwiunga-Bukula ridge there are again alternating beds of steeply dipping amphibolites and biotite-quartz schists, exposed in a belt less than a mile wide running south-east to north-west and separating two bodies of leucogranite. The schists are intimately injected by veins, *lits*, and stringers of aplitic material, and have many sheets of aplite cutting them, running parallel to the strike. The dips are steep, generally greater than 70° and mostly to the north-east.

(*a*) *Tremolite Schists*

Finely banded dark bluish green cleaved schists with a satiny lustre were found on examination of thin sections (41/1326, 1327) to be composed almost entirely of small parallel crystals of tremolite with actinolite fringes and margins, a little interstitial quartz, and streaks of secondary brown amorphous iron ore. In specimen 41/1327 there are scattered actinolite crystals among the tremolites. These schists show a sedimentary banding and are probably metamorphosed calcareous sediments.

(*b*) *Biotite-quartz Schists*

The biotite-quartz schists, which have a fairly extensive outcrop, are buff-coloured, cleaved and finely banded rocks. In thin section (41/1330, 1331) they show irregular granoblastic mosaics, quartz and biotite being the main component minerals, together with subordinate granules of felspar and minute flakes or occasional crystals of muscovite.

(*c*) *Knotenschiefer*

Schists, light silvery in colour with a micaceous lustre, and showing a decussate arrangement of bluish prismatic knots on the cleavage surfaces, are intercalated in the biotite-quartz schists. In thin section (41/1332) one example is seen to be composed of generally coarse crystals and aggregates of pale greenish brown bleached biotite and knots of shimmer aggregate (possibly after cordierite), together with sporadically distributed quartz granules and aggregates.

(*d*) *Ironstones*

The ironstones on Rukungu are finely stratified streaky ferruginous rocks, with streaks of grey and red-brown iron ore alternating with lenses and streaks of fine quartz granules making up the greater part of the rocks (41/1328). The only other component is a bright yellow mineral of high refractive index and birefringence which does not show any extinction position under crossed nicols, and is possibly a mineral of the epidote family in aggregated fine granules.

(*e*) *Amphibolite Schists*

Amphibolites form the greatest proportion of the schists on the Kwiunga-Bukula ridge. They are dark green crystalline schists, and in some of the thicker bands the remains of a primary texture, probably ophitic or intergranular, can be recognized where the rocks have locally resisted complete deformation.

In thin section (e.g. 41/1143) a granoblastic mosaic of bluish green pleochroic actinolitic hornblende and water-clear plagioclase is seen. Some of the plagioclase granules show a faint polysynthetic twinning, and partial saussuritization is evident.

(4) Pre-Tertiary Intrusions

The pre-Tertiary intrusions comprise:—

(*a*) The Muhoru granites and the Angugo Valley granite

(*b*) The Kitere granite

(*c*) The Nyagongo granite

(*d*) The Kaksingiri-Takivere granite

(*e*) Minor intrusions

The granites are believed to be of two ages and following Shackleton (1946 p. 21) are labelled G_2 and G_3. The older G_2 granites are post-Nyanzian but pre-Kavirondian in age, and the G_3 granites are post-Kavirondian. Huddleston (1951, p. 38) has shown that granites of the G_3 type are pre-Bukoban in the Kisii area.

The dolerites can also be divided into two age groups. The older, D_1, dolerites are Nyanzian in age and are closely associated with the Nyanzian basic volcanic rocks, as is clearly seen on the map. The older dolerites are also older than the G_2 granites, being metamorphosed to hornblende schists near to the granite contact. Elsewhere they have undergone the same degree of low-grade metamorphism as the rest of the Nyanzian rocks. The younger dolerites, D_2, are post-Kavirondian in age.

Of the other minor intrusions a dacite porphyrite and the syenodiorites can only be dated as post-Nyanzian. Quartz porphyries in the Mirogi belt are believed to be of Nyanzian age, but Huddleston (1951, p. 41) has noted some post-Kavirondian quartz porphyries in the adjoining Kisii area. The remainder of the minor intrusions—granite porphyry bosses at Mirogi, augite hornblende porphyrite and quartz diorite dykes at Rapogi, and the giant quartz veins—are post-Kavirondian in age.

(*a*) *The Muhoru Granites and the Angugo Valley Granite*

The "granites" in the south-western corner of the area consist of older G_2 granodiorite invaded by G_3 porphyritic leucogranite.

The granodiorite is porphyritic and consists of stumpy well-formed crystals of oligoclase in a matrix of quartz, microcline and hornblende, together with a little biotite and sphene. It is strongly sheared and foliated near its northern margin and contamination, producing hybrids, is a common feature. Full details of the batholith, of which a mere fragment is exposed within the Gwasi area, are given by Shackleton (1946, p. 22).

The later granites are unsheared and poor in mafic minerals. They frequently form tor-covered hills, a typical feature of the granites of North and Central Nyanza. They are typically light grey in colour, with few dark minerals and a scarcity of xenoliths. Quartz in large anhedral grains is fairly abundant. Well-formed microcline phenocrysts are characteristic, and sometimes a rude fluxional structure is shown by their parallelism. Small pegmatite segregations with quartz cores occur in these granites.

The small area of granite exposed below the Tertiary volcanics in the Angugo valley is believed to be part of a body of leucocratic G_3 granite.

(*b*) *The Kitere Granite*

This granite outcrops over an area of about 110 square miles; about 30 square miles lie within the Gwasi area, the balance being within the Kisii area (Huddleston 1951, p. 36) to the east where gold deposits are associated with it at Kitere. The granite is poorly exposed within the Gwasi area, the west end of its outcrop lying in swampy ground near the Kuja and Sare rivers, and only a brief summary of its main characteristics is given here.

The age relation of the granite to the Kavirondian system is uncertain; parts of it are possibly older, since boulders of granite identical in character are crowded within outcrops of Kavirondian conglomerate along its southern margin. Huddleston, however, recorded metamorphism of Kavirondian grits along its contact near Mirindi, suggesting that in part it is post-Kavirondian in age (*see* also p. 24). No differentiation into separate phases is possible, however, owing to paucity of exposures and, as a provisional measure, the whole of the granite is indicated on the map as of G_2 age.

Contrasting with the tor-forming granites of Muhoro and Nyagongo, the Kitere granite has low and insignificant outcrops. In hand-specimen it is normally fine-grained, and grey to pale pink in colour. It is often moderately porphyritic, with felspar phenocrysts, usually pink in colour or of a greenish tinge, up to 1 cm. in length. Rarely hornblende phenocrysts of the same size are present. Huddleston (1951, p. 37) described the Kitere granite as characterized in the main by intensely kaolinized and sericitized orthoclase, patchily replaced by clear microcline, albite or albite-oligoclase (An_8-An_{12}). Hornblende, the main mafic mineral, is a pale green pleochroic variety and is not normally abundant. Epidote and chlorite replace the hornblende in part. Biotite is subordinate and present in ragged highly altered and chloritized flakes. Sphene, apatite and zircon are accessories together with magnetite and sparse pyrite.

The specimens obtained from the western end of the intrusion during the present survey are granodioritic, with hornblende far more prominent than in the normal granites and corresponding with the marginal types described by Huddleston. In specimen 41/1785, from the north side of the Sare river, quartz is only a minor constituent. The greater part of the rock is made up of well-formed crystals of partly and sometimes heavily sericitized sodic-andesine (An_{31}). Microcline is absent but orthoclase occurs interstitially in small quantities, coating the plagioclases and sometimes forming a fine-grained micropegmatite intergrowth with quartz. A spongy hornblende, pleochroic from pale blue green to almost colourless, together with subordinate partly decomposed biotite, occasional chlorite pseudomorphs of biotite, and magnetite are the only primary mafic minerals represented. Granular epidote is associated with or replaces some of the hornblende but also occurs as discrete aggregates. Apatite and zircon are accessories. These granodiorites near the Sare river probably represent a marginal contaminated phase.

(c) The Nyagongo Granite

The Nyagongo G_3 granite forms a kidney-shaped mass about five miles long north of Rapogi, part of it lying in the Kisii area (Huddleston, 1951, p. 38). It is a highly leucocratic, pink or more rarely grey, usually coarse-textured granite and weathers into tor forms (Plate II, Fig. 1).

The body was clearly emplaced in an almost dead condition, that is volatiles and mineralizers were absent. Both Shackleton and Huddleston suggest a quiet assimilation of the country-rock as the mode of emplacement of this kind of granite since the intrusions do not appear to disturb the strike of the country-rocks. A slight disturbance of the Nyanzian strike is, however, apparent in the vicinity of Nyagongo. The lack of volatiles and emanations is evidenced by the complete lack of contact effects in the country-rocks and by the fact that minor apophyses are restricted to a few veins of microgranite an inch or so wide cutting the Kavirondian conglomerates.

Only three examples of this granite were sliced. Specimen 41/1752 from Nyagongo summit has undergone some cataclasis and alteration. Microcline, oligoclase, and quartz are present. Chlorite after biotite, and iron ore, are the only mafic constituents.

Specimen 41/1769 from the southern margin of the granite mass shows prominent pink felspars and colourless quartz grains. White felspar is subordinate. The texture is moderately coarse and non-porphyritic. Sparse biotite is the only dark mineral recognizable in the hand-specimen. In thin section the rock is seen to be comparatively unaltered. Perthitic microcline felspar, oligoclase-andesine and quartz make up the bulk of the rock. Chlorite after biotite, aggregated with epidote granules, remnants of biotite and iron ore are the only mafic constituents. Darker, possibly contaminated granite, with profuse biotite flakes visible on its surface was noted at the eastern end of the intrusion.

(d) The Kaksingiri-Takivere Granite

The greater part of the older rocks exposed within the central area of the eroded Tertiary volcano of Kisingiri consists of leucogranites more closely resembling the G_3 granites of Shackleton and Huddleston that the earlier G_2 granites, in spite of the fact that they are not tor-forming. The granites outcrop on the inwards-facing spurs of Gembe and Gwasi, now laid bare by erosion on the Kwiunga ridge, and also on the spurs projecting southwards from Rangwa. Takivere island and the two small Mbassa islands are also composed of this granite. The granite mass forms an almost circular outcrop having been brought to its present position, about two thousand feet above the sub-Miocene peneplain, by doming in early Tertiary times.

These granites are mostly altered as a result of fenitization associated with the Tertiary alkaline complex; the fenitized granites have a green colouration. When not appreciably fenitized their colour is white or pinkish white. They form rounded hills, with poor grassy vegetation and covered with small boulders of granite, but showing relatively few outcrops of appreciable dimensions. The texture is mostly fine, and frequently schistose: porphyritic granite is conspicuous on Kwiunga but elsewhere is rare.

In thin section the Kaksingiri granites show granoblastic, irregular, fine textures. Microcline is usually the most abundant felspar. A little plagioclase, ranging from oligoclase (A_{27}) to andesine (An_{34}), is usually present, and in some specimens collected it is the most abundant felspar. It is often to some extent clouded by alteration products. Mafic minerals are rare in the specimens sliced. Biotite and hornblende are present in some contaminated granitoid schists of granodiorite composition on Olori and biotite was observed in a few other specimens examined.

The granite south of Nyamarandi and on Sagurumi shows a strongly developed cataclasis. The rock appears brecciated and discoloured, and in a thin section large areas of the slide are occupied by finely milled aggregates derived from the original coarser mosaic. On Kasasa an aplite sheet (41/1329) within Kaksingiri schists and marginal to the granite shows a granulite texture, enclosing large residual crystals of felspar and fragments of the earlier coarser quartz mosaic. It is clear that the granite has suffered considerable deformation subsequent to its intrusion, in part of an orogenic nature, and in part consequent on the emplacement of the alkaline complex of Rangwa in Tertiary times. The granodiorite bands within the granite on Omutuma, Omutageti and Olori are considered to be contamination products due to assimilation of the country-rock. A hornblende-biotite schist of tonalitic composition on Omutuma is also considered to be of hybrid origin. Some granulite schists (41/1256) on the south-east spur of Rangwa are thought to be enclaves of sedimentary origin within the granite.

The Takivere granite is a leucogranite of type similar to that of the mainland outcrops at Kaksingiri. A little biotite and granular epidote is however present.

(e) Minor Intrusions

The diverse types of pre-Tertiary minor intrusions which cut the Nyanzian and Kavirondian formations in adjoining areas have been described in considerable detail by Shackleton (1946, p. 26) and Huddleston (1951, p. 40). The minor intrusions in the Gwasi area represent a continuation of the same dyke suites, and follow closely the strike of the Precambrian rocks. They include granite porphyries, aplites, quartz porphyries, dacite porphyrites, augite-hornblende porphyrites, quartz diorite and dolerites of two ages. A brief description of the intrusions is given below; for petrographical detail on similar types the works quoted above should be referred to.

Granite Porphyry.—A small boss of granite porphyry is exposed within the outcrop of the Kavirondian conglomerate east of Okok Chief's Camp. It seems fresh and unweathered, and it seems most likely that it is an intrusion into the Kavirondian, rather than a hillock on an older granite surface upon which the conglomerate was deposited. The porphyry (41/1838) is a pinkish grey moderately coarse-textured rock, with a thin pinkish buff weathered skin. Green-tinged phenocrysts of felspar are crammed into a pink and grey base in which dark specks of amphibole can be discerned. In thin section highly sericitized oligoclase phenocrysts, and rounded quartz phenocrysts, together with prisms of green chloritized hornblende and associated epidote granules and aggregates, are seen to be set in a granular felspathic base. Secondary calcite is present.

Judging from the petrographical similarity, it seems possible that the boss is a marginal apophysis of the Kitere granite. If so, the fact is significant, as it suggests that part of the Kitere granite at least is post-Kavirondian in age. Huddleston (1951, p. 37) notes metamorphism of the Kavirondian by the Kitere granite east of Mirindi, yet the Kavirondian conglomerates near the Sare river include abundant boulders of granite exactly like the Kitere granite, which is exposed only a hundred yards away. It is possible that the Okok boss is an inlier, but the Mirindi evidence is difficult to explain unless the granite mass is composed of separate but similar intrusions of different age.

Aplites.—Aplite sheets and dykes are associated with the Muhoru leucogranites south of Kadem point, and with the Kaksingiri leucogranites. In both areas there is complete gradation from aplite into the leucogranite forming the main body of the granite and no differentiation has been attempted on the map.

Syenodiorite Intrusions.—Pulfrey (1954, p. 217) described a syenodiorite intrusion from the lower north-west flank of South Ruri. During the present survey a further body of syenodiorite was discovered on the south-east spur. Explosion breccia crammed with included blocks of syenodiorite, suggesting the presence of a further body nearby, was discovered on the ridge joining North Ruri to South Ruri.

The syenodiorites are dark grey to greenish grey highly porphyritic rocks and have a coarse hypidiomorphic texture. In thin section oligoclase forms large, often zoned crystals (up to 4·5 mm.) and there are also crystals of microcline, abundantly replaced by spindles and plates of hornblende. Microcline also occurs interstitially, accompanied by orthoclase which is in part microperthitic. Rare small patches of quartz are associated with the felspar. The ferromagnesian minerals are hornblende and biotite. The only accessory noted was apatite. In the specimen from the south-east spur of South Ruri only needley aggregates of hornblende are present, there being no well-formed individual crystals.

The syenodiorites bear no resemblance whatever to the Tertiary alkaline intrusions of Ruri, and they are considered as minor intrusions of Nyanzian or Kavirondian age.

Quartz Porphyries.—Dykes and sheets of quartz porphyry are numerous at the western end of the Migori gold-belt (Shackleton, 1946, p. 27). They occur particularly amongst shales and slaty rocks near to the granite boundary. Quartz is usually the only identifiable mineral in the hand-specimen in the form of small corroded crystals. The matrix is grey, except where the rocks are sheared and hydrothermally altered, when it is a yellowish white kaolinitic or sericitic phyllite with scattered quartz blebs. Under the microscope the base is seen to consist of microgranular quartz-orthoclase mosaic, with flakes of sericite, green biotite (or hydrobiotite) and inky blue chloritoid. The rocks are strongly sheared and also clearly metamorphosed by the granite.

The swarm of quartz porphyry dykes near Akala and Macalder Mine is composed of very persistent dykes with prominent felspar phenocrysts. They are intrusive into Nyanzian rocks and older dolerites.

Towards Karungu dykes without quartz phenocrysts, otherwise similar to this suite, were distinguished by Shackleton by the symbol P.

Dacite Porphyrites.—A type of porphyrite differing from the quartz-phenocryst-free dykes near Karungu referred to above, occurs in a broad dyke that cuts Nyanzian metabasalts south of the Olando River in the north-east corner of the area. It is a fresh, grey, coarsely porphyritic rock (41/1504) with prominent greenish white felspar phenocrysts up to 3 mm. in length, set in a light grey base. In thin section the felspars are seen to be heavily saussuritized zoned plagioclase, about oligoclase-andesine. Smaller comparatively unaltered flesh-coloured prisms of augite lie between the felspars, in a chloritic base. Some secondary calcite and quartz mesostasis are also present.

Augite-Hornblende Porphyry.—A green dyke with dark green platy prismatic augite and hornblende set in a compact pale green base follows the boundary between an interdigitation of porphyritic andesite and Kavirondian conglomerate a few hundred yards west of Rapogi Mission. In thin section (41/1761) colourless and pale green crystals of augite and prisms of brownish green hornblende are seen, set in network of felspar prisms. Both oligoclase-andesine and orthoclase can be recognized in the base. Granular epidote and chlorite are also abundant in the base. Scattered interstitial pools of quartz and secondary calcite are present, and magnetite is a fairly abundant accessory.

Quartz Diorite.—A variably fine-grained dyke (41/1765–7) with a dull cherty appearance, in places mottled with dark green patches, separates the more northerly infold of Nyanzian porphyritic andesite from Kavirondian conglomerate north-west of Rapogi.

In thin section the dyke is seen to be mainly composed of a felt of plagioclase prisms. Chlorite and iron ore are present in varying abundance, and a little quartz can be recognized. The name quartz diorite has been given to this dyke, but it is not possible in its altered state to determine the composition with any accuracy.

Older Dolerites (D_1).—The more fine-grained members of the dolerite suite are difficult to differentiate from the metabasalts. The coarser bodies have lustre-mottling caused by plates of augite 5 to 10 mm. in diameter enclosing smaller chloritized felspar crystals. Their textures are ophitic, but the edges of most of the intrusions are sheared to chlorite schists. In the more altered dolerites the coarseness of grain can often be estimated from the size of the whitish leucoxene specks; in the dolerites these are up to 2 mm. in diameter, but in the lavas they are usually much smaller than a pin head. The specks persist in even the most sheared and chloritized basic rocks.

Under the microscope the older dolerites are seen to consist of plates of augite, spongily replaced by actinolite and chlorite and enclosing prisms of plagioclase. Leucoxenized ilmenite is invariably present. Secondary calcite and epidote are present to a varying degree depending on the amount of alteration that has taken place. Interstitial quartz is sometimes present.

The intrusions are sheet-like masses or sills which, though locally transgressive, in general follow the regional strike. No dykes of older dolerite have been recognized.

Near the Migori granite the older dolerites have been converted to epidiorites by metamorphism.

The Younger Dolerites (D_2).—Dykes of fresh dolerite are abundant in the western part of the Migori belt, and tend to form well-marked ridge features. They are bluish fresh-looking rocks and are seen under the microscope to be ophitic quartz dolerites. The augite is colourless or pale, and is fresh, being seldom altered to actinolite and then only marginally. The felspar is a zoned labradorite, which in the less fresh rocks is altered to albite or oligoclase. Ilmenite is present and quartz is always found either as interstitial grains or in micropegmatite.

The dykes in general follow fractures parallel to the strike of the country-rock but are occasionally deflected along oblique tear-faults for a short distance. They post-date the Masara faulting as they fill the fault fractures in places (Shackleton, 1946, p. 30) and they cut the Kavirondian conglomerates. Dolerites also invade the later Bukoban system (Huddleston, 1951, p. 44), but it is not known whether they are the same age as the D_2 dolerites. Huddleston noted, however, that the D_2 dolerites do not cut the G_3 type granites in the Kisii District, and the same applies to the present area, so that it is possible that there are dolerites of at least three ages in South Nyanza.

(5) Giant White Quartz Veins

Large veins of white quartz, barren of any other minerals, outcrop a few miles north-west and south-west of Macalder Mine and at Rapogi. There is a similar giant vein along the margin of the Nyagongo granite north of Rapogi, where there is an obvious displacement of the Nyanzian formations, and it is considered that the vein was emplaced along a fault that dropped the granite down to the east.

2. Tertiary Rocks

The Tertiary rocks of the Gwasi area are of extreme complexity, including as they do at least two major alkaline complexes, six explosion vents (five with associated carbonatite ring complexes), agglomerates, and a great variety of surface or near-surface lavas. It is doubtful if such a complexity exists within a small area elsewhere in East Africa. There is a further complication in that the lower Miocene lake beds of Rusinga, themselves largely tuffaceous, are intercalated with many purely pyroclastic beds and cannot be divorced from their context as part of the volcanic sequence of the great Kisingiri volcano, while in contrast the apparently equivalent sedimentary series of Karungu is an unrelieved series of lake sediments.

The descriptions given below do not treat the Tertiary rocks in strictly chronological order, but the arrangement does perhaps make the contents most easily understandable to the reader. The descriptions are divided into the following sections:—

(1) Lower Miocene lake sediments of Karungu
(2) The Kisingiri volcano
  (*a*) The updoming of the Precambrian floor
  (*b*) The Rangwa alkaline, ultra-basic and carbonatite ring complex
  (*c*) The Kisingiri Volcanic Series
    (i) Lower Kisingiri nephelinite and mela-nephelinite lavas
    (ii) Middle Kisingiri pyroclastic group: the lake beds and intercalated pyroclasts of Rusinga and Ikoro
    (iii) The Kiangata agglomerate of the Middle Kisingiri pyroclastic group
    (iv) The Upper Kisingiri mela-nephelinite plateau lavas
    (v) Minor intrusions
(3) The North Ruri, South Ruri, Tuige and Sokolo alkaline and carbonatite ring complexes

The Kisingiri Volcanic Series includes the Gwasi Volcanic Series of Shackleton (1946, p. 6), a term that is considered less appropriate and which does not include the sediments and intercalated agglomerates of the islands and Ikoro.

(1) The Lower Miocene Lake Sediments of Karungu (Karungu Lake Beds)

At Nira, on the western foot of Nundowat, a considerable section of lake sediments is exposed between the Precambrian rocks of the sub-Miocene erosion surface and the upper nephelinitic agglomerates of Kisingiri (Plate II, fig. 2). The sediments stand out sharply on the hillside at Nira owing to the bright red colour of the lowest members. The outcrop can be followed round the foot of Nundowat and the head of the Angugo valley, and further considerable section is exposed at Kikongo on the east side of this valley.

The Miocene sediments near Karungu were carefully investigated and described by Oswald (1914), and only a brief reconnaissance was made during the present survey. Oswald divided them into three series:

	Average thickness (feet)
3. Upper Series.—Grey and brown clays and shales, containing few fossils. Rare beds of sandstone	70
2. Middle Series.—Variable red and grey clays with white sandstones in the lower half	30
1. Lower Series.—Buff-coloured sandstones and torrential gravels (containing *Deinotherium*) passing down (at Nira) into clays and sandstone ..	55

Travertine beds occur at intervals throughout the whole thickness. The fossils collected by Oswald include *Deinotherium* remains, rhinoceros, a giant tortoise, crocodile, and freshwater and lacustrine shells, amongst which gastropods and mussels predominate. The fossils found are listed in Table I.

TABLE I.—THE MIOCENE FAUNA OF KARUNGU, RUSINGA AND MFANGANU

	Karungu*	Rusinga†	Mfanganu†
MAMMALIA—			
Limnopithecus legetet Hopwood	—	×	—
Xenopithecus koruensis Hopwood	—	×	—
Proconsul africanus Hopwood	—	×	—
Deinotherium hobleyi Andrews	×	×	—
Trilophodon angustidens subsp.	—	×	?
Aceratherium ? sp.	×	×	—
Teleoceras ? sp.	×	×	—
Pliohyrax championi Arambourg	—	×	—
Myohyrax oswaldi Andrews	×	×	—
Macrotherium sp.	—	×	—
Brachyodus africanus Andrews	×	×	—
Brachyodus sp. indet	×	×	—
Cervulinae gen. et sp. indet	—	×	—
Amphitragulus ? sp.	—	×	—
Listriodon jeanelli Arambourg	—	×	—
Suidae indet	—	×	—
Amphicyon sp.	—	×	—
Herpestes sp.	—	×	—
Felis sp.	×	×	—
Carnivora indet	?	×	?
Rodentia, several genera	×	×	×
Orycteropus sp.	—	×	—
Palaeoerinaceus sp.	—	×	—
AVES INDET	—	×	—
REPTILIA—			
Crocodilia indet	×	×	—
Testudo crassa Andrews	×	×	—
Trionyx sp.	×	?	—
Podocnemis sp.	×	—	—
Cycloderma victoriae Andrews	×	—	—
Chelonia indet	—	×	×
PISCES—			
Cichlidae indet	—	×	—
ARTHROPODA—			
Telphusa sp.	×	—	—
Julus sp.	—	×	×
Polydesmus ? sp.	—	×	×
MOLLUSCA—			
Aethera sp.	—	×	×
Unionidae indet	—	×	—
Gastropoda, several genera	×	×	×

*After Oswald, 1914; Kent, 1944, p. 110 †After D. G. MacInnes in Kent, 1944, p. 110

In general the Karungu deposits are composed of detrital material derived from the underlying Precambrian rocks. The lowest beds at Nira are coarse red gritty clays, carrying detrital grains clearly derived from the nearby granites, and little microscopic evidence of volcanic material was observed by the writer, with the exception of some pinkish buff layers in the upper series at Nira, which closely resemble some fossiliferous ashy beds exposed in the Kaniamwia scarp, below the E.A.T.T.R.O. camp. Fragments of green sodic pyroxene are, however, numerous in specimen 41/1735, a pale green flaggy sandstone in the middle group of the Nira sediments, and suggest the incorporation of detritus derived from Tertiary

eruptives of the Rangwa alkaline suite in Kisingiri. Shackleton (1946, p. 46) noted that augite (recognized by Oswald in the Upper Series) is indicative that volcanic activity had already commenced nearby. Augite, or more usually aegirine-diopside, and large biotite flakes (also mentioned by Oswald) are characteristic of the tuffaceous sediments of Kiahera on Rusinga Island and Mfanganu, and there can be no doubt that the lower nephelinite lavas of Kisingiri and the pyroclasts, carbonatites, ijolites and uncompahgrites of Rangwa were erupted prior to the deposition of the island sediments. It seems likely from fossil evidence that the lower Miocene sediments at Karungu are approximately equivalent in age to the volcanic sediments of Rusinga and Mfanganu, and that the augite and biotite flakes noted by Oswald were derived from the first Tertiary eruptives of Kisingiri (*see* p. 44 for further discussion of age relationships).

Sediments of presumed Miocene age—bedded tuffs, brittle clays and intercalated fine agglomerates—outcrop on the Kaniamwia escarpment below the E.A.T.T.R.O. camp. The tuffs are fossiliferous and yielded fragments of gastropods (resembling those in the Karungu beds) none of which, however, was sufficiently well preserved to be identified. A detailed examination of this section would probably produce better specimens, but a search was not possible during the present survey. The pale pinkish buff tuffs resemble some of the horizons in the upper series at Nira. These sediments underly the Upper Kisingiri nephelinite plateau lavas, the upper agglomerate (the Kiangata agglomerate) of the Middle Kisingiri series being absent.

Sediments, an extension of the beds on the escarpment, outcrop in the Goyo river cutting three miles further north-east along the foot of the Kaniamwia escarpment. These sediments consist of alternating light-coloured tuffs and thinly bedded red and grey clays. Fresh-water fossil shells are reported to have been found there by the Settlement Officer, who lives nearby, but none were found by the writer. The sediments, partly composed of volcanic detritus, are interesting since they resemble both the Karungu sediments and the lower part of the Rusinga-Mfanganu succession. They rest on vesicular nephelinite lava of the Lower Kisingiri lava series, and are overlain by the Kiangata agglomerate of Kisingiri, indicating an age equivalent to the Lower Miocene sediments of Rusinga and Mfanganu.

Conditions of Deposition of the Karungu Lake Beds.—Shackleton (1946, p. 46) considered the basal red clays of Nira as a weathering product of the sub-Miocene land surface, and the remainder of the sediments of fluvio-lacustrine origin. He noted that the sediments thin between Nira and Nyagwena and considered that the disappearance of the lower beds in that direction indicates a shore-line and source of detritus to the east. From the nature of the fauna he deduced that the shore-line cannot have been far distant.

Age of the Karungu Lake Beds.—The contrast between the sediments with very sparse volcanic content at Karungu and the volcanic sediments of Rusinga is striking. Fossil evidence, however, is strongly in favour of a similar age, and the difference must be attributed to some local condition operating at the time of deposition—the direction of the prevailing wind and the distance from the vent may have had some bearing on the composition. Lower Miocene sediments at Homa Bay (*see* p. 78) some twenty-five miles from the Rangwa vent show no trace of volcanic content.

The pyroxene in the Karungu sediments is green aegirine-diopside like that of the ijolites and the Kisingiri agglomerates and tuffs. It may represent air-borne volcanic detritus blown out during the explosive phase—but there is an alternative possibility in view of the evidence at Rangwa (p. 32) that the ijolites and syenites were laid bare by erosion prior to the deposition of the Miocene lake beds, so that the pyroxene may be a product of that erosion.

(2) The Kisingiri Volcano

The existence of the eroded remains of a single great central volcano at the western end of the Kavirondo Gulf was mentioned by Kent (1944, pp. 101 and 109), and Shackleton (1951, p. 373) described its components. It must be noted that the Kisingiri volcano embraces the Kaniamwia plateau, the Gembe and Gwasi mountains, Rangwa, Rusinga island and Mfanganu, and in addition the Uyoma peninsula on the north side of the Kavirondo gulf.

The extrusive and pyroclastic volcanic rocks of Kisingiri, dominantly of nephelinitic composition, outcrop over an even greater area than the nephelinites of Mount Elgon; from the north end of Uyoma to Nundowat and Odio, south of Karungu, they stretch over a span of more than fifty miles. Kisingiri contrasts with Mount Elgon in that erosion has here

exposed an alkaline ring complex and the central explosion vent. Intrusive bodies of biotite uncompahgrite, ijolite, nepheline syenite and carbonatite, together with the up-domed early Tertiary surface of rocks of possible Nyanzian and Kavirondian age and granite of Precambrian age are all represented in the central core of the volcano, now laid bare by erosion. Mount Elgon is comparatively little eroded, and partly on this account Davies (1952, p. 48) has ascribed it to a younger period than Kisingiri, the later volcanic stages of which can be demonstrated to be of Miocene age.

(a) The Up-doming of the sub-Miocene Peneplain under Kisingiri

The existence of a pre-volcanic dome under the Napak alkaline ring complex in Karamoja, Uganda, has been demonstrated by King (1949, p. 15). This feature has again been encountered within the present area in Kisingiri and in the Ruri complexes.

In Kisingiri an outer range of hills is formed by the outward-dipping volcanic rocks of the volcano's outer slopes. This hilly ridge (of which Gembe, Gwasi, Usengere and Mfanganu are parts) encloses an area of much lower country forming an amphitheatre from the centre of which rises another sharp hill feature, Rangwa. Rangwa is formed by pyroclasts of the central vent, together with a carbonatite ring complex. In an annular zone between the outer ridge and Rangwa are extensive outcrops of granite and metamorphic rocks (probably Nyanzian and Kavirondian) and alkaline and ultra-basic intrusives of Tertiary age.

The altitude of the sub-Miocene peneplain at Karungu and Homa Bay is at lake-level, i.e., a little below 3,800 feet above sea-level. In contrast, the granite within the central amphitheatre of Kisingiri stands in many places over 5,000 feet above sea-level. This would suggest that it has been pushed up some 1,200 feet; but in addition, it must be remembered that both Homa Bay and Karungu lie on the upthrow side of the Kaniamwia fault. Owing to the faulting, the sub-Miocene peneplain under Kisingiri has dropped several hundred feet in relation to its counterpart south-east of the fault, and the vertical distance by which the old erosion surface was elevated at the volcanic centre must thus be of the order of two thousand feet.

That the updoming is related to the Tertiary alkaline ring complex and is not of residual origin is shown by the fact that the granite forms a circular, symmetrical outcrop within the central amphitheatre, but is nowhere exposed on the outer slopes on the floor of the Lambwe valley, nor in Rusinga and Mfanganu islands. The sub-Miocene surface is below lake-level at Ragwe point, Kimaboni island, Mfanganu island and Kibibura hill, north of Rangwa, but at Takivere Island it reappears on the upthrow side of the Mfanganu fault. In spite of the upthrow along the north side of this fault, the sub-Miocene erosion surface on Takivere stands at an altitude below 4,000 feet. It is apparent from the mapping that the surface slopes steeply outwards symmetrically from a centre coinciding with the Rangwa vent.

The doming is considered to have taken place largely before the outpouring of the first nephelinite lava flows and before the deposition of the lower Miocene lake beds of Rusinga and Mfanganu. The lower nephelinite lavas in the Gembe and Gwasi inner scarps have low dips (10° to 20°), a feature not in accordance with a subsequent updoming of the dimensions that have been described. Similarly, the Lower Miocene lake beds of Rusinga and Mfanganu would be much more disturbed, and would show strong outward dips if they had been affected by such a movement. Also there are no Miocene lake sediments in the centre of Kisingiri, indicating that there was an area of high ground on the site of the present Kisingiri massif in lower Miocene times.

Though the updomed area cannot represent a simple erosional residual on the sub-Miocene peneplain, it is not certain that the doming was subsequent to the peneplanation. There is an alternative that an area was domed up during the erosion cycle but before its completion (believed to have been effected during the upper part of the Oligocene), and remained as a dome standing above the bevel at the end of the sub-Miocene peneplanation.

In the subsequent text, the updoming both at Rangwa and at Ruri (p. 57) is referred to as an updoming of the peneplain surface, but it is the opinion of the writer that the date of eruption of the first alkaline intrusion of Rangwa and the first alkaline intrusion of Ruri (p. 58) and the explosion vents and carbonatite diatremes of Ruri (pp. 62-63) were not necessarily later in date than the maturity of the sub-Miocene peneplanation.

(b) The Rangwa Alkaline, Ultra-basic and Carbonatite Ring Complex

Although Rangwa is but three miles from the main steamship route around Lake Victoria, it is situated in remote and largely uninhabited country on the far side of the Lambwe valley, and it was not examined by a geologist until Shackleton paid a brief visit in 1947 (Shackleton 1951, p. 373). He described the plug as consisting largely of carbonatites and noted the presence of pyroclastic rocks, explosion brecias and lapilli tuffs. He apparently did not see the southern margin of the complex which is by far the most interesting sector, since it is not obscured by alluvium, and neither Shackleton nor any other worker on the Miocene sediments of Rusinga appears to have noticed the granite dome, either on the mainland or on Takivere island. Shackleton considered that Rangwa probably had the form of a ring complex, and that the vent was probably that from which the nephelinite agglomerates of Rusinga, Gwasi and Gembe were ejected. This is borne out by the further evidence obtained during the present survey.

With the completion of the recent photographic survey of much of East Africa by 82 Squadron of the R.A.F., air photographs showing the perfect circular form of this vent were for the first time available.

Physical Features of Rangwa.—Rangwa forms a crescentic hill some three and a half miles in diameter, rising to 5,690 feet at the summit, some 2,000 feet above the lake (*see* fig. 10 at end). Sheer cliffs form much of the outer slopes, rising above talus-covered slopes; the inner slopes facing a central valley floored with deep deposits of stratified red alluvial soil and boulders, are not less steep, but are less regular in form, since the outer cliffs mark the margin of the almost circular vent. The central valley opens to the lake shore on the northern side of the vent.

Alluvial plains, in which deep sections of gravel (probably deposited in the Pleistocene pluvial periods) can be seen, border the hill except on the south side, where two spurs of Tertiary igneous rocks and Precambrian country-rock project from Rangwa. One ridge standing 4,900 feet above sea-level connects Rangwa to the Gwasi ridge, a complete section of Kisingiri being thus exposed in this locality, from Gwasi into the centre of the vent.

Summary of the Geology of Rangwa.—The Rangwa complex consists of a central plug of pyroclastic rocks, invaded by cone-sheets, dykes and irregular plugs of carbonatite (*see* fig. 9). Peripheral to the almost circular plug, are a series of confocal bodies of ultra-basic and alkaline igneous rocks (biotite uncompahgrite, ijolite and nepheline syenite). Around the periphery of the complex, country-rock is well exposed, comprising a dome of the Precambrian leucogranites, metamorphic rocks and associated hybrids. Some fenitization is evident near the contacts. Marginal dykes of foyaitic, alnöitic, and nephelinitic rock cut the Precambrian country-rock and alkaline intrusive rocks of the complex but never the plug itself. A few outlying carbonatite dykes also cut the Precambrian rocks.

The rocks of the Rangwa complex can be divided into:—

(1) Alkaline igneous rocks and associated fenites, including—
Syenites (foyaites, malignites)
Ijolites, urtites, melteigites
Minor dykes—micro-foyaites, micro-ijolites
Fenites and fenitic hybrids
Nephelinite dykes (feeders of the Kisingiri lava series)
Late nephelinite dykes radiating from Rangwa

(2) Ultra-basic igneous rocks, comprising—
Biotite uncompahgrite
Alnöitic dykes

(3) Pyroclastic (vent) rocks

(4) Carbonatites

For convenience, the minor intrusions are described in a separate section (*see* p. 54) after the description of the volcanic rocks of Kisingiri. The presence of an ultra-basic melilitic inner zone is, as far as is known, unique amongst African alkaline complexes.

(i) *The Nepheline Syenites* (*Foyaite Suite*).—Syenitic igneous rocks are the least well-represented group of the igneous complex of Rangwa. They occur in two well-defined intrusive bodies, and also as subordinate phases within the zone of ijolitic rocks (*see* map of Rangwa complex, at end). Micro-foyaites together with micro-ijolites clearly allied to the syenites and ijolites of the ring complex form a marginal suite of tangential and radial dykes centred on Rangwa. A closely-spaced radial swarm of these dykes cuts the syenite on the spur south of Usengere. The origin of the syenite is discussed in the section dealing with fenitization (p. 34).

A spur of syenitic rocks projects northwards from Usengere, one mile south-west of Rangwa, where they are in contact with granite at both their inner and outer margins. The occurrence was discovered late in the survey, when mapping conditions were poor since the spur was covered with thick grass and bush. An examination early in the year when the grass is burnt would produce more accurate details than could be obtained during the present work.

These syenites are grey in colour, medium-grained, and usually have porphyritic texture (cf. Pulfrey, 1954, p. 211), with large well-formed crystals set in a more fine-grained base. Felspar phenocrysts and well-formed nephelines weather out on the surfaces, the felspars having a decussate arrangement. Calcite is often readily detected on fresh surfaces. Darker patches in the syenites, which show considerable variation in composition over a small area, contain dark green prismatic pyroxenes. There is often a streakiness in the arrangement of the dark and light minerals, the lineation being roughly parallel to the margin of the Rangwa vent.

Essentially the syenites form a foyaitic suite but the relative proportions of the constituent minerals vary even within the area of a thin section, and many more mafic specimens of malignitic composition were collected than of foyaites.

The pyroxenes mainly occur as stout prisms but smaller needles are sometimes scattered through the more fine-grained base material. A spheroidal arrangement of the needles is not uncommon. The pyroxene consists either of aegirine-diopside with deep green outer zones of aegirine, or aegirine alone, or both may be present together. The needles are aegirine. The felspars are frequently Carlsbad-twinned, and occur in a decussate arrangement of prisms, as large as 5 mm. in length, in the more felsic syenites. They are a sodic orthoclase and sometimes have perthitic structure. In specimen 41/1833 anorthoclase is present and in specimen 41/1835 the felspars have grown in spheroidal clusters. Some of the specimens collected are poor in felspar, and nepheline predominates. The nephelines are not usually of good crystal form and are largely altered to aggregates of cancrinite and zeolites. The nepheline in specimen 41/1827 is, however, idiomorphic and little altered.

Cancrinite is abundant in all nepheline-rich specimens. It appears to be to a certain extent primary, but in the main is of secondary origin. Calcite is a major constituent both in fine granular aggregates with cancrinite, and in pools of coarse mosaic. Apatite and sphene are common accessories, but magnetite is a very sparse accessory. In specimen 41/1834 a marked replacive relationship between aegirine and felspar is seen, suggesting metasomatic alteration of an originally leucocratic rock (cf. Pulfrey, 1954, pp. 218-219). The felspars in this slide are noticeably ragged and irregularly replaced by calcite. In specimen 41/1832 broad prisms of aegirine-diopside form a decussate network overriding a base of nepheline (mostly altered to cancrinite, which forms large granular pools), subordinate orthoclase, apatite, and large crystals of sphene.

Specimen 41/1833 is unusual in that small fresh crystals and growths of anorthoclase showing polysynthetic twinning are present in interstices and replacing the earlier felspars along their margins and on cracks.

Malignites on the South-east Flank of the Rangwa Vent.—A small outcrop of green and white rock with prominent felspars occurs below the cliffs of explosion breccia on the south-eastern side of the Rangwa vent. The rock contains finely speckled bands alternating with coarse pegmatoid bands. The exposures are poor, consisting mostly of disturbed boulders, and it is not possible to determine the attitude of the compositional banding without excavation. In thin section the coarser rock (41/1236) is seen to consist of spheroidal aggregates of dark green aegirine needles, with subordinate Carlsbad-twinned orthoclase, and nepheline. The orthoclase is patchily heavily clouded by alteration products. The growths of aegirine needles appear to penetrate the light minerals, which presumably crystallized at an earlier

stage. Specimen 41/1236 is a finely speckled micro-malignite layer from the same outcrop. The aegirine forms mossy dark green spheroids set in a base of granular cancrinite (after nepheline) and subordinate patches of water-clear orthoclase, which contains included aegirine needles.

Other Syenites.—Syenitic rocks have also been found within the ijolites and melteigites on the south side of Rangwa. They are indistinguishable from these rocks in the field but the presence of orthoclase, revealed by microscope examination, shows that they are foyaites. Specimen 41/1257 from the spur projecting south from Rangwa contains Carlsbad-twinned orthoclase, nepheline, cancrinite and calcite with accessory sphene. Analcime is present in scattered pools. The pyroxenes are zoned; the outer zones are deep green aegirine but the cores are variably colourless augite with a maximum extinction angle about 40°, or green aegirine-diopside.

Another syenitic rock (41/1298) was collected from the micro-melteigite on the Rangwa-Gwasi connecting ridge. It closely resembles the micro-ijolites. The pyroxene is a deep green zoned aegirine-diopside, and sphene is an abundant accessory. Subordinate patches of Carlsbad-twinned orthoclase are also present, indicating a foyaitic affinity.

The presence of foyaitic phases within the ijolites suggests that there is a gradation and not a marked break between the foyaitic and ijolitic rocks, in contrast to the sharp contact that exists between the ijolites and the uncompahgrites.

Relative Age of the Syenites.—The syenite of the spur south of Usengere is directly overlain by nephelinite agglomerate (the upper agglomerate of the Middle Kisingiri group) which is of much later date. It is at once apparent that the cover below which the syenites were emplaced had been removed prior to the agglomerate eruptions, and that the syenites and associated foyaitic dykes were probably greatly eroded before the deposition of the agglomerates. This observation is strong evidence that the Rangwa complex was greatly eroded prior to the Kisingiri lava and pyroclast eruptions—indeed it is possible that the alkaline intrusive complex may have preceded the sub-Miocene peneplanation.

(ii) *The Ijolites.*—Two main outcrops of ijolite are exposed, at Sagurumi and on the southern margin of Rangwa.

Sagurumi Ijolite.—Sagurumi is a small, kidney-shaped, grassy hill rising some three hundred feet above the edge of the lake, two miles north-east of the margin of the Rangwa vent. The hill consists of a banded ijolitic intrusion forming the two spurs composing the western half of the hill, with fenitized Precambrian leucogranite cut by small marginal dykes of ijolite and micro-ijolite forming the crest and eastern flank.

The ijolite on the western margin of the hill is mainly a black and white rock of extremely coarse texture, showing on fresh surfaces sub-idiomorphic crystals of nepheline with a resinous lustre, together with aggregates of dark green pyroxene prisms, melanite garnets and black lustrous aggregates of magnetite. The composition alternates rapidly, however, over a few inches and ranges from urtitic through to melteigitic, the light-coloured urtitic bands being relatively free from mafic minerals. Bands of ijolite, poor in magnetite and composed almost entirely of green pyroxene prisms and nepheline, are also intercalated. Half-way up the southern spur of the hill a pink urtitic ijolite is exposed. The pink colour is due to discolouration of the nepheline and not apparently to any unusual mineral content. A compositional banding is clearly visible at several points and invariably dips steeply at 70° to 80° to the north-east.

About fifty feet below the summit, near to the contact of the ijolite with the Precambrian leucogranite, bands of compact dark green micro-ijolite and micro-melteigite make their appearance. These have a markedly fissile jointing, giving them the appearance of cleaved rocks or metamorphic green schists. A general decrease in coarseness of texture in the ijolite was noted near to the granite contact.

The contact with the granite is marked by the massive body of ijolite passing into a series of marginal micro-ijolite and micro-melteigite dykes of similar texture to the bands described above. These mostly run parallel to the margin of the main body but many irregular veins of micro-ijolite, often less than an inch wide, cut the granite near to the ijolite contact. The granite has a green discolouration and thin sections reveal a considerable degree of fenitization.

In thin sections the ijolites show coarse holocrystalline textures and in some cases are pegmatoid. The coarser examples are typified by specimen 41/1202B. This consists of an aggregate of allotriomorphic nepheline crystals up to 5 mm. in length, among which are set prisms of irregular, zoned, grass-green aegirine-diopside of similar length. The pyroxenes show a high extinction angle and weak pleochroism. Large irregular grains of magnetite are aggregated with the pyroxene. Apatite in small well-formed prisms and in large irregular grains associated with the magnetite is an accessory. The nepheline shows some alteration along cracks to cancrinite.

Specimen 41/1202A is a typical magnetite-poor ijolite. It resembles the specimen described above but is almost entirely made up of pyroxene and nepheline. It is cut by a vein of cancrinite, calcite and white mica, derived from alteration of the nepheline as a result of late passage of fluids. Apatite is an abundant accessory, and a small amount of chestnut-brown mica is present along the vein as partial coronas on the pyroxene. A segregation of melteigitic composition is represented by specimen 41/1202C. This contains many dark brown to opaque sub-idiomorphic or irregular melanite garnets, distinguishable from magnetite aggregates by their crystal form and less pronounced brilliance under reflected light. Small crystals of chestnut-brown mica are again present.

An urtite band composed of nepheline, wollastonite, and sparse and insignificant pyroxene individuals is exemplified by specimen 41/1801 (Plate X, Fig. 2). The wollastonite has the form of broad prisms up to 2 to 3 mm. long, and is replacive on the mosaic of nepheline. It is partly altered to calcite. An urtitic ijolite (41/1803) shows no magnetite, and only sparse melanite.

A marginal ijolite dyke, slightly coarser in texture than most, is represented by specimen 41/1812 (Plate XI, Fig. 1). It is a melanite ijolite with prominent nearly opaque sub-idiomorphic crystals of melanite. The nepheline grains are sub-idiomorphic and are enclosed by irregular growths of grass green aegirine-diopside which curve round them. Minute prisms of the same pyroxene are included within the nephelines. The garnets contain poikilitic inclusions of sphene, and enclose sub-idiomorphic nepheline crystals and pyroxene. The order of crystallization is apparently nepheline—aegirine-diopside—melanite.

Another marginal dyke from Sagurumi (41/1810) differs from the ijolite described above, in that the pyroxene is partly a zoned bottle-green aegirine with, in some cases, lighter aegirine-diopside cores. A tendency for the pyroxenes to be concentrated around the margins of the nephelines is again obvious. Sub-idiomorphic wedge-shaped crystals of sphene are a prominent accessory, and granules of secondary cancrinite are abundant.

The most fine-grained micro-ijolite dykes and veins have a granoblastic texture. In specimen 41/1805, for example, the nepheline forms a fine granoblastic mosaic together with bright green irregular granules of aegirine-augite, which tend to be moulded on the margins of the nepheline crystals. Granular sphene, apatite, and a little magnetite are accessories.

The Ijolitic Rocks of South Rangwa.—A zone of ijolitic rocks confocal and peripheral to the uncompahgrite zone is exposed on the south and south-east side of Rangwa. In the two easterly spurs projecting south-eastwards only a narrow zone of ijolitic rocks, passing rapidly into a series of discrete ring dykes, separates the uncompahgrite from the granite. On the most southern spur (the ridge connecting Rangwa and Gwasi) the ijolite zone has a width of a quarter of a mile, and passes into a marginal zone of discrete dykes cutting the granite country-rock.

Dark green fissile micro-ijolite and micro-melteigite with a close jointing parallel to the length of the ijolite zone form the greater part of the southern ijolite body. Coarsely crystalline ijolite, like that which makes up the bulk of the Sagurumi ijolite mass, is limited to a few localized bands in the intrusion. Such coarse bands dip steeply inwards or outwards and a ring dyke form with associated smaller marginal ring dykes is deduced for the ijolitic body.

One of the micro-melteigites (41/1293) shows in thin section a directional texture, aegirine-diopside prisms, with dark green outer zones and paler green cores being roughly aligned. There is also a tendency for alignment of the nepheline. The pyroxene prisms have ragged edges and are accompanied by small granules of aegirine-diopside which, together with nepheline, form a granoblastic base to the rock. Granular patches of nepheline almost

free of pyroxene indicate that the rock was originally coarse-textured or porphyritic. Sphene, which is sometimes elongated and shares in the parallel texture, is an abundant accessory while magnetite is more sparse. The granoblastic texture suggests that the rock has crystallized under considerable stress.

In specimen 41/1297, a micro-ijolite, a granoblastic texture is less completely developed and there is a less marked directed orientation of the minerals. Well-formed nepheline individuals are numerous, through the base is granoblastic. Sphene is an abundant accessory while magnetite is limited to sparse grains. Specimen 41/1263, a micro-melteigite, has a coarser granoblastic texture and consists of nepheline, unzoned aegirine-diopside, and melanite, together with magnetite and sphene. It is, however, devoid of both large pyroxene prisms and pools after nepheline, but it has a schliere in which coarser nepheline and pyroxene are developed and no magnetite or melanite are present. Specimen 41/1258 is a micro-melteigite similar to 41/1263 but the pyroxene is rather darker, and melanite is absent. There is a little golden brown mica in patches and sphene is abundant in large crystals.

An example of the coarser intrusions of ijolite from the eastern spur of Rangwa is represented by specimens 41/1264, which was taken from a dark green moderately coarsely crystalline band among the micro-ijolites and micro-melteigites. In thin section (Plate X, Fig. 1) it is seen to be composed of light green aegirine-diopside, magnetite, perovskite and nepheline. Specimen 41/1264A from the same band is slightly more fine-grained and has a directed texture. It is a perovskite melteigite.

Specimen 41/1397 is a melanitic melteigite with a granoblastic directed texture. Melanite, biotite (greenish brown to orange-brown in colour), light green aegirine-diopside and nepheline make up the granoblastic mosaic. Specimen 41/1292 is similar but shows no directed texture and contains perovskite.

Marginal Effects of the Alkaline Complex—Fenitization.—The process of fenitization was first described by Brögger (1921) in the Fen district of Norway. A discussion by Baker (1953, p. 40), incorporated in a description of the alkaline complex of Jombo hill, Kenya, gives a concise summary of ideas on the process.

Fenitization is essentially a process of metasomatic replacement in the wall-rocks of alkaline intrusive complexes, involving the abstraction of silica and sodium and the introduction of potassium and calcium (with some iron, titanium and phosphorus) into the wall-rocks. How much metasomatic processes akin to fenitization play a part in the formation of the alkaline igneous rocks of the confocal zones in a ring complex such as Rangwa is not known, but it is certain that the present compositions of many of the alkaline igneous rocks are due to metasomatic replacement, caused by later pulsations of more mafic solutions through already crystallized rock. This is evidenced by the replacement relationship of the aegirine and aegirine-diopside to the felsic minerals in many of the ijolitic and foyaitic rocks of Usaki, Ruri and Rangwa.

The alkaline igneous rocks of Rangwa were emplaced in Precambrian leucogranites which, in the course of their prolonged geological history, had undergone some shearing and shattering producing abundant microfractures in their fabric. The presence of such suitable paths for pulsating fluids has led to the introduced material being here concentrated along microfractures and the boundaries of larger crystals, and spreading out from these channels as replacive patches in the surrounding granite fabric. It is probable that part of the shattering of the granite is directly related to the alkaline intrusion and is the equivalent of von Eckermann's thermo-dynamic shock zone (von Eckermann, 1948, pp. 29, 161).

The first indications of fenitization are the shattering of the granite, and the presence of green and brown veins along microfractures (cf. Garson, 1952, p. 22). With increased fenitization the granite takes on a grey-green tinge (e.g. specimen 41/1296 from south of Rangwa). The extremely fenitized granites of Mbassa Island and Omutuma (e.g. specimen 41/1847) are mottled green and white felspathic rocks with the appearance of diorites.

In thin sections the fenitized granites are seen to be veined by stringers of aegirine, and more rarely arfvedsonite. In the least altered examples (e.g. 41/1806, from Sagurumi) stringers of recrystallized anorthoclase felspar with minute aegirine prisms, iron ore, sporadic carbonate and in places aggregates of light brown fine-grained mica form a network in the shattered rock. Fresh recrystallized orthoclase crystals in the fabric of the cataclastic granite are associated with aegirine and iron ore stringers in another specimen (41/1808) from Sagurumi.

Reddish brown biotite is conspicuously developed in specimen 41/1296, from the south side of Rangwa, in which magnetite grains also appear in association with the aegirine stringers, and where the additional new minerals may be due to the contact effect of the uncompahgrite intrusion. In some specimens (e.g. 41/1255, from the eastern spur of Rangwa) the aegirine is finely divided and has the form of a greenish dust only resolvable into distinct grains under a high-powered objective. In some of the outlying exposures of cataclastic granite, as on Kwiunga and Olori, the microfractures are filled only with carbonate and amorphous iron ore, and in some cases the carbonate is present in such quantity as to convert the granite into a calcareous breccia (41/1144, 41/1221). Whether these carbonate-bearing ferruginous veinlets are contemporaneous with the aegirine stringers is not certain. There is always an association between the aegirine and iron-ore-carbonate stringers, but the latter may be at least in part later introductions associated with the carbonatite intrusions of Rangwa. It is possible that some of the coarser of these veins, such as specimen 41/1144 from Kwuinga represent injections of tuff from Rangwa.

More completely fenitized granite is seen in specimen 41/1809 from Sagurumi. The granite has taken on a greenish dioritic appearance and in thin section replacive aggregates of grass-green aegirine-diopside and aegirine are conspicuous, spreading out from microfractures, and forming a notable proportion of the rock. Carbonate and iron ore are again associated with the aegirine. Near to the ijolite contact on Sagurumi the fenitized granite is veined with small irregular bodies of micro-ijolite of apparently replacive origin, and these irregular veins pass into a series of parallel marginal dykes of micro-ijolite closely spaced in the granite, and parallel to the margin of the main body of ijolite. In specimen 41/1847, a fenitized granite from Mbassa, radiate growths, aggregates and crystals of aegirine and arfvedsonite have spread out from microfractures and in specimen 41/1241 from Omutageti the same minerals have spread from cracks curving around the crystal margins.

The most extreme example of fenitization was seen on Omutuma, where a grey body of rock mapped as a dyke forms a band roughly parallel with the margin of the Rangwa complex and "cuts" fenitized granite. From a study of thin sections of the grey rock it would appear to be in part derived by metasomatic replacement, but it may be a mobilized fenite. The thin sections (41/1239) show a mixed rock made up of a network of stringers and patches of micro-ijolite composed of aegirine, nepheline aggregated with cancrinite, and a little sphene and apatite, enclosing patches of freshly crystallized orthoclase and oligoclase. The orthoclase forms large crystals while the plagioclase occurs in smaller individuals and in part as skeletal residuals of larger crystals in the process of being replaced by the orthoclase.

This rock is interpreted as a fenite hybrid, the last stage in the formation of a syenitic rock by metasomatism and "soaking" of a microcline-oligoclase leucogranite and, indeed, were the plagioclase felspar to disappear it would be indistinguishable from the Rangwa syenites. The dividing line between metasomatic alteration and the introduction of magmatic material to form a hybrid has been reached, and perhaps the extreme of this hybridization is seen in the foyaitic phases within the ijolite zone south of Rangwa (e.g. specimen 41/1257, from the south-eastern spur of Rangwa). Such rocks may represent the last stage in the process of fenitization of the country-rock, accompanied by hybridization, before an ijolitic felspar-free rock of purely magmatic origin is attained.

The question presents itself whether all the syenites of Rangwa are not due to hybridization, and derived by a similar process of intimate magmatic soaking accompanied by metasomatic reconstitution (fenitization) of the country-rock. This would account for the lack of any well-defined boundary between the ijolitic and syenitic rocks and the gradual disappearance of foyaitic rock types away from the margin of the ijolite zone. A similar derivation for marginal syenites by reaction of ijolite magma with the country-rock is accepted at Ahvenvaara, Finland and also in the Fen district ofNorway (Shand, 1945, p. 502).

(iii) *Biotite Uncompahgrites.*—The biotite uncompahgrites are coarse-grained rocks containing melilite and, as such rocks are rare, are of unusual interest. Melilitic igneous rocks of plutonic aspect have been described from the inner zones of the alkaline ring complexes of the Kola peninsula (Kranck, 1928) and Iron Hill, Colorado (Larsen, 1942, p. 9) Kranck called the Kola rock *turjaite* and defined it as coarse-grained and consisting of: melilite 35 per cent, nepheline 17 per cent (together with perovskite, titanomagnetite, melanite, cebollite, etc.), biotite 33 per cent, apatite 5–10 per cent.

Uncompahgrite was defined by Larsen as an exceptionally coarse-grained rock containing 70 per cent or more of melilite, with small amounts of pyroxene, magnetite, perovskite and apatite.

The majority of the melilitic plutonic rocks of Rangwa contain no nepheline, thus differing from the turjaites, and though they more closely resemble uncompahgrites, they differ in having biotite as a major constituent; moreover the melitite content shows a considerable variation, some relatively melilite-poor rocks being represented. The term biotite uncompahgrite has been adopted for these rocks.

The biotite uncompahgrite forms a single body one and a half miles long and about 700 feet in maximum thickness in the southern cliffs of Rangwa, immediately below the margin of the pyroclasts of the vent. The rock is characterized by pronounced compositional banding (*see* Plate III, Fig. 1) dipping into the hill at an average of 30°, and suggesting that its form is that of a cone-sheet.

It is a coarse rock, with texture varying from "giant-grained" to medium-grained. When fresh the coarser rocks have a bluish colouration, and the melilite base shows a greasy lustre: magnetite forms prominent black patches on the surface, while black books of biotite up to an inch across are also prominent (*see* Plate IV, Fig. 2). Smaller red-brown grains of perovskite and apatite prisms can also be recognized on fresh surfaces. Weathered surfaces are usually buff to cream with brown-stained magnetite standing out conspicuously. More fine-grained examples have a compact steely grey appearance when fresh, still, however, preserving the slightly resinous lustre of the melilite. The melilite rarely shows good crystal form, but rectangular sections can be clearly seen in some very coarse bands (*see* Plate IV, Fig. 1). Pale green alteration products resembling serpentine often fill cracks in the melilite.

In thin section the uncompahgrite shows a base of melilite in xenomorphic plates. Inset in this base are large plates of biotite, magnetite aggregates, and smaller individuals of perovskite and apatite. The melilite has low birefringence often showing the anomalous "Berlin blue" polarization colours. Distinction of melilite from nepheline is not always easy in the field, but under the microscope it is distinguished by the nature of the alteration products along cracks and also by the higher refractive index. Little or no nepheline appears to be present in these rocks.

In specimen 41/1398 the melilite shows secondary alteration in broad marginal zones and along cracks to a pale green mineral resembling serpentine (cf. Plate XI, Fig. 2). This is tentatively identified as cebollite ($Ca_5Al_2(OH)_4Si_{13}0_{12}$?) (Larsen, 1932, p. 11). Under crossed nicols the fibrous nature of the mineral is apparent, the fibres having straight extinction. Peg structure is not usually apparent in the melilite.

The biotite is usually a reddish brown variety with a very low optic angle, when it is dichroic from shades of very pale pinkish brown to a foxy reddish brown. In specimen 41/1260 the mica is blotchily foxy reddish brown and green in the direction of maximum absorption, and dichroic to light brownish pink.

Perovskite is present in the form of large grains up to a millimetre across and showing good crystal form (Plate XI, Fig. 2). It has a clove-brown colour, and is anisotropic, showing first order grey and yellow polarization colours and narrow polysynthetic twin lamellae. Chemical analysis has shown the perovskite to be a columbian variety, containing about a half per cent of Nb_2O_5. The result of an analysis carried out by the Mineral Resources Department of the Directorate of Colonial Geological Surveys is as follows:—

	per cent
CaO	39·65
TiO_2	56·36
Nb_2O_5..	0·56
Fe_2O_3	1·30
Rare earths	0·73
Ta_2O_5	not detected $<0·05$
	98·60

Anal. P. J. Moore

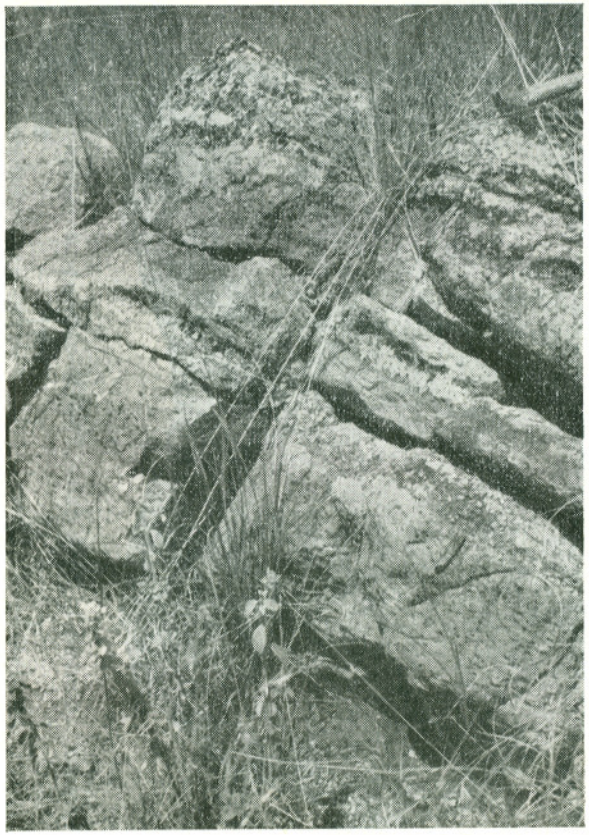


Fig. 1.—Uncompahgrite at Rangwa, showing banding dipping inwards to the volcanic centre.

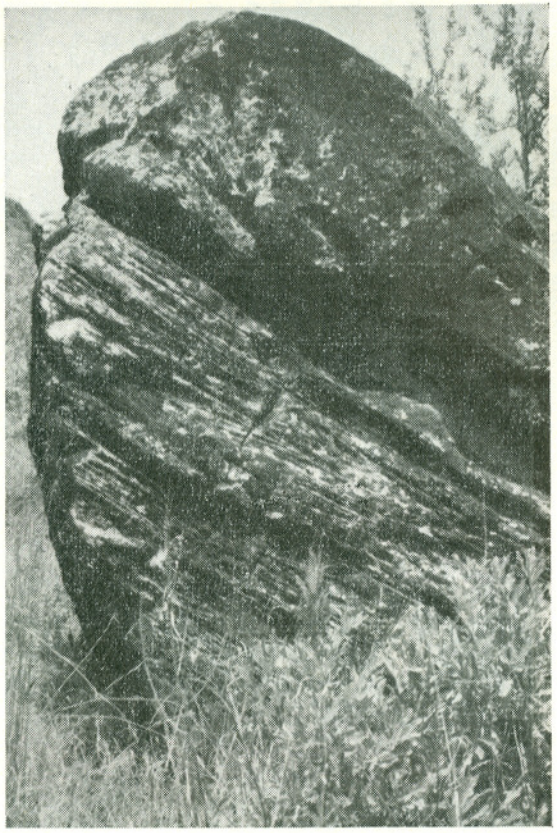


Fig. 2.—Stratified ash and lapilli tuff (upper layer) dipping in towards the centre of the Rangwa complex. South-east margin, Rangwa vent.

Plate IV



Fig. 1.—Well-formed melilite crystals standing out on the weathered surface of a giant-grained band in the uncompahgrite, Rangwa.



Fig. 2.—Coarse-grained uncompahgrite, containing large books of biotite.

Apatite is present in the uncompahgrites as idiomorphic or sub-idiomorphic prisms, and in some of the coarser specimens they are up to a centimeter in length. Diopside, pale green in colour and with a large extinction angle, is sometimes present in sparse well-formed prisms. Melanite garnet, rather pale brown in colour, is a rare component. A basic segregation rich in melanite and biotite is seen in specimen 41/1260. The magnetite has a tendency to be aggregated with the perovskite and biotite and in some thin sections (e.g. 41/1275) reaction rims, an inner one of perovskite and an outer one of biotite, enclose the magnetite (Plate XII, Fig. 1).

Turjaite is present within the uncompahgrite body, but is intimately mixed up with it, and cannot be mapped as separate intrusions. The turjaite (specimens 41/1390, 41/1391, 41/1396 and 41/1398) differs from the uncompahgrite in the presence of patches and stringers of water clear, unaltered nepheline, forming a granoblastic mosaic. It has probably originated as a result of the marginal reaction of uncompahgrite with ijolite country-rock.

Analyses of uncompahgrite specimens 41/1395 and 41/1394 are given in the table below. Both specimens are medium-grained.

CHEMICAL ANALYSES OF UNCOMPAHGRITES FROM RANGWA AND IRON HILL, COLORADO

	1	2	A	B
	per cent	*per cent*	*per cent*	*per cent*
SiO_2	34·68	33·73	38·57	38·04
Al_2O_3	6·70	7·18	5·79	6·34
Fe_2O_3	7·30	9·11	5·41	8·45
FeO	7·28	6·79	3·33	5·90
MgO	7·48	8·77	8·44	7·81
CaO	30·12	26·89	30·72	27·19
Na_2O	1·84	1·88	2·34	2·16
K_2O	0·45	1·15	0·42	0·12
$H_2O+110°C$	0·99	0·62	0·62	0·48
$H_2O-110°C$	0·14	0·06	0·34	0·22
CO_2	0·18	0·98	1·28	0·30
TiO_2	1·75	2·05	1·71	1·98
P_2O_5	n.d.	n.d.	0·83	0·24
SO_3 (Sol. Sulphates)	0·02	n.d.	—	—
Cl	0·06	Tr.	—	—
F	Tr.	n.d.	—	—
S (combined)	0·15	n.d.	0·03	0·02
Cr_2O_3	n.d.	0·13	—	—
MnO	0·14	0·18	0·16	0·23
BaO	0·03	0·03	0·28	—
Total Rare Earths and ThO_2	Tr.	0·14	—	—
Nb_2O_5	0·08	0·10	—	—
	99·39	99·79	100·64*	99·74†
Less O for Cl and S	0·02			
	99·37			
Sp. Gr.	3·31	3·18	3·25	

n.d.—not detected.
*including ZrO_2 0·02, SrO 0·35
†including SrO 0·26

1. Biotite uncompahgrite, specimen 41/1395, south flank of Rangwa. Analyst, Mrs. J. M. Stephens.

2. Biotite uncompahgrite, specimen 41/1394, south flank of Rangwa. Analyst, Mrs. J. M. Stephens.

A. Coarse fresh uncompahgrite (U–718), south Beaver Creek, Iron Hill (Larsen, 1942, p. 13).

B. Uncompahgrite, millimeter-grained (U–2015), east of Beaver Creek, Iron Hill (Larsen, 1942, p. 13).

NORMS

	1	2	A	B
an	8·90	7·51	4·03	7·23
lc	1·74	6·54	1·80	0·44
ne	8·52	7·95	10·79	9·94
di	8·21	3·23	21·55	39·07
wo	—	35·96	—	—
ol	21·80	—	7·63	1·57
cs	36·64	18·58	37·61	23·39
mt	10·67	13·22	6·03	12·30
hm	—	—	1·28	—
cm	—	0·15	—	—
il	3·34	3·95	3·26	3·80
ap	—	—	1·64	0·67
pr	0·49	—	—	—
cc	0·50	2·30	2·90	—

MODES

	1	2	A	B
melilite	65	68	72	64
calcite	2	—	2	1
pyroxene	—	—	9	15
magnetite ilmenite	15	12	7	13
perovskite	7	12	—	4
apatite	—	1	1	1
melanite	—	—	8	—
biotite	1	1	1	2
cancrinite	1	1	—	—
alteration products of melilite: cebollites and (?) zeolites	9	5	—	—

The modes of specimen 41/1395 and 41/1394 were derived by rough visual assessment of the volume proportions in microscope slides. The proportion of the various minerals shows great variation over a few centimetres of rock, and such figures are only an approximate expression of the composition of the rock as a whole. Biotite is unusually sparse in 41/1395 and is generally absent from 41/1394. By chance a specimen with low biotite content was analysed in both cases.

The analyses reveal a slightly lower silica content than the uncompahgrites from Iron Hill; otherwise there is a remarkable correspondence. With respect to modal compositions the proportion of pyroxene appears to be much lower in the Rangwa rocks as a whole, whilst biotite, though not apparent in the samples analysed, is proportionally more abundant and in some cases forms up to 15 per cent of the rock. Apatite is of patchy distribution in both of the analysed samples, but is conspicuous in some bands in the uncompahgrite.

(iv) *The Pyroclastic Vent Rocks.*—The greater part of the plug at Rangwa is composed of pyroclastic rocks. These preserve their original textures but are all much altered and replaced by carbonate. The degree of calcification increases towards the volcanic centre, the peripheral rocks being the least altered.

On the north-east margin of Rangwa where the hill abuts on the lake, purplish grey explosion breccias containing angular fragments or lapilli tuffs are exposed. They are the most common pyroclastic types in the vent. In thin section the breccias are seen to have a base of rounded fragments, closely packed and heavily calcified, and inset with larger angular fragments. Boulders of leucogranite and metabasalt derived from the Precambrian floor are common inclusions in them.

On the southern margin of the vent lapilli tuffs, only slightly calcified, are exposed (Plate III, Fig. 2). They are greenish grey rocks containing dark green fragments of lava, pyroxene crystals and enclaves of uncompahgrite. Under the microscope nepheline crystals pseudomorphosed by calcite can occasionally be seen, revealing that the original rock was probably a nephelinite tuff. Large golden flakes of mica are also present.

The coarser pyroclasts consist mainly of the explosion breccias and lapilli tuffs described above. Extremely coarse agglomerates were noted in only two localities. At one, on the north-east side of the vent, agglomerates are exposed that contain boulders a foot or more across, mainly of syenite similar to the peripheral syenites of the vent. Intercalated in the coarser breccias are bands of more fine-grained pyroclasts. They are mostly seen near the edge of the vent and have their greatest development on the east and north margins.

The very fine tuffs are best seen in an exposure in the western cliffs. They are compact flaggy grey rocks showing a definite stratification dipping gently into the centre. In thin section they are seen to be heavily calcified, but fragments of aegirine-diopside and melilite are identifiable. On the northern margin some stratified green tuffs are exposed, the stratification once again dipping gently inwards. The continuation of these outcrops can be followed round to the south-east sector of the outer wall of the plug (Plate III, Fig. 2). Several bands of such tuffs can be detected alternating with coarser purplish breccias and brown lapilli tuffs.

The alternation of fine-grained and coarse pyroclasts makes up a banded series dipping everywhere inwards to the volcanic centre with dips varying from 5° to 40°. The dips are occasionally steeper, but such steep dips are local. The finer stratification and the boundaries of the coarse and fine bands are parallel and the dip is thought to represent the angle of repose at which the pyroclasts came to rest within the vent. It seems most probable that the plug is cylindrical rather than funnel-shaped, and that the steep outer cliffs reflect the almost vertical walls of the vent. A nearly vertical inward-hading set of confocal joint fractures is present at the margin of the plug besides a less steep inward-dipping set filled by carbonatite cone-sheets.

It is noteworthy that the finer pyroclastic material at Rangwa is near to the periphery of the vent: such material corresponds, presumably, to the lower Miocene tuffs and intercalated agglomerates of Rusinga and Mfanganu. The centre of the vent is composed of much coarser explosion breccias and presumably corresponds to the thick upper agglomerate of Kisingiri.

The pyroclasts, besides being heavily calcified, show a yellow discolouration over large areas. Some of the more fine-grained calcified ashes contain orbicular structures resembling pisolites, but in thin section they are seen to be spheroids of secondary origin, and were probably developed during the calcification process.

In the middle of the vent, within the central valley, a blue carbonatite is exposed which, however, on close examination is seen to have palimpsest structures indicating that it is derived from an agglomerate. In thin sections the whole rock is found to be composed of a carbonate mosaic, only dirty greenish patches representing the minerals that comprised the original pyroclastic rock.

A second small vent of pyroclastic rocks similar to those of Rangwa is situated at Rukungu, a small knoll three miles west of Rangwa. In thin section the fine tuffs from this locality are seen to be composed partly of quartz and felspars derived from the Precambrian granite.

No pyrochlore or monazite has been detected in the pyroclastic rocks but the yellow discolouration of the breccias gives them a strong resemblance to the rare earth- and columbium-bearing breccias of Mrima hill south of Mombasa, which contain little visible monazite or pyrochlore. It is possible that the same minerals may be found here in a very finely divided state.

(v) *The carbonatites.*—Rangwa differs from the Ruri complexes (p. 63) in that great ring dykes of massive carbonatite are not present. In the outer part of the complex the intrusive carbonatite is restricted to minor cone-sheets not more than a few feet thick, and to small vertical dykes, usually radially orientated, cutting the calcified pyroclasts. In the centre several larger irregular bodies of carbonatite, apparently small plugs, are exposed. It seems probable that Rangwa has been eroded to a lesser extent than the Ruri complexes, only the uppermost part of the carbonatite ring complex being exposed. Alternatively it may have been emplaced at a different level.

In the centre of the vent the carbonatite ranges from cream to brown in colour and is often coarsely crystalline. Magnetite in perfect octahedra forms conspicuous clots and schlieren. Red phlogopite crystals are also conspicuous on the weathered surfaces, and tend to accompany the magnetite. Pyrochlore in yellow resinous crystals showing cube-octohedral form can be recognized with a hand lens. In thin section the carbonate is seen to form a coarse mosaic with varying amounts of iron-staining, often along sutures in the mosaic and cracks in the carbonate crystals. The phlogopite is heavily altered to a bronze-coloured vermiculite or colourless mica. Pale yellow isotropic crystals of pyrochlore with sub-idiomorphic form and up to 1 mm. in diameter are concentrated in the magnetite schlieren (Plate XII, Fig. 2). Clusters of apatite prisms are also associated with enrichments of magnetite and pyrochlore.

Numerous minor intrusions of carbonatite cut the pyroclasts in the outer part of the vent and are mainly exposed in the outer cliffs. On the upper slopes very few carbonatites are seen, suggesting that the higher remaining parts of the volcano have been eroded only sufficiently to expose the uppermost level of the carbonatite complex. The cone-sheets are composed of fine- to medium-grained compact buff or brown carbonatite or greenish crystalline carbonatite. Small veins of exceedingly fine-grained ochre-yellow carbonatite are also widespread both as separate bodies cutting the pyroclasts and as patchy segregation in the larger cone-sheets. In thin section the carbonatite cone-sheets and minor dykes reveal little information of interest. The mosaics of carbonate vary from coarsely crystalline to very fine-grained. Yellowish brown amorphous iron ore fills the interstitial spaces and forms stain patches scattered at random throughout. Vesuvianite is present in specimen 41/1218. No pyrochlore can be detected, but magnetite, phlogopite and apatite grains are sometimes present. In one exposure on the south wall of the vent perfect rhombs of carbonate (dolomite?) with brown ferruginious skins are set in the carbonate mosaic, giving the rock a "porphyritic" structure.

The iron-staining of the carbonatites is much less developed than in the Ruri complexes and there is not the abundant development of ironstone segregations and veins seen there. As would be expected the absence of copious hydrated iron oxide deposits is parallelled by an absence of areas of high radio-activity. A slight rise in radio-activity up to four times background was noted towards the centre of Rangwa over areas where the carbonatite contains pyrochlore, and over the deep fill of red alluvium in the central valley. It seems likely that the greater part of the radio-activity of Rangwa is due to pyrochlore.

A geometrical projection of the cone-sheets downwards, taking the average dip at 30° and allowing for some inwards steepening, leads to the deduction of an explosion focus at approximately 4,000 to 5,000 feet below the present erosion surface (taken as 4,000 feet above sea-level).

Three carbonatite samples from the outer cone-sheet zone of Rangwa were partially analyzed, with the following results.

CHEMICAL ANALYSES OF CARBONATITES FROM RANGWA

	41/1168	41/1172	41/1218
SiO_2	0·74	0·23	2·56
Al_2O_3	5·71	3·30	6·00
Fe_2O_3	2·19	1·73	6·48
MgO	0·28	2·37	6·50
CaO	50·05	49·57	37·80
Loss on Ignition	37·90	41·42	38·12
TiO_2	0·08	0·07	0·16
TOTALS	96·95	98·69	97·82

Analyst: Mrs. J. M. Stephens.

41/1168. White crystalline carbonatite, Rangwa (north side).

41/1172. Brownish buff crystalline carbonatite, Rangwa (north side).

41/1218. Yellow compact carbonatite veins in carbonatite dyke, Olori.

Specimen 41/1218 contains appreciable vesuvianite, which accounts for the high alumina and silica.

The analyses closely match those of carbonatites from Ruri, Tuige, Sokolo and Homa mountain (Saggerson 1952, p. 81). It is seen that the small bright yellow veins and dykes which are widespread on Rangwa (represented by 41/1218) are more dolomitic than the other carbonatites, which are dominantly calcitic. No beforsites have, however, been identified. The cone-sheets and dykes are relatively pure alvikites with negligible silica content.

A specimen, 41/1323, of pyrochlore-bearing carbonatite from Rangwa was analyzed in full, with the following result:—

CHEMICAL ANALYSES OF PYROCHLORE-BEARING CARBONATITE FROM RANGWA

	per cent
SiO_2	0·45
Al_2O_3	4·84
Fe_2O_3	5·89
FeO	0·84
MgO	0·11
CaO	50·08
Alkalies as Na_2O	0·31
H_2O (+105°/110°)	1·18
H_2O (—105°/110°)	0·31
CO_2	33·12
TiO_2	0·28
P_2O_5	0·17
SO_3	0·32
Cl	0·03
F	0·07
Cr_2O_3	0·07
MnO	0·66
BaO	0·63
T.R.E.+ThO_2	0·16
Nb_2O_5	0·28
	99·80
Less O_2 equivalent of F and Cl	0·04
	99·76

Analyst: W. P. Horne.

(c) The Kisingiri Volcanic Series

The Kisingiri Volcanic Series was erupted from the Kisingiri volcanic centre after the cover of the alkaline and melilitic igneous rocks had been removed by erosion. It is clear that the great cone of Kisingiri rose from a lake or a chain of shallow lakes encircling the volcano and, while on the upper slopes agglomerates and tuffaceous deposits were banked up, around the lower edges the pyroclastic material was mingled with water-laid sediments composed in the main of reworked volcanic material. These are the extreme marginal deposits of the Lower Miocene lakes. A similar relation has been observed by Searle on Mount Elgon (Searle 1952, p. 58).

The Kisingiri Volcanic Series can be divided into three stratigraphic groups:—

	Maximum Thickness (*feet*)
3. Upper Kisingiri lavas	500
2. Middle Kisingiri Pyroclastic group (nephelinite agglomerates and associated pyroclasts)	1,500
1. Lower Kisingiri lavas	900

The volcanic rocks are dominantly nephelinitic and lavas of the types described by Searle (1952, p. 56) from Mount Elgon are found. No stratigraphic distinction according to composition can be made.

The lavas include the following types:—

Nepheline-bearing	*Nepheline>mafics*	*Nepheline<mafics*
	Nephelinite	Mela-nephelinite
	Nepheline+melilite>mafics	*Nepheline+melilite<mafics*
	Melilite nephelinite	Melitite mela-nephelinite
Nepheline-free	*Melilite>mafics*	*Melilite>mafics*
	Melilitite	Melanocratic melilitite

Olivine is present in some of the melanocratic types, which are referred to as olivine nephelinites, melilite olivine nephelinites and olivine melilitites.

(i) *The Lower Kisingiri Nephelinite Lavas.*—The oldest extrusive rocks of the Kisingiri volcano consist of a series of nephelinite lava flows, which are mainly exposed on the inner side of the Gembe-Gwasi-Usengere ridge, resting directly upon the updomed surface of Precambrian rocks within the central amphitheatre. The lower nephelinites are exposed on the west face of Gembe (Fig. 3), the north slopes of Nyadenda and Gwasi, and at Ragwe Point. On the north slope of Usengere and at Kibibura they are absent, nephelinite agglomerates resting directly on the Precambrian rocks at these points. It is possible that pene-contemporaneous erosion has removed the lower lava group at these localities, but it seems more likely that the lavas formed a series of separate tongues, extruded radially from fissures down the surface of the dome of Precambrian rocks. The lower lavas do not outcrop in many localities distant from the Kisingiri centre, but they have been identified at the Goyo River section below the Kaniamwia escarpment, near Mbita point and on the north side of Mfanganu Island. On Mfanganu the nephelinites underlie lower Miocene lake beds (equivalent to the Hiwegi series of Rusinga Island ?—*see* p. 50) and melanite nephelinite agglomerate (equivalent to the Rusinga agglomerate ?—*see* p. 50). At the Goyo river section they underlie lake beds of presumed lower Miocene age, which themselves underlie the upper agglomerate of the Middle Kisingiri group. Boulders of nephelinites have been discovered by R. M. Shackleton and the writer in the Kiahera brown breccias (*see* p. 50) of Rusinga. It is apparent then that these nephelinite lavas are older than part at least of the lower Miocene sediments of Rusinga and Mfanganu. It is probable that the so-called Hota basalt of Rusinga (Whitworth, 1953, p. 84) is part of this lava series.

On the west side of Gembe the lava immediately overlying the Precambrian granite is a fine-grained dark green rock, with small but numerous cloudy white phenocrysts of nepheline and a few small dark pyroxene phenocrysts visible to the naked eye. Overlying these are porphyritic mela-nephelinites of a similar colour with prominent dark-coloured pyroxene phenocrysts, but no visible nepheline phenocrysts. The nephelinite lavas are overlain by

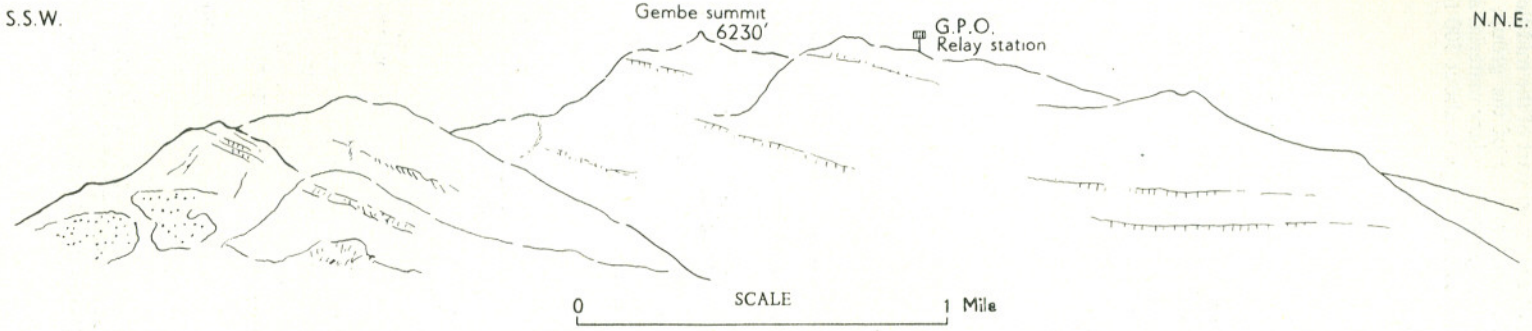


Fig. 3.—View of Gembe from the east showing the dip of the volcanic rocks sweeping up in a steeping curve towards the centre of the volcano.

coarse nephelinite agglomerates of the upper part of the middle group. Considerable secondary calcification has affected the higher lavas of the group, and vesicular lavas with the vesicles infilled by cloudy white and pink secondary material are not uncommon. The total thickness of the Lower Nephelinites on Gembe is about 500 feet.

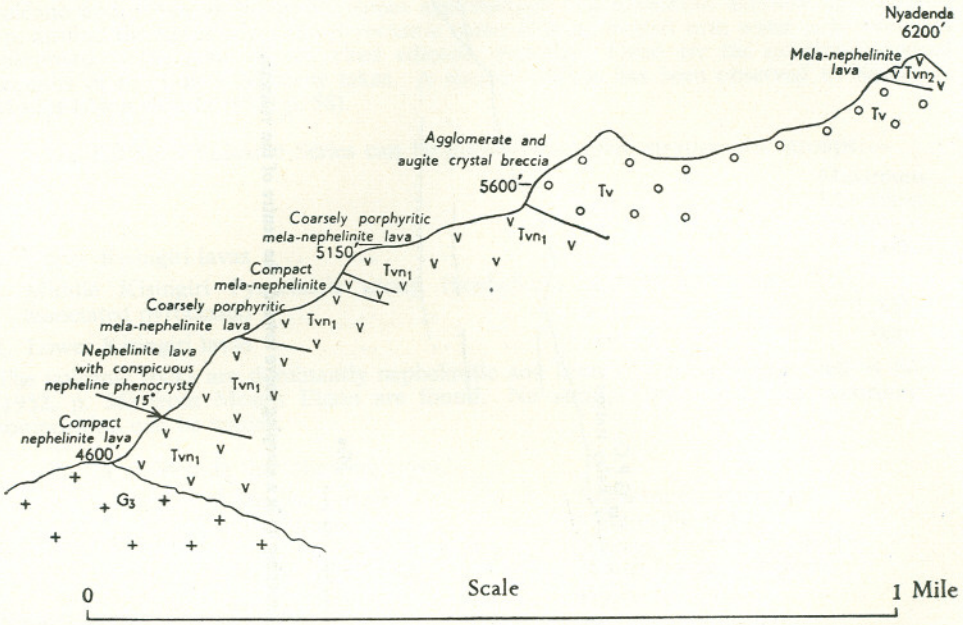


Fig. 4.—Sketch section of more than 900 feet of Lower Kisingiri nephelinite lavas on the north slope of Nyadenda.

On the north slope of Nyadenda (Fig. 4) the succession is much the same, except that the lowest lavas contain much larger nepheline phenocrysts than their analogues on Gembe (41/1335, 41/1341). Nearly a thousand feet of nephelinite lava is here exposed, the lavas dipping gently outwards at 10 to 15 degrees from the centre of Kisingiri. On the north slope of Gwasi the same succession is seen, but compact non-porphyritic nephelinites have a much greater development and the total thickness of the lava succession is about 500 feet.

Agglomerate was noted in a thin band within the nephelinites on Gembe but otherwise pyroclasts are absent. In the case of the mela-nephelinites with large and abundant pyroxene crystals set in a fine-grained altered and stained base it is often difficult to decide whether the rocks are crystal breccias of pyroclastic origin or lavas, but it is the opinion of the writer that most of the highly porphyritic mela-nephelinites (e.g. 41/1157, 41/1392) originated as flows. They are often vesicular, and contain no exotic inclusions as would be expected if they were tuffs or crystal breccias.

The lavas near Mbita point that are included in the Lower Kisingiri nephelinite group are dark blue-green vesicular melilitites (41/1641). They outcrop below the upper agglomerate of the middle pyroclastic group, and occur on the west coast some miles north of Rangwa and about a mile south of the point. The lavas (e.g. 41/1439) underlying the agglomerate and Miocene sediments in the Goyo river are similar, coarsely vesicular lavas, but are nephelinites. The lavas of these two localities are included in the lower nephelinite group because of their position, and because they bear a close resemblance to some of the vesicular members of the group on Gembe.

The lavas of the Lower group exposed on Mfanganu Island form a small outcrop on its north side. They are fine-textured compact mela-nephelinites, closely resembling the mela-nephelinite lavas on the west face of Gembe.

The nephelinitic lavas of the lower group of Kisingiri were undoubtedly fed by narrow radial and tangential dykes (described under "Minor Intrusions", p. 55) that cut the granitic rocks, Kaksingiri schists and syenite in the peripheral area of the Rangwa complex.

In thin section the nephelinites are seen to be essentially porphyritic. The lowest flows contain numerous small sub-idiomorphic phenocrysts of nepheline and an isotropic (analcitic ?) base. The phenocrysts vary greatly in size, grading from two millimeters across down to about a quarter of a millimeter, and are set in a matrix of crystals of nepheline crammed between the larger individuals. Specimen 41/1341, from Nyadenda, shows this texture well, but is rather unusual in that the pyroxene is a zoned emerald-green aegirine-diopside, instead of the pale green to flesh-coloured augite which is more typical of both the Lower and Upper Kisingiri nephelinite lavas. Judging from the difference of degree of alteration among the phenocrysts, they consist of more than one generation. Specimen 41/1208 from the north slope of Gwasi shows the more usual pyroxene, an augite weakly pleochroic from flesh to pale green.

Specimen 41/1159, from the south-east slope of Gembe near Kwitari, is an unusually coarsely porphyritic variety of nephelinite, with abundant augite accompanying the nepheline phenocrysts. The thin section shows prominent zeolite-filled vesicles, both rounded and irregular in form and frequently drawn out to an elongated shape. A vesicular nephelinite (41/1539) from the Goyo river section south of Ruri has a feeble trachytic texture, the augite prisms, which are pleochroic from flesh-coloured to pale green, showing a weak directed orientation due to flow. Between the prisms are crammed very small sub-idiomorphic nepheline crystals. The base is colourless and mainly isotropic, with analcite apparently forming the greater part. The vesicles are infilled with zeolites or with zeolites and calcite.

The mela-nephelinites are characterized by the same mineral assemblage as the nephelinites but flesh to pale green zoned augite and subsidiary zoned emerald green aegirine-diopside, together with magnetite, form the majority of the phenocrysts. Nepheline is subordinate or only present in the fine-grained glass-clear base, where it is associated with analcime. Specimen 41/1344 is a typical example of the porphyritic mela-nephelinites, while 41/1311 is a fine-textured vesicular variety with oval zeolite-infilled vesicles. Magnetite and perovskite are common accessories in these lavas.

Apatite is a rather less common accessory in all the nephelinites and mela-nephelinites, while a few crystals of red brown biotite, partly resorbed and with dark reaction rims, are sometimes present. For example in specimen 41/1214, from the north slope of Gwasi, large plates of biotite are visible to the naked eye on fresh surfaces. Specimen 41/1295, a compact porphyritic nephelinite from the northern slope of Usengere immediately above the junction with the granite, contains abundant brown biotite. It is also characterized by the more unusual green aegirine-diopside pyroxene. The rock is highly altered but appears to have been a lava. It is possible, however, that it may be a dyke rock; the outcrop is poorly defined.

Melilite nephelinites are found in this lava group (e.g. specimen 41/1340, from Nyadenda) but true melilitites are not so common as in the Upper Kisingiri lava series. Specimen 41/1641 from a mile south of Mbita point was taken from a bluish green vesicular lava flow underlying the upper agglomerate of the pyroclastic group and is clearly a flow of the lower lava series. Besides the usual augite prisms there are subidiomorphic plates, now pseudomorphosed by greenish alteration products, which are identified as representing former melilite. The median crack is often apparent in sections perpendicular to the basal plane. Perovskite in large brownish pink grains is an abundant accessory in this rock, which also contains a clot of a much coarser crystalline assemblage of augite, magnetite, calcite and perovskite. A porphyritic mela-nephelinite (41/1157) from the slope of Gembe above Kwitari contains phenocrysts of colourless olivine, altering to iddingsite. The presence of olivine nephelinites among the lavas of the lower series is matched in the more melanocratic lavas of the Upper Kisingiri nephelinite series. All the nephelinite and melilitic lavas contain some isotropic colourless "glassy" material which is probably finely crystalline and largely analcitic in composition. The nepheline always shows some breakdown to a cancrinitic secondary aggregate.

(ii) *The Middle Kisingiri Pyroclastic Group.*—The middle pyroclastic group includes the lower Miocene tuffaceous lake beds of Rusinga, Mfanganu, the Goyo river, Kaniamwia, Ikoro and White Rock Point, and the nephelinitic agglomerates intercalated within them.

The lower Miocene lake beds of Rusinga Island, first discovered by E. J. Wayland (1931, pp. 25-27) were described by Kent (1944, p. 87) and in greater detail by Shackleton (1951B, p. 350) and Whitworth (1953, p. 77). Shackleton derived the sequence quoted in

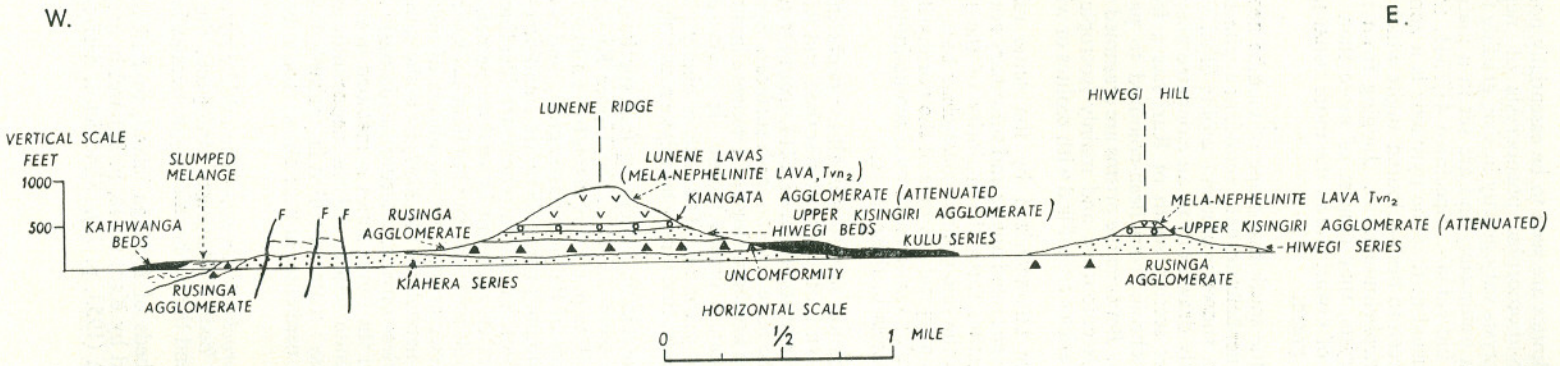


Fig. 5.—Geological section across Rusinga Island. Copied from Shackleton, 1951, p. 353, by permission of the Council of the Geological Society of London.

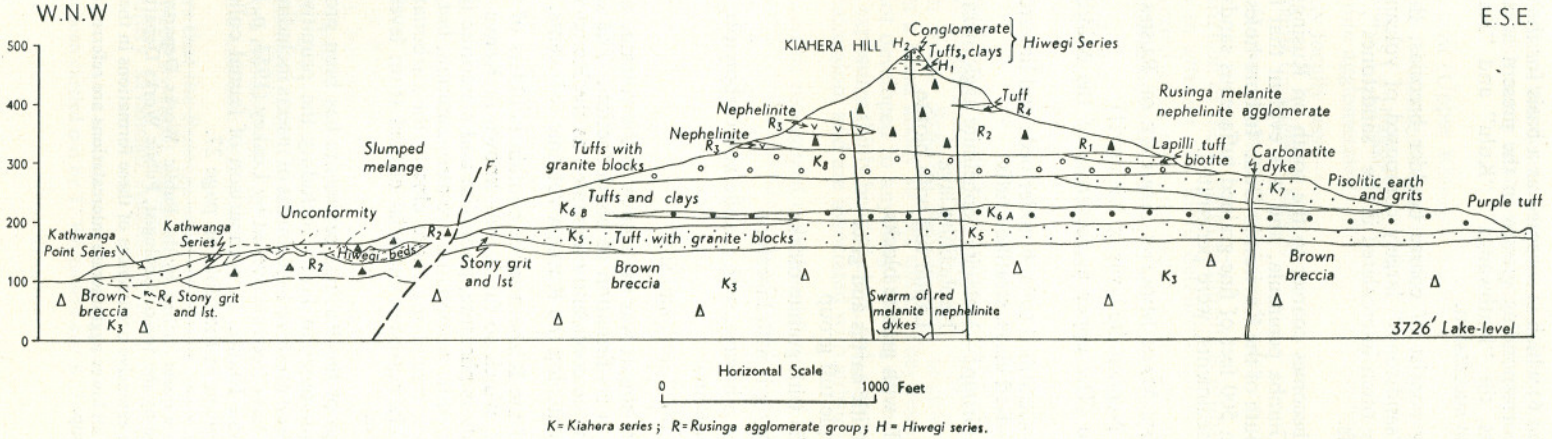


Fig. 6.—Geological section of Kiahera hill, Rusinga Island. Copied from Shackleton, 1951, p. 353, by permission of the Council of the Geological Society of London.

Table II (*see* also figs. 5 and 6) which is accepted as a basis for the purposes of the present report. Names used for corresponding groups in the present area are given in brackets. Other groups of sediments, the "Kathwanga", "Kulu" and "Kathwanga Point" Series could not be fitted into the succession.

The sediments mainly consist of coarse boulder breccias, thought to be mud-flow deposits, and tuffaceous "sandstones" largely composed of volcanic material. Lenses of nephelinite agglomerate are often intercalated in the "sandstones", which are perhaps best described as stratified tuffs.

The detrital material becomes coarser to the south on Rusinga, as Whitworth (1953, p. 91) determined in the Gumba peninsula, and it is evident that it also becomes coarser from east to west at the mouth of the Kavirondo Gulf. In bore-holes in Uyoma, a few miles east of Rusinga, more than 500 feet of fine-grained tuffaceous sandstones*, which contrast sharply with the Rusinga sediments, were penetrated.

TABLE II.—THE MAIN MIOCENE SEQUENCE OF RUSINGA ISLAND

(v) Lunene Lavas (Upper Nephelinite lavas of Kisingiri†)

(iv) Kiangata Agglomerate (The upper agglomerate of the Middle Kisingiri Pyroclastic Groups†)

(iii) Hiwegi Series: Upper—Stratified tuffs, boulder beds and limestones
Lower—Red clays, stratified tuffs

(ii) Rusinga Agglomerate Group‡—Melanite nephelinite agglomerate
Nephelinite lava
Lapilli tuff with biotite

(i) Kiahera Series—8 Tuffs with granite blocks
7 Pisolitic earths and grits
6 Purple tuff group
5 Tuffs with granite blocks
4 Stony grit with limestone
3 Brown breccia, with granite and carbonatite blocks
2 Limestone
1 Stratified tuffs and silts.

Whitworth suggested that Kisingiri was the source of the volcanic material in Rusinga and the evidence from Uyoma is confirmation of his deduction. The source of the reworked tuffaceous material can now be confidently identified as the Rangwa vent, which is in part composed of tuffs closely matching the Rusinga volcanic sediments.

The brown breccias of the Kiahera series contain boulders of turjaite (41/1639A), the rare melilitic plutonic rock, which so far is only known in Kenya at Rangwa. They also contain boulders of melanite nephelinite, phonolite and cancrinite ijolite (Shackleton 1951, p. 352). Blocks of coarse biotitic carbonatite are also common, but are not very similar to the carbonatites of Rangwa, resembling more closely the carbonatites of the Homa and Ruri centres. They probably represent material ejected from levels in the Rangwa vent deeper than are yet exposed.

The lower Miocene age of the Rusinga sediments has been proved by fossil evidence. The beds contain a rich mammalian fauna including the primitive hominoid *Proconsul*. Recently some remarkably well preserved specimens of insects including fossilized caterpillars, cockroaches and ticks, etc. have been recovered by Leakey (1953, p. lxxi) from Rusinga and equivalent beds in Mfanganu Island. A comparison of faunal collections from Karungu, Rusinga and Mfanganu is given in the table on page 27.

*The samples from three bore-holes drilled by the Public Works Department in Uyoma were made available for examination by the Senior Geologist, Public Works Department, Kenya.

†Names used to cover the more extensive occurrences of these formations in the Gwasi area.

‡The Rusinga agglomerate and all lower agglomerate intercalations are referred in this report to the Middle Kisingiri Pyroclastic group.

Unlike Rusinga, *Mfanganu* has been relatively untrodden by geologists. The succession derived during a four day visit made in the course of the present survey is given below (*see* also Fig. 7)*:—

6. Mela-nephelinite lava (Upper Kisingiri Series) (=Lunene Lava)
5. Upper agglomerate (=Kiangata agglomerate ?); here about a thousand feet thick
4. Upper lake sediments (=Hiwegi Series ?)
3. Melanite nephelinite agglomerate (=Rusinga agglomerate ?)

——Unconformity locally seen——

2. Lower lake sediments (=Kiahera Series)
1. Nephelinite lava (Lower Kisingiri Series); only seen on the west of the island.

The rapid lateral variation of the Rusinga sediments is probably repeated in Mfanganu and it was not possible to attempt any more detailed correlation. However, two clearly defined formations separated by a melanite agglomerate can again be distinguished, the upper being probably equivalent to the Hiwegi Series of Rusinga.

The lower nephelinite lava is only exposed on the north side of the island where it underlies the melanite nephelinite agglomerate. Elsewhere the lowest formations exposed are lower Miocene lake beds showing great similarity to the Kiahera Series. The best section is in a gully at the south-east corner of the island. At this point over four hundred feet of mixed sediments and volcanic rocks outcrop below the melanite agglomerate. They are dominantly light-coloured tuffaceous sandstones with abundant flakes of brown mica, and with two thick bands of nephelinite agglomerate, the upper of which carries abundant melanite, intercalated in them. Breccias bearing large angular boulders of granite and metamorphic rocks form a band about 30 feet thick. They resemble the brown breccia of Kiahera, but are here not developed to anything like the extent that they are on Rusinga. In the lowest part of the exposures thinly bedded clays, red, green and yellow in colour, form the greater part of the succession, and are associated with subsidiary tuffaceous sandstones.

No unconformities can be recognized on the south side of the island but on the north-east side strongly tilted sediments of the Kiahera Series appear to be unconformably overlain by the melanite agglomerate. These local disturbances of the sediments are not, as Whitworth (1953, pp. 89, 91) has pointed out, of any great significance in relation to major Rift Valley structures. The border of the Lambwe rift valley on which Rusinga and Mfanganu are situated, would be expected to be an area of continuous minor warping and subsidence. The melanite agglomerate occurs in two bands on the south-east corner of Mfanganu. It is overlain by an upper group of tuffaceous sandstones and clays, the outcrops of which can be traced from Ugena, in the extreme west around the south-east coast to the north side of the island. Coarse dark red and greenish stratified tuffs east of Ugena strongly resemble the Hiwegi Series of Rusinga. On the north-eastern scarp, this upper series of sediments consists of much more fine-grained flaggy water-laid tuffs.

The main nephelinite agglomerate of the Kisingiri volcanic series overlies these sediments; the lowest horizons include a few fine-grained tuff partings, but the section consists almost entirely of unrelieved coarse agglomerates.

The Precambrian floor ("Basement Complex") was said by Wayland (1931, p. 26) to be exposed on Gumba hill in Rusinga. This has been refuted by Higginbottom (discussion of Whitworth, 1953, p. 95), but since Mbassa island and Takivere are composed of granite, it is clear that the lowest Gumba and Kiahera sediments must closely overlie the Precambrian floor, the level of which, due to the updoming under Kisingiri, rises to the south. The nephelinite of Hota (Whitworth, 1953, p. 84) may be the equivalent of the lower nephelinites of Kisingiri; judging from the description given by Whitworth it closely resembles the lavas of this group. The granite and lake beds may thus be separated by lavas.

Whitworth considers that the Rusinga sediments were deposited in permanently shallow and restricted lakes, choked by rapid accumulations of debris from the nearby volcanoes. In the surrounding country savannah conditions with rich fauna, and arid conditions, alternated.

*A detailed survey has since been carried out by T. Whitworth and R. J. G. Savage, during 1955.

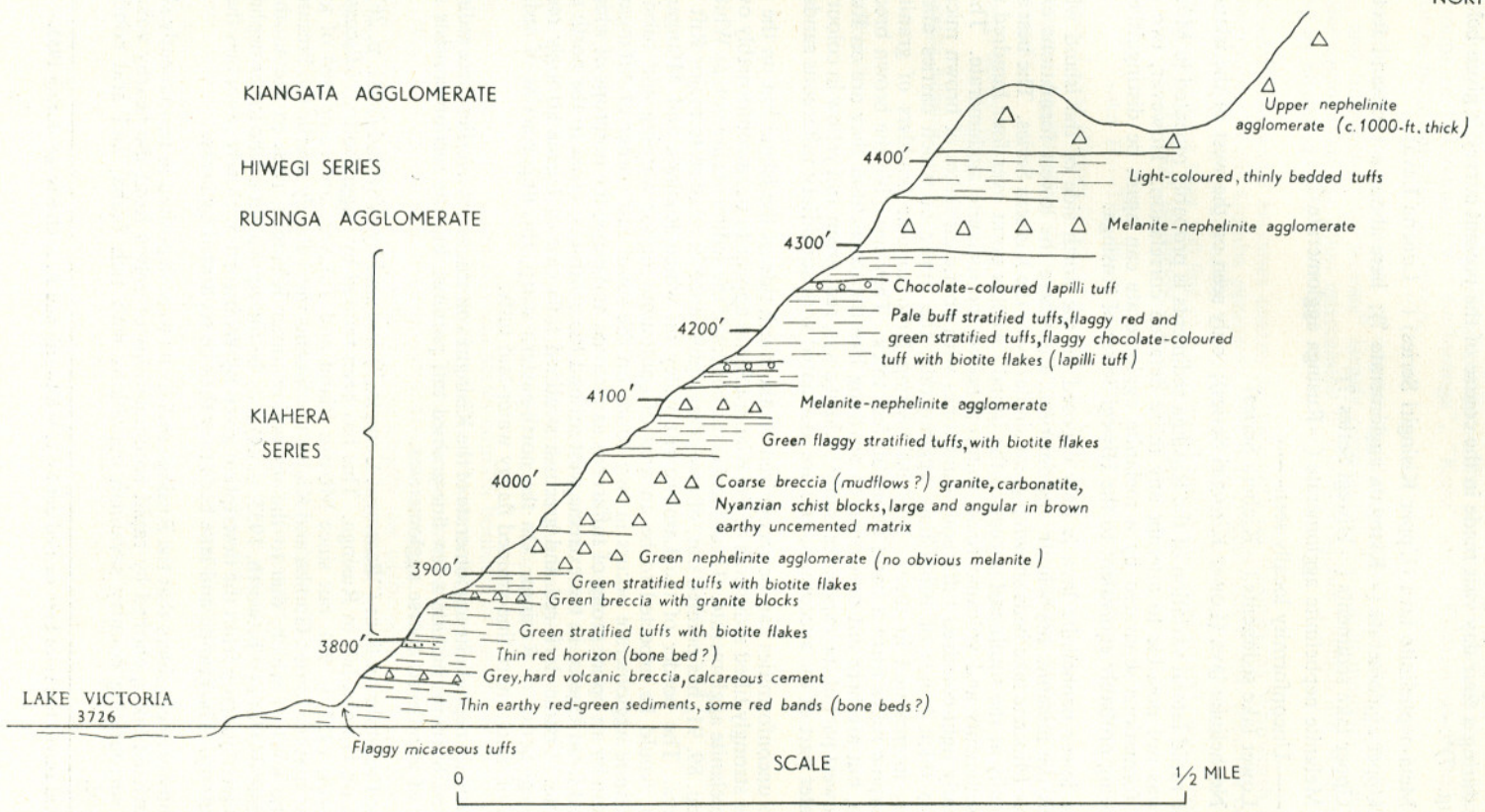


Fig. 7.—Sketch section of the lower Miocene sediments exposed in the south-east corner of Mfanganu island. The probable equivalence with the series on Rusinga island is indicated on the left. The upper agglomerate is the equivalent of the upper agglomerate of the Middle Kisingiri group.

The *Kaniamwia* and *Goyo River* exposures have already been briefly referred to in relation to the Karungu Lake Beds (*see* p. 28).

At *Ikoro hill* nephelinite agglomerates of the Middle Kisingiri group are intercalated with thin bands of light green tuffaceous sediments, containing thin subordinate limestones. On the east side of the hill a considerable thickness of crystal breccia is exposed, made up of sub-idiomorphic crystals of dark green augite crammed into a calcareous matrix. All the Ikoro sediments contain abundant calcified fossil wood, but no other fossils have so far been recovered.

A few feet of tuffaceous sediments are intercalated in nephelinite agglomerate, which is full of fragments of fossil wood, at *White Rock Point*.

(iii) *Kiangata agglomerate*.—The main agglomerate of Kisingiri (the equivalent of the upper or Kiangata agglomerate of Rusinga) was mentioned by Kent (1944, p. 101). It directly overlies the Lower Nephelinite lavas on the inner slopes of Gwasi and Gembe but its extensions on Rusinga, Mfanganu, Kaniamwia, at the Goyo River and at Ikoro, overlie volcanic sediments with intercalations of similar agglomerate forming the lower part of the Middle Kisingiri group. The Kiangata agglomerate and its equivalents are of varying thickness due to primary thinning laterally, and probably also partly to subsequent erosion before the overlying lavas were extruded. Kent estimated the maximum thickness to be 1,200 to 1,500 feet on Mfanganu but the writer would put it at not more than 1,000 feet. On Rusinga it has maximum thickness of 400 feet and in places is much thinner. The agglomerate is composed of angular and rounded blocks of nephelinite lava in a fine tuffaceous matrix. It varies in coarseness from a coarse lapilli tuff to an agglomerate composed of boulders a foot or so across. The basal beds on Rusinga (Kent, 1944, p. 93) contain blocks of Precambrian rocks, suggesting an early widening of the vent at the start of the eruptions that gave rise to the Kiangata agglomerate. Similarly the lower part of the section on Mfanganu contains many perovskite ijolite blocks, identical with the Sagarumi ijolites. Coarse lapilli tuff horizons are not uncommon, but in general no form of stratification can be seen. On Gembe the matrix of the agglomerate, locally shows heavy calcification.

The agglomerate resembles the Elgon agglomerates but the matrix is not so tough and compact. It is also similar in appearance to the nephelinite agglomerates of Tinderet.

The Kiangata agglomerate outcrops over a vast area, being found as far east as Homa Bay, and as far south as Nundowat and Odio.

The source of the agglomerate must have been the Rangwa vent. Besides the evidence of the perovskite and ijolite inclusions thin sections of little altered agglomerate from Rangwa show a close resemblance to those of the Kiangata Agglomerate. Green aegirine-diopside, pseudomorphs after nepheline, perovskite and biotite are typical of both. The scarcity and attenuation of the upper agglomerate around Ruri rules out the Ruri vents as a possible source, and the agglomerate is completely absent near Homa Mountain.

The agglomerate is said by Shackleton (1951, p. 353) to contain interdigitations of lava. Such lava interdigitations have been noted on Mfanganu, at Ikoro, and on Kimaboni. On Kimaboni lavas of the lower Kisingiri series and agglomerate seem to be very mixed up, but it is probable that this is due to erosional disconformity, the agglomerate resting on an irregular surface of lava. There probably are, however, interdigitations of nephelinite lava within the agglomerate group either as contemporaneous flows, or as feeders of the upper lava series which have locally adopted a layer form within the agglomerate. As the agglomerates erupted from the central vent and the lavas from a peripheral zone of fissures, it is possible that they were erupted contemporaneously. Further, as the lava eruptions were probably localized, no regular succession of lavas and agglomerate can be expected around the outer slopes of the volcano.

(iv) *The Upper Kisingiri Lava Series*.—The uppermost part of the Kisingiri Volcanic Series consists of a monotonous series of mela-nephelinite lavas, which extend over a roughly circular area around Kisingiri, with a span of nearly sixty miles, being exposed in Uyoma, Mfanganu, near Kendu and at Nundowat. They are of remarkably uniform composition and appearance and are typical plateau lavas as could be inferred from Gregory (1921, p. 120) who wrote of the "Gwasi plateau".

North of Karungu mapping reveals a strong erosional disconformity between the lavas and the upper nephelinite agglomerate of the Middle Kisingiri series. Narrow feeder dykes are often visible cutting the Precambrian rocks or the Tertiary agglomerates near the present-day erosional boundary of the lavas. The dykes occupy a system of narrow fractures a foot or less in width radiating from the Kisingiri centre. The uniformity of the lavas and the great distance from the Kisingiri centre at which the feeders are found, suggests a relatively deep source not in connexion with the magma chamber that supplied the Rangwa alkaline intrusions. They are, moreover, of much later date than those intrusions.

The mela-nephelinites are black or very dark green, rough-textured lavas characterized by numerous phenocrysts of dark green augite. The textures vary in coarseness; some specimens collected contain numerous phenocrysts up to a centimeter in length crammed into an isotropic base. In thin section the textures are seen to range from porphyritic to trachytic. Nepheline is never visible to the naked eye.

The porphyritic lavas consist of sub-idiomorphic phenocrystic prisms of pale green to flesh-coloured augite, set in a colourless isotropic base of analcite with a glassy appearance. Nepheline phenocrysts are rarely seen, though some small individuals of nepheline are usually detectable in the analcitic base. Magnetite is an abundant accessory. The porphyritic lavas occasionally contain rounded, colourless, partly resorbed phenocrysts of olivine, altered along cracks to brown iddingsite and with iddingsitic reaction rims. Specimen 41/1489 from south of Asego is the best example of these porphyritic olivine nephelinites. Olivine was noted only in the most melanocratic lavas.

The more fine-grained lavas have a trachytic arrangement of augite prisms, which are again pale green to flesh-coloured. The greater part of these finer lavas consists of an analcitic base. Vesicular types are common, the vesicles being usually small and rounded, with infillings of calcite or zeolites.

Melilite is a not uncommon minor constituent in the upper nephelinites, and true melilitites are also included in the series. They closely resemble the mela-nephelinites in the field, but in thin section phenocrysts of melilite are seen to be abundantly distributed through the rocks and no nepheline can be recognized. A porphyritic melilitic lava-flow (41/1708) that overlies the nephelinite agglomerate of White Rock Point contains partly resorbed phenocrysts of melilite together with the usual flesh-coloured augite (Plate XIII). The melilite exhibits anomalous blue and yellow polarization colours and well-developed median cracks, but no peg structures. A fine-grained lava (42/1345) from Nyadenda summit also contains subordinate melilite phenocrysts together with augite, magnetite and perovskite set in a fine-grained matrix with an analcitic base. A fine-grained lava from the Ruri-Kasigunga road was also identified as a melilitite.

The feeders, which are well seen on Nundowat and near Ikoro, are fine-textured black rocks, identical with the more fine-grained mela-nephelinite lavas.

(v) *Minor Intrusions of Kisingiri.*—The minor intrusions are all dykes. A complex series of alkaline dykes cuts the Precambrian granite near Kaksingiri, the Kaksingiri schists, and some but not all of the alkaline igneous rocks peripheral to the Rangwa complex. These minor intrusives are clearly related to the alkaline intrusions and were apparently emplaced and reached by erosion before the eruption of the Kisingiri nephelinite volcanics.

The remaining Tertiary minor intrusions are of later age. The late alnöitic suite radiating from Rangwa cuts lower Miocene lake beds on Mfanganu and the upper agglomerate of the Middle Kisingiri group on Kibibura and Nyadenda. The late nephelinite suite which also radiates from Rangwa cuts lower Miocene lake beds on Rusinga and Ikoro, and the upper agglomerate on Kimaboni.

Some feeders of the lower Kisingiri lavas are seen cutting the granite at Kaksingiri; they are not very numerous and it is probable that most of the feeders are obscured by the lavas that welled out from them. The locus of eruption appears to have been some distance from Rangwa. The feeders of the Upper Kisingiri lavas are well exposed near Ikoro and on Nundowat. They are the most distant of the alkaline intrusives related to the Rangwa centre, and are extremely narrow wall-like bodies of dense black lava, cutting the upper agglomerate of the Middle Kisingiri group.

For the purpose of description, and excluding the carbonatite dykes which have already been described, the minor intrusions can be divided into the following suites:—

(*a*) Micro-foyaite and micro-ijolite dykes marginal to the Rangwa complex

(*b*) Nephelinite and mela-nephelinite feeders of the Kisingiri lavas

(*c*) Late alnöitic suite

(*d*) Late melanite nephelinite suite

Micro-foyaites and micro-ijolites.—The domed-up area of granite and the Kaksingiri schists at Kaksingiri are cut by a swarm of micro-foyaite and micro-ijolite dykes. These closely resemble the outermost rocks of the ijolite zone of Rangwa and undoubtedly represent injections of the marginal phases of the alkaline intrusion.

The dykes are orientated both radially and tangentially to the Rangwa complex. They are comparatively wide, being up to twenty feet in width. They are green in colour and show prominent whitish nepheline phenocrysts on their weathered surfaces. Occasionally felspar phenocrysts are also visible.

Members of this suite outcrop south of Gembe, on Omutageti, on Rukungu and Kasasa, and on the Rangwa-Gwasi ridge. A very numerous and closely-spaced swarm of dykes radiating from Rangwa and cutting the syenite on a spur north of Usengere is believed to belong to the suite also, but the only dyke sliced from the locality appears to be a nephelinite, possibly of later date. Closely related dykes characterized by brown sodic hornblende as well as aegirine-diopside cut the granite of the Kwiunga-Usengere ridge and a large dyke of micro-foyaite is exposed further west towards Ragwe point. Dykes of the suite are found up to six miles from the Rangwa centre. They are not seen on Takivere.

The dyke rocks are typically holocrystalline and porphyritic. In a thin section of specimen 41/1252, a micro-foyaite from Omutageti, highly altered idiomorphic phenocrysts of nepheline, and clusters of nephelines up to 5 mm. in length, are set in a matrix of orthoclase prisms and a granular cancrinitic aggregate after nepheline. Aegirine-diopside is present as prismatic phenocrysts, much smaller than the nepheline phenocrysts. Minute prisms and needles of the same deep green pyroxene are abundant in the groundmass. Specimen 41/1294, a micro-foyaite from the Rangwa-Gwasi ridge, has a decussate arrangement of Carlsbad-twinned orthoclase laths, through which are scattered altered nephelines, ragged aegirine-diopside crystals and occasional large sphenes. The orthoclase is relatively unaltered but the nepheline is replaced by aggregates of zeolites. The largest dyke of this suite (41/1299), which cuts the syenite and fenitized granite on a small spur north of Usengere, shows phenocrysts of nepheline and orthoclase up to a centimetre and more in length on its weathered surfaces. Smaller phenocrysts of zoned aegirine-diopside are seen in thin section. The base is a micro-crystalline pilotaxitic aggregate of aegirine needles, orthoclase laths and nepheline. Calcite, cancrinite and zeolites of secondary origin are present.

The micro-ijolites differ from the micro-foyaites only in the absence of orthoclase. In specimen 41/1291 from the Rangwa-Gwasi ridge highly altered phenocrysts of nepheline are set in a melanocratic matrix of aegirine-diopside, zoned garnet that appears to consist of light brown andradite with melanite fringes, and cancrinite aggregates and grains. A zeolite of low birefringence is also present in light-coloured patches in the matrix. In specimen 41/1334 from Kasasa sub-idiomorphic phenocrysts of nepheline, altered to zeolites, are set in a melanocratic matrix composed of zoned aegirine-diopside, magnetite, abundant apatite, and occasional sphene, and a zeolitic groundmass. Sphene, apatite and magnetite are common accessories in the dykes of this suite; the presence of abundant sphene is a point of similarity to the plutonic micro-melteigites south of Rangwa, to which the dyke suite is believed to be closely related.

Radial dykes of this group on the Kwiunga-Usengere ridge are unusual in that besides the usual zoned aegirine-diopside they contain prominent sub-idiomorphic phenocrysts of a deep brown sodic hornblende (41/1149, 41/1150).

Nephelinite Dykes.—A few nephelinite, mela-nephelinite and melilite nephelinite dykes were recognized cutting the domed-up Precambrian granite at Kaksingiri. They are apparently feeders of the lower Kisingiri lavas, though some feeders of the upper lava series may possibly be present.

Most of these dykes are dark green mela-nephelinites, which closely resemble the porphyritic mela-nephelinite lavas of the lower group. The dykes often have the form of discontinuous lenticles only a foot or so wide. Dark green phenocrysts of augite stand out on surfaces from a fine-textured greenish black matrix. A thin section of specimen 41/1132 from Bukula is typical of the dykes of this suite. Pale green to flesh-coloured augites, like those found in the Kisingiri lavas, are crammed in an altered micro-crystalline matrix. Apatite and magnetite are abundant accessories and attain microphenocryst size. In specimen 41/1146 from nearby the pyroxene sometimes shows alteration around its rims to a deep green mineral, tentatively identified as aegirine, and small flakes of a reddish brown biotite are clustered interstitially to the pyroxenes. Nepheline is only recognized as rare crystals in the mela-nephelinites of Kisingiri, and any nepheline that has been present in the base of these dykes has been completely altered to a secondary zeolitic aggregate.

Specimen 41/1253 from Omutageti is a melilite nephelinite. Both nepheline and melilite phenocrysts are prominent in a thin section, together with prisms of pale green augite. Magnetite and clove-brown perovskite are accessories. The matrix is a micro-crystalline network of augite needles, among which are set small crystals of nepheline.

Feeders of the Upper Kisingiri lavas are seen cutting the upper agglomerate of the middle Kisingiri group near Ikoro and on Nundowat. They are also seen on Kiahera hill, Rusinga, cutting Miocene lake beds, where they are shown by Shackleton (1951, map) as basaltic dykes (B). They are narrow wall-like dykes, usually less than a foot wide, with very fine textures, and black in colour. Specimen 41/1623 from Kiahera, a melilite mela-nephelinite, is largely composed of a pilotaxitic aggregate of almost colourless pyroxene needles. The interstitial leucocratic minerals are considerably altered but the outline of many nepheline crystals can be made out, and pseudomorphs after melilite can also be detected. Some analcite is present and magnetite is an abundant accessory. There are numerous well-rounded vesicles filled with calcite, zeolites, etc. This rock resembles to some extent the alnöitic dykes described below, and it is possible that that suite also feeds some of the Upper Kisingiri lavas. Specimen 41/1741 from north-west of Ikoro is an even finer textured non-vesicular mela-nephelinite dyke, but is otherwise similar to the Rusinga dykes.

Some coarsely porphyritic dykes on the syenite spur north of Usengere have the characteristics of the Kisingiri nephelinites. In specimen 41/1830 nepheline phenocrysts and clusters of nepheline crystals together with phenocrysts of colourless to pale green augite are set in a heavily calcified microgranular matrix, speckled with magnetite. This was the only dyke collected from the large swarm that cuts the syenite, and is unusual in character. The majority of the dykes seen in the field to cut the syenite are of typical foyaite character.

The Alnöitic Dyke Suite.—A series of alnöitic dykes radiates out from the Rangwa centre. The dykes cut the uncompahgrite intrusion, the lower Miocene lake beds on Mfanganu, and the upper agglomerates of the Middle Kisingiri series on Kibibura and Nyadenda. Together with the Upper Nephelinite plateau lavas and the late red nephelinite dykes of Rusinga, also radiating out from Rangwa, they represent the last stages of volcanic activity in Kisingiri.

The alnöites are greyish to dark greenish black micaceous dykes and vary in width from a foot or so to ten feet. In thin sections they are seen to be dominantly melilitic. Specimen 41/1826 from a small granite knoll west-south-west of Rangwa contains pseudomorphs of melilite phenocrysts with the median crack strikingly preserved, the pseudomorphs being set in an aggregate of secondary minerals (cebollite, cancrinite, zeolites, etc.). Perovskite, magnetite, pinkish brown biotite, and apatite make up the remainder of the rock. Specimen 41/1346 from Nyadenda is finer in texture; a fine meshwork of prisms of a brown barkevikitic amphibole, prisms of fresh melilite and minute prisms of colourless augite are set in a groundmass composed of analcite, zeolites and a little nepheline. Magnetite and apatite are accessories. Specimen 41/1353 from Kibibura contains relic melitite phenocrysts, together with irregular crystals and flakes of a crudely-zoned fresh yellowish brown to deep foxy red biotite with a very small optic angle, and abundant perovskite. Alteration and calcification are far advanced in this specimen and the groundmass is now composed of zeolites, calcite and alteration products of melilite. Magnetite and apatite are accessories.

Specimens from south of Rangwa (41/1270) and Mfanganu (41/1864) are heavily altered and calcified.

No olivine has been recognized in these dykes, but otherwise they show alnöitic characteristics, and they are tentatively referred to as alnöites.

Late Melanite Nephelinite Dykes.—The late nephelinite dykes form a small swarm on Kiahera hill and also occur elsewhere on Rusinga Island. The Kiahera swarm is apparently a radial swarm that emanated from the Rangwa centre. The dykes are red in colour and numerous melanite garnets are visible on their weathered surfaces. In thin section (41/1622) they are seen to be made up of well-formed crystals of nepheline, melanite and green aegirine-diopside set in an analcitic and calcified matrix containing small pyroxene prisms. Calcite is also abundant, together with cancrinite, replacing the nepheline; apatite is a sparse accessory. Small dykes of similar appearance radiating from Rangwa were noted on Ikoro and Kimaboni, but they are usually too decomposed for microscope examination, though specimen 41/1727 from Ikoro can be seen to be of melanitic melilite nephelinite composition. The texture of the dyke, however, suggests a tuff rather than a lava.

This late suite of radial nephelinite dykes emanated from Rangwa approximately contemporaneously with the alnöitic suite. The green aegirine-diopside in the Kiahera dykes is quite different from the common pyroxene of the Kisingiri lava suite, and closely resembles the green zoned pyroxene typical of the Ruri and Nyamaji phonolitic nephelinites

(3) The North Ruri, South Ruri, Tuige and Sokolo Alkaline and Carbonatite Ring Complexes

About eleven miles to the east of Rangwa are situated four more explosion vents, with associated carbonatite ring complexes and alkaline intrusions. Like Homa Mountain further to the east, these four vents do not obviously have connexions with large central volcanoes comparable with Kisingiri. North Ruri and South Ruri (Plate VII, Fig. 1) are two distinct vents and ring complexes, though their outer margins are almost in contact. Tuige and Sokolo are not well-exposed and have been considerably disturbed by the subsequent "intrusion" of the Nyamaji phonolitic nephelinites.

The sequence of events derived from the field evidence in the two Ruri complexes, which are first described, is:—

1. Alkaline intrusions—Ijolite
   Nepheline syenites
2. Vent pyroclasts
3. Carbonatite intrusions
4. Phonolitic nephelinite plugs (Gotjope type)
   (Kisingiri Volcanics)
   (Main rift faulting)
5. Phonolitic nephelinite plugs and dykes (Nyamaji type)
6. Phonolitic nephelinite plugs and dykes (Ruri type)
7. Late agglomeratic explosion breccia
8. Late explosion breccia and tuff dykes
9. Late carbonatite dykes and cone-sheets

(*a*) *North and South Ruri*

(i) *The Precambrian country-rock—Nyanzian metabasalts.*—The oldest rocks of Ruri are non-alkaline metabasalts first referred to by Pulfrey (1944) as "metabasalts of unknown age". These have been described in the section dealing with the Nyanzian system. They are similar in appearance and composition to metabasalts east of Homa Bay township. They form sharp dome-like hills through the centre of which alkaline intrusions, pyroclasts, and carbonatite ring complexes have risen. The metabasalts are thought to have been domed-up in the same manner as the Precambrian rocks underlying Kisingiri. The evidence for the up-doming is given in the next paragraph.

The metabasalts stand over 5,000 feet above sea-level on North Ruri, and not far short of that height on South Ruri. On the south-east side of the Kaniamwia fault the surface of the Miocene peneplain is dropping gently north-westwards, having an altitude of 3,800 feet at Homa Bay township (Fig. 2). The metabasalts do not form pronounced hill features on the surface of this peneplain. On the north-west side of the Kaniamwia fault, except on Ruri and Tuige, no single exposure of Nyanzian or other Precambrian rocks is seen in the eastern side of the area. Although the downthrow of the Kaniamwia fault is probably only a few

hundred feet near Ruri it is sufficient to have taken the surface of the sub-Miocene peneplain well below the present land-surface. It is unlikely that two hills rising over 1,500 feet above the level of the peneplain and a third, lower, hill would have been left, coinciding moreover exactly with the site of three carbonatite complexes, North Ruri, South Ruri and Tuige. Hence an up-doming of the Precambrian floor (the sub-Miocene peneplain surface) must be deduced.

The up-doming possibly commenced with the emplacement of the alkaline intrusives but the explosive carbonatite building up under the complex seems the most likely source of this upward pressure. High-standing outcrops of Nyanzian rocks are also marked on Saggerson's (1952) map of Homa Mountain and a similar up-doming may also have been operative there.

(ii) *The Alkaline Intrusions.*—The oldest members of the alkaline suite on Ruri are the alkaline intrusions which comprise:—

(*a*) Ijolite (and associated urtites, melteigites, etc.)

(*b*) Nepheline syenites (with local developments of urtite)

The Ijolite of the Usaki Mass.—The Usaki ijolite has been described in a detailed petrological study by Pulfrey (1950). It was originally discovered by the geologists of Kenya Consolidated Goldfields Ltd. (Hallam, Fitch and Edgeworth-Johnstone, 1936-7). Though the present writer does not entirely agree with Pulfrey's succession for the Ruri area (Pulfrey 1944), there is complete agreement that the ijolite is the oldest member of the succession. The ijolite is found as boulders in the early pyroclasts (agglomerates, tuffs and explosion breccias) of the Ruri vents and also in the phonolitic nephelinites of Nyamaji.

The ijolites occur in one large mass about three miles long at Usaki, lying to the north of North Ruri. They form rounded, low-lying grassy hills, and are in general poorly exposed. The contacts were only mappable on the west, where fenite outcrops. Tuff was discovered by pitting on the east side a little way from the ijolite, but this rock is thought by the writer to be a deposit of tuffaceous material washed down from Ruri and deposited in the low-lying valley, and thus of much later date than the ijolite.

Urtites, ijolites and melteigites of the Usaki mass have been described by Pulfrey. They are mostly coarse-grained, holocrystalline rocks, felspar-free, carrying varying amounts of felspathoid which is dominantly nepheline, with some cancrinite and natrolite, together with analcite and other zeolites. Melanite garnet, aegirine-diopside, and wollastonite all form a considerable proportion of some of the rocks. In some very melanocratic types, melteigites and jacupirangitic melteigites, up to 34·5 per cent of magnetite is present. Accessories include magnetite, pyrite, biotite, apatite, perovskite and calcite (usually secondary). Many drawings of microscope slides of these rocks are given by Pulfrey (1950).

The fenite is a much-jointed, hard, grey or greenish, leucocratic rock. It is granular and crystalloblastic with average grain size less than 0·2 mm. diameter. It contains allotriomorphic felspar which Pulfrey identified as a soda-bearing orthoclase. It is not possible to determine the nature of the original rock but it is suggested by the writer from the general evidence of the succession in the Ruri hills and at Rangwa, that the ijolite was intrusive into an alternating series of Nyanzian basalts and rhyolites, and that the latter are the most likely country-rock from which the fenite was derived.

Pulfrey considers that the part of the ijolite exposed at Usaki is the hood of a large body of much more melanocratic composition from which light nepheline crystals rose into the vicinity of the roof. Replacement textures in the ijolitic rocks indicate that the first crystallized leucocratic, nepheline-rich rocks underwent several phases of alteration due to successive pulsations of more lime-magnesia and iron-rich fluids working their way through the crystal mush forming the hood, during the protracted period of crystallization of the whole body of magma.

Nepheline Syenites.—The syenites form small bodies on North and South Ruri, and have been described by Pulfrey (1954)*. It was Pulfrey's view that the syenites represent the late stages of the intrusion of alkaline magma, subsequent to the intrusion of the

*The descriptions of the syenites given here follow those given by Pulfrey. Only the melanitic syenite from South Ruri discovered during the present survey and the syenite from Sokolo point are newly described by the writer.

Plate V

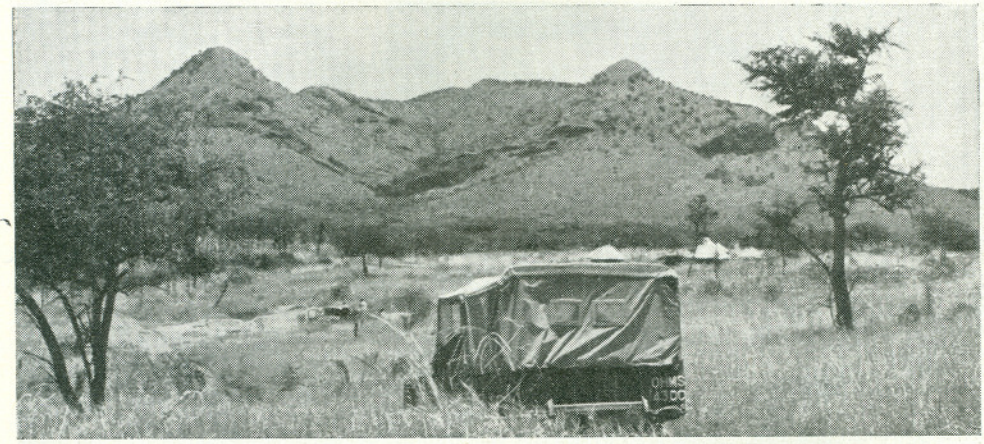


Fig. 1.—South Ruri from the east, showing carbonatite ring dykes and conical plugs of Ruri-type phonolitic nephelinite. The dark crest immediately to the left of the cone on the right-hand side of the photograph is formed by a narrow dyke of similar phonolitic nephelinite.

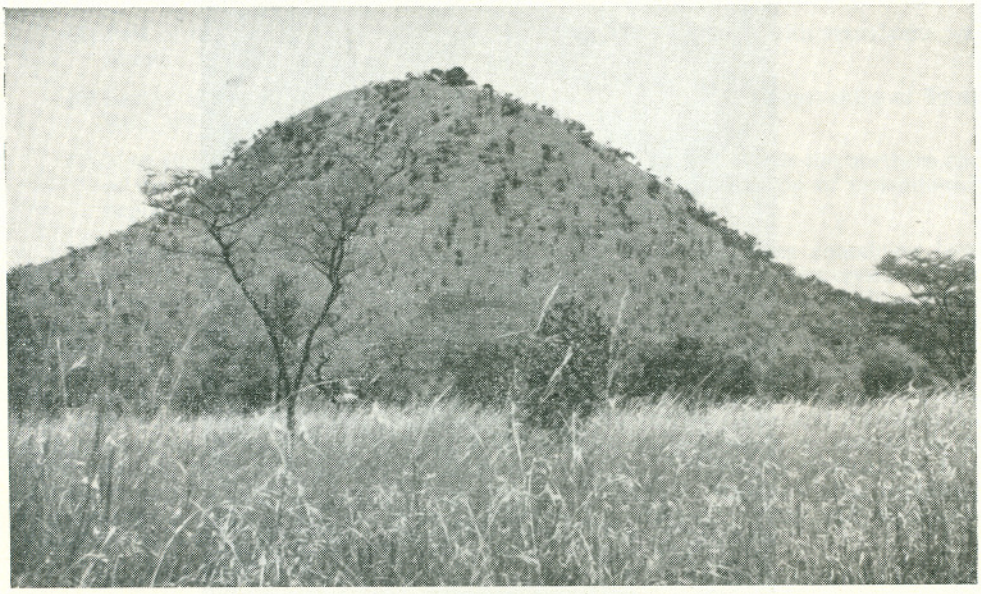


Fig. 2.—Phonolitic nephelinite plug (Ruri-type) on the west side of the Ruri hills.

Plate VI



Fig. 1.—A massive ring dyke of crystalline carbonatite with enclaves of the older syenite. North-east shoulder, North Ruri.



Fig. 2.—Small marginal cone-sheets of red carbonatite, North Ruri.

carbonatite ring dykes. Fresh evidence has, however, been discovered during the present survey showing that the carbonatite ring dykes were emplaced in existing bodies of syenite. On North Ruri (north-east spur) carbonatite ring dykes are clearly seen cutting an irregular mass of syenite, and the carbonatite contains included boulders of the syenite (Plate VI, Fig. 1). Further the syenite is intensely shattered while the carbonatite is quite unaffected by cataclasis. Again, on the east side of South Ruri, the syenite is highly shattered and forms a breccia due to intricate veining by carbonatite. A few boulders of syenite have been found in the explosion breccia but evidence of this nature is unreliable, since at least three phases of pyroclastic activity are known to have occurred on Ruri. It is thus the opinion of the writer that the syenites are older than the explosion vents; on Rangwa exactly similar nepheline syenites are closely associated with ijolitic rocks, and the two are thought to be congeneric. The ijolites in the Ruri complex can be shown to be older than the explosion breccia though there is no absolute proof of this on Rangwa. Pulfrey, (1954, p. 210) has stated that he considers the Ruri syenites to be congeneric with the ijolite mass of Usaki.

From field evidence on North Ruri, it appears that the syenites form ring intrusions that cut the up-domed Nyanzian metabasalts, and are now preserved only in vestigial form as small and isolated outcrops owing to subsequent invasion by pyroclasts and carbonatite, which form the greater part of the hills. It is possible that they form marginal bodies around a central mass of ijolite represented by the Usaki mass.

The localities at which the syenites have been noted are:—

(1) On the north side of the summit of North Ruri. Syenite has been noted on three separate spurs, and two separate ring dykes, separated by metabasalt appear to be present. The syenite is nepheline syenite, and shows some evidence of basic facies (hybrids).

(2) About $\frac{3}{8}$ mile south-west of North Ruri trigonometrical point, a very small mass.

(3) At two localities west of North Ruri trigonometrical point where there are boulders of syenite amongst metabasalt outcrops, suggesting the presence nearby of small residuals of syenite.

(4) On the west side of the north-eastern ridge of South Ruri, a large outcrop. Nepheline syenite, nepheline analcime syenite, analcime syenite and an apparently non-felspathoidal syenite have all been found in this outcrop.

(5) East of the summit of South Ruri, where a nepheline syenite with vesuvianite was found.

(6) East of the large phonolitic nephelinite dyke forming the north-east ridge of South Ruri, where a nepheline syenite forms a small outcrop.

(7) Near the margin of the outermost carbonatite ring dyke, towards the northern end of the same ridge and slightly east of it, where a small outcrop of melanite-rich nepheline syenite was found.

The syenites of North Ruri include nepheline syenite porphyries containing large phenocrysts of various minerals, in a sparse much-altered matrix of smaller crystals. They are composed predominantly of nepheline, orthoclase and aegirine-diopside, with accessory augite, sphene and apatite, together with late replacements by calcite and cancrinite. One specimen contains small patches of analcime. The orthoclase is present in platy poikilitic crystals often exhibiting Carlsbad twinning, and ranging up to 18 mm. in length. The optic angle is large and no sign of fine twinning was seen. The nepheline, which is idiomorphic and occasionally zoned by secondary products, occurs both as separate crystals and as chadacrysts within the orthoclases and pyroxenes. The pyroxenes include grey augite as cores within the more common aegirine-diopside. Accessories are sphene and possibly wollastonite now entirely replaced by fibrous aggregates of calcite. Cancrinite, secondary after nepheline, is sometimes present, and calcite occurs in secondary replacive patches and as rhombs within the orthoclases.

An aegirine syenite which also occurs on North Ruri is thought by Pulfrey to be either a hybrid marginal type or possibly a melanocratic fenite. It is a fine-grained green rock with occasional white streaks. The texture is seen in thin section to be in part crystalloblastic.

the summit of North Ruri. Phlogopite, aegirine and aegirine-diopside are abundant as fragments, and pseudomorphs after nepheline have been tentatively recognized. Carbonate forms a considerable proportion of every slide studied, but is thought to be mainly due to secondary replacement by carbonate solutions during the subsequent intrusion of carbonatite dykes (cf. Rangwa). The original pyroclasts were probably mostly free from carbonate, and nephelinitic in composition.

At many points around the periphery of North and South Ruri the pyroclasts show secondary alteration to a deep brown ironstone. This is invariably associated with networks of dark iron-rich veins and an abnormally high radio-activity.

(iv) *The Carbonatites.*—The carbonatites of the Ruri hills (Plate V, Fig. 1 and Plate VII Fig. 1) form nearly perfect ring-shaped intrusions. On South Ruri two separate rings and a central core can be recognized; on North Ruri there is not quite such a marked separation into separate rings, and the ring dykes follow a fracture pattern more nearly resembling a figure eight than a simple ring. Screens of pyroclastic material running parallel to the rings are found within these great ring dykes. The carbonatites are in general dark brown or buff in colour, weathering to fluted and grike forms. Pure white crystalline limestones are seen on the summit of South Ruri. Crystalline texture is usual, though great variation is seen in the coarseness of grain, some of the smaller dykes showing no evidence of crystalline texture to the naked eye. A prominent feature of the carbonatites is a banding structure, or "vertical streaming", caused by a compositional layering in planes parallel to the walls of the dykes. In the main carbonatite rings of the Ruri hills, the banding is mainly vertical or dips outwards at a steep angle, though locally steep inwards dips are observed. The dips of the carbonatite ring forming the western side of North Ruri can be traced along the strike, rapidly alternating from inward to vertical and outward. The dips are, however, invariably very steep and the limestone bodies, must have the form of nearly cylindrical ring dykes. Dixey (1937, p. 8) described this vertical streaming in carbonatites of the Chilwa vents, Nyasaland.

The width of the carbonatite rings on Ruri, and the presence of screens of pyroclasts, suggest that they are not true ring dykes, but compound rings of carbonatite composed of true carbonatite intrusions together with carbonatite formed by replacement of the country-rock (pyroclasts). It is certainly difficult to imagine a process by which ring dykes of such dimensions could be emplaced purely by a process of intrusion.

The carbonatites are dominantly composed of calcite. Locally iron-rich segregations with the form of lenses or schlieren concordant with the vertical banding are developed. These iron-rich segregations range in composition from ferriferous carbonatites to almost pure iron ore. The iron ore when fresh is magnetite, and is often arranged in strings of well-formed octahedra, but more often the ironstone consists of red aggregates of hematite (and goethite?), with yellow streaks of limonite.

Apatite can frequently be recognized megascopically in the carbonatites and tends to be concentrated near the contact with bodies of nepheline syenite. A dark brown phlogopite mica is ubiquitous throughout the carbonatites, frequently having the form of books up to a centimetre in length.

Thin sections of the carbonatites show mosaics of well-twinned calcite crystals up to 5 mm. in diameter with straight or slightly sutured margins. An elongation of the individual crystals parallel to the local strike of the dykes is not uncommon. Segregations of brown amorphous iron ore frequently fill the sutures between the carbonate individuals, and also small cracks parallel to the strike of the dykes.

Phlogopite, pleochroic from red brown to golden yellow, is present in many thin section, examined. It is often highly decomposed, only a skeletal pseudomorph in iron oxides remaining. The phlogopite frequently shows alteration to a bronze-coloured fibrous minerals possibly vermiculite.

Apatite, in the form of small sub-idiomorphic crystals, is abundant and frequently has a linear arrangement parallel to the banding in the carbonatites. Vesuvianite in clusters of colourless crystals of low birefringence, either with good crystal form or allotriomorphic, is a more rarely observed constituent. Other minerals such as aegirine and hornblende have been noted but are usually very ragged and decomposed. They are probably xenocryst ragments o f the country-rock picked up by the carbonatite.

Magnetite is a constituent of iron-rich bands, veins and segregations. These "ironstones" are, however, mostly composed of cryptocrystalline blood-red iron ore and brown amorphous iron ore. It is deduced that they were probably derived from segregations of magnetite, as there is always a little unaltered magnetite preserved in the thin sections. Calcite is usually present scattered sparsely through the iron ores, though in one thin section examined a small amount of microcline was found amongst the iron ores, while calcite was completely absent. The ironstone segregations are usually very spongy in texture. Thin sections of ironstone veins (41/1556) from an area of high radio-activity on the North Ruri summit contain crystals of iron ore "floating" in a colourless matrix which consists largely of fluorite. There are also small crystals and aggregates of barytes which are usually adjacent to the iron ore crystals, and "ooliths" apparently composed of two minerals. The "ooliths" consist of a large core of fluorite, surrounded by a narrow zone of a weakly birefringent mineral, with refractive index greater than that of fluorite but less than canada balsam, which has not yet been identified with certainty, though it may possibly be strained fluorite. There are also occasional spherulites of the same mineral. The "ooliths" and spherulites have a matrix of normal fluorite. An analysis of this rock is quoted below.

ANALYSIS OF RADIO-ACTIVE IRONSTONE, NORTH RURI

	per cent
SiO_2	4·11
Al_2O_3	0·05
Fe_2O_3	34·75
MgO	6·38
CaO	22·77
Alkalis as Na_2O	0·51
H_2O+	2·89
H_2O-	3·15
CO_2	0·53
TiO_2	0·33
P_2O_5	0·08
SO_3	2·83
Cl	0·02
F	11·84
Cr_2O_3	0·26
Mn	7·63
BaO	6·58
T.R.E.+ThO_2	0·06
Nb_2O_5	0·08
	104·85
Less O_2 for F	4·98
	99·87

Analyst: W. P. Horne

Assuming that the manganese is present as MnO, and that the oxygen required to convert the manganese of the analysis to oxide is represented by part of the oxygen in the Fe_2O_3, the percentages of iron and manganese oxides present can be calculated as Fe_2O_3 21·78, FeO 10·76, MnO 9·85.

The ironstone segregations, which are mostly concentrated near the outer margin of the carbonatites, are invariably associated with abnormally high radio-activity. No radio-active minerals have been identified in them, however, and it is suggested that the anomalies are due to thoria absorbed by the cryptocrystalline oxidation products of the iron ores, in the manner described by Ostle and Taylor (1954) in the Chilwa and Tundulu vents of Nyasaland. Monazite has been tentatively identified in soil samples. Pyrochlore was detected in two specimens from North Ruri, and it is also present in the carbonatites of the nearby vent of Tuige, and has been identified in soil samples from Ruri (Bear 1952). It is here a grey variety, contrasting with the bright yellow resinous variety of Rangwa, which also appears yellow in thin section. The high radio-activity (up to 15 times background) is, however, too great to be accounted for by pyrochlore and monazite alone, especially in view of their sparse distribution, and supports the suggestion that some other radio-active material is probably present in the iron ores. The beta-gamma ratio observed on North and South Ruri suggests that thorium is the main source of the radio-activity.

Several rare minerals have been identified in the soil mantle of Ruri and are noted in a subsequent paragraph dealing with superficial deposits. It is inferred that they are derived from the carbonatites.

Analyses of the carbonatites given below show that magnesia is low, and that dolomite cannot form more than a small fraction of the carbonate. It occurs as rhombs outlined by iron ore in some specimens, but such carbonatites are comparatively scarce within the complexes. Manganese is present with the ironstone segregations, but no rhodocrosite has been detected. Barytes also has not been detected in the carbonatites. In general, the composition on comparison with analyses of the Alnö Island suite (von Eckermann, 1948, p. 74) is that of pure sövite, though the Fe_2O_3 content is rather higher than in any of the Alnö sövites. The major carbonatite ring dykes of the Gwasi area can thus be described as sövites. The minor carbonatite intrusions (Plate VI, fig. 2) have very similar mineralogical composition. No analyses are available but they are mostly calcite and light or dark grey in colour. They are of lower silica content than most of the alvikites of Alnö Island (von Eckerman, 1948, pp. 128–137) and are considered to be very pure alvikites comparable with the dyke referred to in analysis 120 of von Eckermann's paper.

ANALYSES OF CARBONATITES FROM NORTH RURI, SOUTH RURI, TUIGE AND SOKOLO

	No. 15	No. 14	No. 12	No. 18
	per cent	*per cent*	*per cent*	*per cent*
SiO_2	1·48	0·65	0·34	0·66
Al_2O_3	5·37	Trace	0·32	3·21
Fe_2O_3	3·47	3·78	2·27	3·95
MgO	0·62	0·29	0·40	0·59
CaO	48·79	51·59	53·89	48·89
Alkalis (Na_2O)	0·27	0·30	0·38	0·41
Loss on Ignition	37·74	40·16	41·41	38·49
Moisture	0·32	0·21	0·26	0·22
TiO_2	0·27	0·18	0·09	0·36
P_2O_5	1·65	1·70	0·90	1·70
MnO	0·37	0·31	0·08	0·31
BaO	0·41	1·05	Trace	1·32
	100·76	100·12	100·34	100·11

Analysts: E.A. Industrial Research Board, Dec., 1949.
(Samples collected by B. N. Temperley).

15. East spur, South Ruri summit.
14. West of summit, North Ruri.
12. Foot of north-east spur, North Ruri.
18. Tuige summit.

ANALYSES OF CARBONATITES FROM SOKOLO POINT

	Sk/1	Sk/2	Sk/3	Sk/4
	per cent	*per cent*	*per cent*	*per cent*
SiO_2	1·83	0·92	0·74	0·89
Al_2O_3	1·33	1·78	2·30	1·74
Fe_2O_3	3·20	4·53	7·54	10·04
MgO	0·71	0·91	1·26	1·61
CaO	50·15	46·66	44·99	42·58
Total H_2O	1·26	2·22	2·22	2·43
CO_2	37·49	33·81	34·73	27·72
TiO_2	0·20	0·24	0·14	0·34
P_2O_5	2·31	3·65	0·46	5·81
SO_3	0·34	0·83	1·31	0·99
F	0·20	0·39	0·10	0·90
MnO	0·35	1·36	2·71	1·54
BaO	0·28	0·54	1·89	2·05
	99·65	97·84	100·39	99·64
Less O_2 for F	0·08	0·16	0·04	0·38
	99·57	97·68	100·35	99·26

Analysts: E.A. Industrial Research Board

Sk/1. West foot of Sokolo hill.

Sk/2. From cave at south-west foot of Sokolo hill.

Sk/3. About a third of the way up the south-west side of eastern hill, Sokolo.

Sk/4. From near summit of eastern hill, Sokolo.

Samples collected by Dr. Parsons.

(v) *The Relationship of the Kisingiri Volcanics to the Ruri Complexes.*—Plateau lavas consisting of mela-nephelinites of the upper Kisingiri Series and dark green nephelinite agglomerates of the middle Kisingiri Series occur around the foot of Ruri and near Tuige. From their position it is apparent that the lavas flowed up against the alkaline igneous rocks, pyroclasts, and carbonatites of those centres after a considerable period of erosion. At Rangwa the igneous rocks, carbonatites and finer pyroclasts are believed to have preceded the main nephelinite agglomerate and plateau lavas, and the age relationship on the margin of the Ruri and Tuige centres is similar. The Kisingiri nephelinites are older than the rift faulting of the Kanianwia escarpment, while the plugs of phonolitic nephelinite and nephelinite of Ruri type can be demonstrated to be later than that faulting.

(vi) *The Phonolitic Nephelinite and Nephelinite Plugs.*—Ruri is surrounded by a great number of conical hills, formed of light-coloured phonolitic nephelinites, and nephelinites characterized by green aegirine-diopside pyroxenes (Plate V, figs. 1 and 2). These rocks are quite different in appearance from the Kisingiri nephelinites, which are never phonolitic in composition and are characterized in thin section by large flesh-coloured augite phenocrysts. Besides the conical hills surrounding Ruri, which are clearly lava plugs, there is a chain of similar conical hills along the line of the Kaniamwia fault from east of Homa Mountain near Kendu Bay to Makokot. Simenya, Asego and Makokot are all situated near to the fault-line, and Makokot in fact straddles a branch fault of the Kaniamwia system, but shows no evidence of faulting. It is deduced from this that the lava plugs are of later age than the faulting. L. D. Sanders, in the annual report of the Mines and Geological Department for 1952 (1953, p. 11), noted in these plugs a planar flow fabric striking towards one of the Ruri centres, paralleled by chilled margins with spheroidal structures. Sanders considered that the plugs are part of a radial dyke system rather than individual plugs. During the present survey, however, several plugs with steep outwardly dipping joint systems, curving around the margins of the hills, were seen, and this suggests that the hills are in fact circular or oval plugs. None-the-less, a clear relationship to certain lines of weakness can be deduced

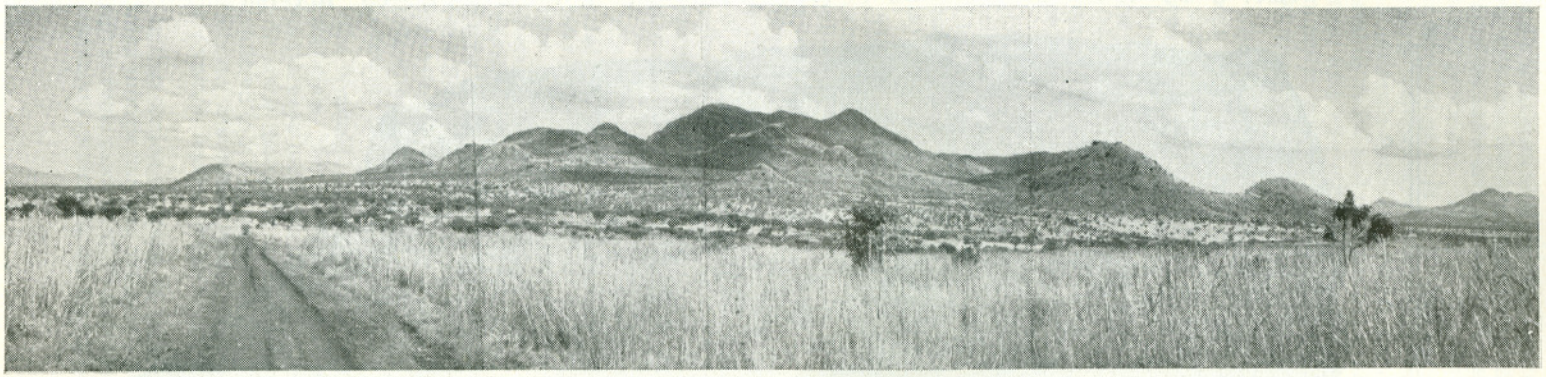


Fig. 1.—Panorama of the Ruri hills from the south-east.

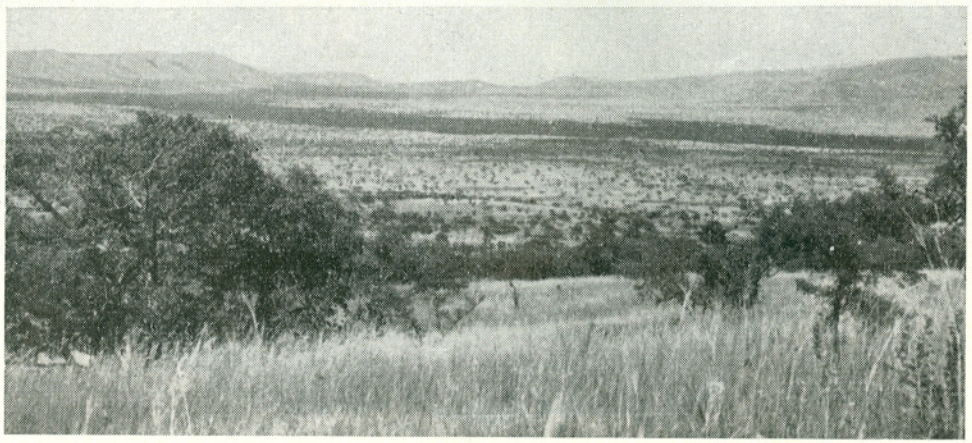


Fig. 2.—The Lambwe valley looking west from South Ruri, showing the Kaniamwia fault-line scarp on the left and the southern slopes of Gwasi to the right.



Plate VIII.—Spheroidal structures in phonolitic nephelinite (Ruri type). From a plug on the east side of the Ruri hills. The scale represents inches.

from the arrangement of the plugs, and it seems that they may be "swells" along dykes of lava filling extensive fractures not connected with the carbonatite centres. Three or four narrow dykes of the same lava are seen on South Ruri where they cut and slightly displace carbonatites and pyroclasts. Sanders' idea that the dykes radiate from the two eruptive centres of Ruri does not account for all the trend lines shown by chains of these plugs and, in view of the clear relationship of Makokot, Asego, Simenya and many other plugs, further along the Kaniamwia fault-line towards Kendu, it seems possible that there was a combination of control by radial and concentric fractures associated with the up-doming under the eruptive centres, and also with fractures associated with the fault movements that formed the Kaniamwia escarpment. Near Sokolo, certainly, the radial pattern noted by Sanders is strikingly preserved.

The Nyamaji hills are composed of coarsely porphyritic phonolitic nephelinite, similar in composition to the Ruri-type plugs. It is clear from field evidence at Sikiri point that there is a sharp junction between the plug of phonolitic nephelinite of Ruri type and the coarser Nyamaji lava. It seems probable that the Ruri type, which appears to have come up through the Nyamaji lavas, represents a slightly later phase of the same eruptions. The extraordinarily coarse porphyritic texture of the Nyamaji lava is comparable with that of kenytes and suggests that Nyamaji represents the deeper part of a volcanic vent. It forms an elongated ridge of uniformly coarse-textured lava, $2\frac{1}{2}$ miles long and standing 1,000 feet above lake level, parallel to the direction of the main rift faulting.

Phonolitic Nephelinite Plugs (Gotjope type).—Two hills composed of biotite phonolitic nephelinite lava stand up sharply in the Ruri complex. One on the south side of North Ruri is clearly a round plug of lava cutting the explosion breccia. The larger occurrence forming Gotjope which stands up from the Lambwe alluvial plain to the west of South Ruri, is also thought to be a plug.

The Gotjope rock (41/1423) is dark green in colour with prominent biotite plates, pyroxene phenocrysts and many dark enclaves. Under the microscope it is seen to consist of well-formed nepheline phenocrysts and green-zoned aegirine-diopside with light-coloured cores set in a microcrystalline base. Biotite of a deep golden brown variety is present as partly resorbed plates and occasional large aggregates of plates, and is usually surrounded by narrow coronas composed of small pyroxene crystals. A patchiness of texture is characteristic of these Gotjope-type nephelinites. The rock resembles the Nyamaji and Ruri phonolitic nephelinites in the dominant aegirine-diopside pyroxene, but no phenocrystic orthoclase is present. It is thought to represent a separate series of lava intrusions but what the age relation is to the other phonolitic nephelinites cannot be determined.

Phonolitic Nephelinites (*Nyamaji type*).—The hog-back ridge of Nyamaji and the smaller rounded plugs and dykes surrounding it are composed of phonolitic nephelinites with coarsely porphyritic textures, though the dyke rocks are not usually so coarsely porphyritic as those of Nyamaji ridge. The dykes are broad and well defined and appear to radiate out from the Nyamaji centre. They cut the explosion breccia of Tuige and the carbonatite and explosion breccia of Sokolo. The Nyamaji lava is similar in composition to those of the Ruri type, but is characterized by abundant partly assimilated enclaves of ijolite. Contacts between the Nyamaji lava and lava of Ruri type are abrupt at Sikiri and the latter appears to be the slightly later in age. Apparently the earlier Nyamaji lava was able to stope off and assimilate the Usaki ijolite country-rock, whilst the slightly later Ruri lava did not do so, and contains no ijolitic enclaves.

The Nyamaji lava is typically light green and shows idiomorphic phenocrysts of felspar and nepheline. The felspars are usually white and glassy in appearance, while the nepheline phenocrysts are brownish and have dull resinous surfaces. The nephelines are up to 3 cm. long in some specimens collected. Smaller blackish green phenocrysts of soda pyroxene are scattered in a pale green fine-grained base between the larger phenocrysts of nepheline and felspar. Melanite crystals that are clearly visible to the naked eye, and may be xenocrysts, are a common feature of the Nyamaji lavas.

In thin section (41/1454, 41/1456) the felspar phenocrysts are seen to be free of lamellar twinning though they are commonly twinned on the Carlsbad law. They are mostly fresh, though in some cases partial alteration has taken place. Smaller prisms of the same felspar are commonly present in the microcrystalline groundmass.

The nepheline phenocrysts are idiomorphic or sub-idiomorphic, and alteration has proceeded further than in the case of the felspars. The alteration commences with the formation of calcite, cancrinite and zeolites along cracks; in more altered specimens the nepheline is almost entirely replaced by these secondary minerals.

The pyroxene phenocrysts are usually zoned, with cores of light green aegirine-diopside and outer rims of dark green aegirine. The larger phenocrysts are broad idiomorphic plates, with large extinction angles up to 30° to the X axis indicating that they are aegirine-diopside. Aegirine as separate crystals is usually only present in the form of small needles with low extinction angles in the groundmass. Dark brown melanite garnet is locally abundant, but was not found in all thin sections made. It is always well formed and sometimes has a reaction rim of mossy aegirine-diopside. Relic fragments of biotite surrounded by haloes of chlorite are present in one microscope slide examined. The biotite, which is pinkish brown in colour, was an early-formed mineral and has been almost entirely resorbed. Sparse part-resorbed biotite is characteristic of the nephelinitic lavas of the Gwasi area, but only in the Gotjope phonolite nephelinites, where also it is attacked but little resorbed, does it occur in quantity. Cancrinite, calcite and white mica are common secondary minerals. Sphene is an abundant accessory in the Nyamaji-type lavas, while apatite and magnetite are much scarcer. The small needles of aegirine and felspar forming the microcrystalline base often have a trachytic arrangement.

The base appears to be a pilotaxitic aggregate of minute crystals of aegirine, nepheline and felspar, and glass is absent.

The Nyamaji lava has invariably the composition of phonolitic nephelinite rather than nephelinite. The felspars enclose chadacrysts of early developed nepheline.

Spherulitic phonolitic nephelinite mottled by slaty green spherulites up to half a centimetre in diameter set in a cream-coloured base outcrops on Nyamaji North. Phenocrysts of felspar are visible in the hand-specimen. In thin section the spherulites are seen to be formed of radiating aggregates of dark green aegirine needles. Together with smaller sub-idiomorphic nepheline and Carsbad-twinned orthoclase phenocrysts the spherulites are set in a microgranular base in which nepheline and aegirine can be recognized. Small felspar laths are also visible in the fine base, together with granules of cancrinite, fan-like aggregates of a zeolite and calcite.

The Nyamaji lavas superficially resemble the kenytes of the Mount Kenya vent; texturally there is considerable similarity, but the composition is that of a phonolitic nephelinite rather than phonolite, and the matrix is microcrystalline and contains no glass. Olivine is also absent.

Phonolitic Nephelinite Lavas (*Ruri type*).—The plugs around Ruri and along the Kaniamwia fault are composed of a finer-textured type of lava, which is also exposed in a few places north of Nyamaji. Field relations at Sikiri point suggest that the Ruri-type lava is slightly later in age than the Nyamaji type. The lavas are pale green or brown in colour and often have a slightly streaky texture, lenticular streaks of white material flecking the otherwise dark compact surface. Mottling caused by aggregation of the dark minerals is also a common feature. The general colour contrasts strongly with the much darker green of the lavas of the Kisingiri series. Felspar and nepheline frequently stand out water-clear in the fine-grained matrices, whilst the pyroxenes are dark green in colour, prismatic in form, and insignificant compared with those of the Kisingiri lavas. Porphyritic textures are common, large orthoclase phenocrysts up to two cm. long and smaller nephelines often standing out on weathered surfaces. The phenocrysts are never, however, as abundant as in the Nyamaji lavas. Chilled margins are frequently seen in the plugs and dykes, and spherulitic textures are commonly developed in these chilled phases especially in the smaller plugs (Plate VIII). The lavas sometimes show flow banding and a directional orientation of the prismatic minerals. Vesicles, discrete (as opposed to the spherulites, which sometimes coalesce), are seen in a few localities but are rather uncommon.

In thin section (41/1577, 41/1666, 41/1676) individual specimens of this type of lava show great variation, though they are characterized by abundant phenocrysts of sub-idiomorphic nepheline. A generation of much smaller nephelines often "crams" the groundmass, which is usually a pilotaxitic microcrystalline aggregate but occasionally contains

some glass. Orthoclase is present as large phenocrysts and as smaller prisms, as well as in the matrix. It is usually, but not always, twinned on the Carlsbad law. No lamellar twinning has been detected in any crystal and it is thought to be a sodic orthoclase and not anorthoclase.

The pyroxene ranges from aegirine-diopside with an extinction angle ($X \wedge c$) up to 25° to aegirine with a very small extinction angle. The former is pleochroic in medium shades of grass-green and bottle-green while the latter is much darker. The pyroxene often has a core of the lighter aegirine-diopside and a darker outer zone of aegirine. The colour of the pyroxene is distinctive: it shows no resemblance to that of the fleshy pink to pale green augite of the Kisingiri lavas. The pyroxene ranges from well-formed crystals to small needles in the groundmass, as well as radiating spherulitic aggregates showing cruciform extinction almost parallel to the cross-wires, and mossy clusters of poorly formed crystals.

A few flakes of partly resorbed red-brown biotite with reaction rims of pyroxene were seen in one specimen from Sikiri Point. Magnetite is rare, amorphous red iron ore probably secondary after magnetite being a more common accessory, but the amount of iron ore is negligible compared with the Kisingiri nephelinites. Sphene is a fairly common accessory in well-formed wedge-shaped crystals.

The microcrystalline groundmass frequently has a trachytic texture, due to parallel arrangement of needles of aegirine and prisms of felspar. Vesicles are particularly well seen in thin sections from Asego (41/1479) and the south margin of South Ruri (41/1400). The vesicles are infilled variably with colourless or brown-stained natrolite, carbonate, and analcite or combinations of these minerals.

The degree of alteration is variable—often the nepheline and the felspar are fresh, but in many cases a breakdown to aggregates of natrolite, cancrinite and zeolites has progressed to a considerable extent. Calcification is a typical feature of these lavas, especially of those near to the Ruri carbonatite.

Melanite garnet is a rather rare constituent of these lavas, and when present it occurs as large idiomorphic phenocrysts. It is much less abundant than in the Nyamaji lavas. Enclaves of included ijolite are not a feature of the Ruri-type lavas—a sharp contrast to those of Nyamaji.

Late Agglomeratic Explosion Breccia.—On the summit of North Ruri is a crescentic outcrop of a coarse pale green agglomeratic breccia containing abundant blocks of green lava with plates of brown mica up to an inch or more in diameter which is identical in thin section with the Gotjope type nephelinite. The breccia also contains blocks of carbonatite similar in appearance to the carbonatite of the major ring dykes, and is accordingly taken as later in age than the main phase of carbonatite intrusion.

Late Dykes of Explosion Breccia and Tuff.—Two dykes of yellow and brown explosion breccia and tuff were noted cutting phonolitic nephelinites. One, running parallel to the elongation of Nyamaji, cuts the south-east shoulder of Nyamaji High Point. The other cuts Ruri-type lava in a plug on the eastern side of the south ridge of South Ruri. The Ruri dyke closely resembles the earlier explosion breccias but a specimen collected from Nyamaji is a pumice tuff quite unlike any of the other rock types of the area. It resembles the Pleistocene tuffs exposed west of Homa Mountain and it is possible that the dyke represents a minor renewal of vulcanism during the Pleistocene period.

Late Carbonatite Dykes.—Minor dykes and cone-sheets of fine-textured red or grey carbonatite cut the ring dykes. They consist both of steep wall-like radial dykes and tangential cone-sheets. The latter are best seen on the ridge separating North Ruri from South Ruri (Plate VI, fig. 2), where they cut the outermost breccia of the North Ruri complex. They have a pronounced flow orientation of large calcite crystals parallel to their walls. These minor dykes are composed almost entirely of calcite and can be referred to the alvikites.

One of these late dykes cuts a small plug of Ruri-type phonolitic nephelinite on the south spur of North Ruri, and is the only observed example of a carbonatite dyke cutting the Ruri or Nyamaji-type lavas. The latest phase of carbonatite activity must have overlapped the extensive eruptions of phonolitic nephelinite around the Ruri centres.

(vii) *Superficial Deposits around Ruri.*—The lower slopes of Ruri are mantled with carbonatite and agglomerate talus, together with soils and gravels. The soils are dark brown and rich in magnetite, a small part of the heavy fraction being non-magnetic. The alluvial gravels are not of great depth or extent in the valleys within the Ruri hills, but two valleys on the west side offer promise of deposits of some extent.

The soils were sampled by L. D. Sanders (1952) and a study of the non-magnetic heavy residues was made by L. M. Bear (1952). Minute octahedra of yellowish microlite-pyrochlore and a small number of grains of monazite-xenotime were confidently identified, while opaque velvety black minerals with a vitreous lustre were tentatively identified as members of the euxenite-polycrase series. Other minerals found were a titaniferous opaque garnet (schorlomite-ivaarite), barytes, apatite, sphene and fluorite. It is worthy of note that columbian perovskite, which is abundant in gravels around Rangwa, was not identified.

(*b*) *Tuige and Sokolo*

There are two clearly defined and separate complexes at Tuige and Sokolo. Both are situated to the north of the Ruri hills and are dominantly pyroclast vents, the central carbonatite plugs being small compared with the massive ring dykes of Ruri.

(i) *Tuige.*—Explosion breccia, red to dark brown in colour, forms the low hill of Luwala a half mile to the south of Tuige and represents the outer part of the vent. The breccia is highly radio-active (up to 10 times background). Tuige hill itself rises two hundred feet above the lake shore and has a fairly gentle profile. It consists of a roughly oval central plug of carbonatite only about a quarter of a mile in maximum diameter cutting the explosion breccia, which is seen on the outer margin of the hill. Though the planar structure in the carbonatite ("vertical streaming") is contorted in places, the linear trace of the streaming planes can be traced completely around the hill. The dips are mostly steep to vertical but locally gentler dips, both outwards and inwards, can be observed.

A small area of Nyanzian metabasalt engulfed by the carbonatite, is exposed on the south side of the hill. The volcanic breccia is cut by two broad dykes of the Nyamaji phonolitic nephelinite.

The breccia on the margin of Tuige is red-stained and highly radio-active. The carbonatite shows the familiar magnetite trains, and is similar to the carbonatite of Ruri. Pyrochlore in well-formed octahedra, slightly yellowish grey in colour and isotropic, can be recognized in thin section (41/1690). Vesuvianite is an accessory.

The vent of Tuige is much obscured on the north side by later plateau lava of the Upper Kisingiri series and by the lake. The vent was probably about a mile and a half in diameter, and slightly smaller than the Ruri vents.

(ii) *Sokolo.*—Sokolo is a part of the remains of a large vent comparable in size with that at South Ruri. The vent breccia is exposed on the coast north and south of Sokolo point and on a small hill, called School hill, about a mile to the west. Further small exposures of carbonatite and breccia can be seen on the north coast two miles from the centre.

The breccia is only slightly radio-active, and is only very weakly stained. A fresh specimen from south-west of Sokolo point (41/1522) contains unaltered emerald-green pyroxene, a pleochroic pyroxene of lighter colour showing zoning, a colourless pyroxene, pinkish brown biotite, and pseudomorphs after nepheline. The assemblage closely resembles that of the almost unaltered lapilli tuffs and explosion breccias of the north side of the Rangwa vent. The breccia here preserves its original greenish colour, but is partly calcified. Elsewhere it is tinged purplish or light brown and thin sections reveal more advanced alteration. One specimen (41/1523) is composed largely of fragments of a granoblastic quartz mosaic and plagioclase, suggesting that the vent is underlain by a body of granitoid metamorphic rock.

A plug of carbonatite forms Sokolo point, a densely wooded precipitous crag rising about 400 feet from the lake. The carbonate is banded and iron-stained, but only a slight increase in radio-activity above normal background was noted. The dip of the banding is everywhere outwards at about 85°. The small outer bodies of carbonatite (which cut the pyroclasts surrounding the plug) have gentle dips. The direction of the dips are, however,

irregular and no regular pattern of cone-sheets can be made out. There is a mass of pure, coarsely crystalline marble near the coast west of the point north of Sokolo. This contrasts with the brown iron-stained carbonatites elsewhere. The Sokolo complex is cut by numerous late dykes of Nyamaji phonolitic nephelinite.

In thin section the typical Sokolo carbonatite shows a fine mosaic of calcite, with interstitial amorphous iron ore. No pyrochlore has been detected. Aegirine was found in the coarse marble type, and is clearly due to assimilation of syenite, since a small body of aegirine syenite is exposed close by. Syenite is exposed only at this one point on the coast west of the north point. It is a highly calcified nepheline syenite with abundant dark green aegirine and deep brown melanite crystals. Cancrinite is abundant.

Sokolo differs from Tuige and the Ruri complexes in that radio-activity is never more than twice the normal background. In this and in general form it more closely resembles Rangwa than the two Ruri vents.

(*c*) *Minor Bodies of Carbonatite (and Carbonate Rock not Connected with a Central Vent)*

A small dyke of carbonate breccia outcrops near the line of the Lambwe fault where it reaches the coast west of Homa Bay. Two or three small dykes of carbonate breccia cut Nyanzian rocks in the north-west corner of the area, but they are almost pure bodies of carbonate with a breccia texture and may be of hydrothermal origin, not connected with the carbonatite intrusions.

(4) The Mode of Origin of the Rangwa Complex, the Kisingiri Volcano and the Ruri Complexes

Though the work of von Eckermann (1948) presents the most detailed study of an alkaline and carbonatite complex, perhaps the most clear and concise discussion of the alkaline deep-seated bodies is provided by Backlund (1932), and the main points made by that writer are summarized briefly below:—

(*a*) The margins of alkaline complexes have a more or less circular trace in plan. They are not large (Umptek, Kola Peninsula, 36 × 46 kilometers, is the largest known). In contrast to the granitic intrusions, which are in general characteristic of orogenic zones, they are typical examples of epeirodiatresis, the perforation of stable areas of the crust. The outer boundaries are steep—near to vertical in the smaller bodies and steep inwards or outwards in the larger ones.

(*b*) The complexes consist of concentrically arranged or confocal zones of different types of undersaturated rocks. The junctions of the zones are usually sharp and there may be evidence of intrusion of the inner zones into the outer, though contact features are rare, suggesting derivation of the different zones from a common magma reservoir. The zones tend to increase in width inwards.

(*c*) The inner boundaries between the zones are of two kinds. Those of the outer zones stand vertically, while those of the inner zones, which are only seen in large complexes, are horizontal or slightly inclined planes. The succession of rock types from the outer edge inwards is one of more and more undersaturated (i.e. less silicic) rocks and the same is seen from the top downwards in the inner horizontally-layered parts of complexes. A typical sequence is—fenitized wall-rock; syenitic types; ijolitic types; apatite rock, or in rare cases melilite rock (turjaite or uncompahgrite).

(*d*) One or all of these zones are frequently cut out in sectors of the ring complexes.

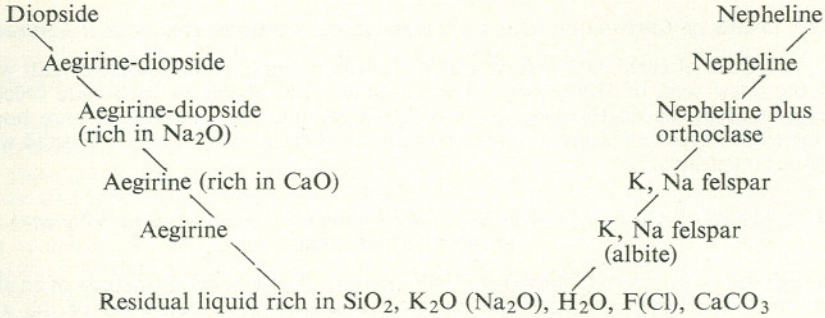
(*e*) Coarse-textured bands and patches, a "giant granularity", are typical of these rocks. This is not pegmatitic in origin, since the coarse streaks are so intimately intermixed with the mother rock that it is impossible to refer them to a late independent endogenous phase of development.

(*f*) Compositional banding is typical.

(*g*) Backlund favours Fersman's distinction of separate and more or less independent intrusions. The outer intrusions are marginally contaminated as a result of assimilation of the country-rocks. The carbonatite rocks, when present, are the latest "piercing" intrusives.

(*h*) An "agpaitic" differentiation sequence is suggested as a mode of origin of these alkaline sequences. Fersman has outlined the peculiar conditions obtaining. The parent magma is taken to correspond to a mixture of felspar, felspathoids and aegirine at a temperature of about 1,100° C. Orthoclase and nepheline separate first and, owing to their low density compared with the residual magma, rise to the top. As the process continues the crystal product becomes richer and richer in nepheline, tending to produce an urtite near the top of the magma chamber. The residual liquor approaches the composition of aegirine. The volatile constituents gradually increase together with the basic residue at the bottom levels. The early crystallized roof prevents the escape of gas, and this causes an increase in pressure and temperature exposing the first-formed crystals to pneumatolytic actions causing recrystallization and grain increment.

During the agpaitic differentiation it is supposed that the minerals change their character by reaction with the residual liquids. The reaction series suggested by Kranck (1928) is:—



Kranck explains the rare occurrence of late-stage melilite rocks by a strong rise of gas pressure in the magma, especially of carbon dioxide, inducing a break up of the remaining silicate minerals and releasing sufficient lime to form melilite. Bowen, later, has shown that in fact the aegirine end-member melts incongruently at about 950° C. to form ferric iron oxide and a liquid of varying composition, and there are indications that the natural aegirines have broken up in this manner, under the influence of rhythmic rises of temperature resulting from the concentration of volatiles in the residual magmas.

The mother liquor is presumed to remain undersaturated to the end; hence no free quartz is ever found in the products of the later stages of development of the alkaline bodies.

The volatiles (CO_2, P_2O_5, Cl and F) accumulate in the later stages; hence the appearance of abundant apatite in the latest-formed intrusions (e.g. apatite rock, uncompahgrite).

(*i*) Backlund believes that assimilation of carbonate wall-rock is not an essential in the production of alkaline suites, the whole series being explained by differentiation. (The origin of the ijolite mother magma has yet to be explained.)

(*j*) The complexes are only rarely found at the roots of great volcanoes and are rarely associated with simple surface extrusion. The mode of intrusion favoured is the cupola mechanism described by Holmes, involving the fusion of a steep dome-shaped funnel or cupola upwards through the country-rock. Stoping is ruled out due to the absence of included blocks of country-rock in the alkaline bodies.

(*k*) Catastrophic explosion, involving dyke emplacement along the fractures so formed and the boring of an explosion vent through the centre of the complex, may be a feature of the later stages of development when gas pressure is building up. The dykes formed at this stage will have a very basic composition.

(*l*) The carbonatites, the last intrusive bodies, are formed of the volatile-rich and silica-poor residue, often rising along fractures formed by catastrophic explosion.

In contrast to Backlund's and Fersman's theory of differentiation from an ijolitic parent magma, Holmes (1950, p. 786) has developed a theory of derivation of the katungites and associated potassic surface alkaline rocks of the Ruwenzori area by the action of carbonate magma, rising from depth, on granite country-rock. He suggests that this theory could be

applied to the soda alkaline suites of Kenya which are pierced by carbonatites. This theory is not favoured by the writer. The alkaline complexes of Kenya are intruded into such vastly differing country-rocks as granite, metabasalt, rhyolite, and a thick sedimentary siliceous formation (Mrima hill). Yet the alkaline intrusions show a remarkable similarity one to another not to be expected as a result of the substratum acting on diverse country-rocks. Further, all the evidence in the South Nyanza complexes favours the idea that the carbonatites belong to a late explosive stage of eruption, following the emplacement of the alkaline intrusions, though it is true that there may have been a build up of carbonatite beneath the complex long before the date of intrusion of the carbonatites now exposed at the surface.

The Rangwa complex reveals enough of the ring structures, in spite of the fact that a large part is obscured by alluvium and talus, for the general form to be determined. The only complete section, which extends from the north scarp of Gwasi northwards, shows the following succession of intrusions (cf. Fig. 9, at end):—

(1) Granite country-rock, fenitized and cut by small dykes of nephelinite, micro-ijolite and syenite.

(2) Ring dykes of micro-ijolite and micro-melteigite cutting granite, succeeded by a wider body of micro-ijolite with coarse bands.

(3) A great cone-sheet of banded uncompahgrite dipping inwards at about 30°, of total thickness more than 700 feet in the centre of its crescentic outcrop.

(4) A pipe-like vent of explosion breccia and other pyroclasts, probably nearly cylindrical in form but expanding slightly upwards, with prominent green aegirine-diopside, nepheline and biotite, besides scattered perovskite grains in the pyroclasts.

(5) Intrusions within the central vent, consisting of cone-sheets of alvikite and irregular central plugs of iron-rich carbonatite carrying pyrochlore.

The syenitic marginal zone is not seen in the section except for a few minor dykes, and as a local development within the ijolite zone. To the west a large outcrop of syenite is exposed, however, apparently in the form of a ring 500 yards wide with granite country-rock on both inner and outer contacts. An exposure of malignite on the lower part of the south-east cliff of Rangwa is a further representative of this syenitic zone, which is, however, very incomplete, as it is absent on Sagurumi, where the ijolite zone alone is present. The syenites and ijolites of Rangwa appear to be part of the same ring intrusion, the former being marginal hybrids. Metasomatism has probably largely altered the composition of the original alkaline igneous rocks.

The sequence fenitized granite—syenite (foyaite, malignite)—ijolite (urtite, melteigite)—biotite uncompahgrite—carbonatite follows the general pattern of desilicification inwards shown in all the examples of alkaline ring complexes cited by Backlund. The concentrations of apatite and biotite in the uncompahgrite fit in well with the reaction series suggested by Kranck, and the general theory of agpaitic differentiation. A horizontally-layered inner zone is not present in this comparatively small ring complex, (approximately 7½ miles maximum diameter), which has moreover had its centre eviscerated by a late explosive vent.

Rangwa is one of the rare carbonatite complexes which can be demonstrated to occupy the core of a great volcano. The explosion vent reached the surface and scattered pyroclastic material of nephelinitic composition far and wide, forming the tuffs and agglomerates of the middle Kisingiri pyroclastic group and the tuffaceous lower Miocene sediments of Rusinga, Mfanganu and Ikoro. Evidence for the origin of these pyroclasts in the Rangwa vent is seen in the fact that they are characterized by the same green aegirine-diopside, nepheline, biotite and sparse perovskite that are seen in the more unaltered Rangwa pyroclasts: large biotite flakes are abundant in the lower members, which also contain boulders of uncompahgrite, and ijolite boulders of identical character to the Sagurumi type are found in the upper agglomerate.

The Kisingiri lavas are connected with a series of dykes filling fissures, probably produced by the explosive eruptions. Though a few mela-nephelinite dykes cut the granite country-rock exposed around Rangwa, none cut the Rangwa alkaline complex or the vent. Most

of the dykes cutting the granite are foyaitic or ijolitic and characterized by green aegirine-diopside, contrasting with the pinkish flesh-coloured or very pale green augite which is the characteristic pyroxene of the mela-nephelinites and nephelinites of Kisingiri. It is suggested that the lavas were erupted from a zone of narrow fissures concentrated mainly beyond the margin of the alkaline ring complex. The magma from which they were formed was very mafic in composition, and from the fact that lavas carrying the pale pyroxenes lie below and above the agglomerates derived from the central vent and containing green aegirine-diopside, it is concluded that the parent magma of the Kisingiri mela-nephelinite and nephelinite lavas, which are typically extensive and of monotonous plateau lava type, was derived from a much deeper source than the syenitic types and probably was not closely connected with the Rangwa alkaline diatreme.

The up-doming of the granite floor is an interesting feature of the Rangwa complex. It would be interesting to know whether such up-doming accompanies diatremes that do not possess late explosion vents and carbonatite intrusions. From the evidence at Rangwa it seems certain that the up-doming antedates the deposition of the Lower Miocene lake beds of Rusinga and Mfanganu Islands, and the first nephelinite lavas (Lower Kisingiri Series). The build up of explosive carbonatite under the complex seems a more likely source of this upward pressure, than the intrusion of the first cylindrical body of ijolite.

The fact that the syenite and other alkaline intrusions are now exposed close to the erosion surface on which the lower Kisingiri lavas or middle Kisingiri agglomerates were deposited, suggests that considerable erosion intervened between the intrusion of the alkaline and ultra-basic rings and the explosive onset of the volcanic phase. The first ring intrusions may well be older than the lower Miocene, the date of the eruption of the Rangwa pyroclasts, and they may even be older than the "sub-Miocene" peneplanation.

Ring complexes of the type seen at Rangwa differ fundamentally from those of Demaraland, South-West Africa (Korn and Martin 1954, Simpson 1954) and from the classic Scottish examples, which were apparently emplaced by a process of cauldron subsidence after the onset of surface vulcanicity. The Nyanza alkaline complexes were apparently emplaced prior to any surface vulcanicity though they may have underlain early volcanic piles which have been completely removed by erosion (e.g. Ruri). The possibility that the effects of some of the explosions may never have reached the surface cannot be excluded. Backlund does not consider cauldron subsidence as a factor in the mechanism of intrusion of alkaline complexes, and indeed it seems unlikely, since intrusion usually begins with a pronounced up-doming movement of the surface and not a subsidence.

Not enough of the alkaline intrusions of the Ruri hills is exposed for it to be possible to decide whether there is one large ring complex pierced by several explosion vents or whether there is a series of closely-spaced ring complexes. The similarity of the rock types leaves no doubt, however, that they are parallel in origin to those of Rangwa.

Incorporating the deductions of Pulfrey (1949, pp. 446–7; 1954, pp. 218–219) the following sequence is derived:—

1. Urtite or pulaskites (giving rise to ijolites etc. and syenites by later metasomatism).
2. Pyroclastic rocks of the explosion vent.
3. Carbonatite ring dykes and cone-sheets.

This fits in well with the sequence of events derived from the more ample field evidence at Rangwa. No evidence of an overlying volcanic pile is seen at Ruri and if the explosions did pierce the surface then the materials thrown out have been completely removed, which may suggest an earlier age than Rangwa, though it is possible they are of like age, and that lack of reinforcement by lava has caused the Ruri volcanoes, certainly of less dimensions than Rangwa, to be rapidly denuded and obliterated. Great erosion is certainly indicated between the emplacement of the Tuige carbonatite and its covering by Kiangata agglomerate and surface flows of Upper Kisingiri mela-nephelinite, now exposed at lake-level a few hundred yards to the north of the carbonatite. African carbonatite complexes range from pre-Cretaceous (Dixey (Chilwa), 1937) and Jurassic (Davies (Uganda), 1947) but at Rangwa the carbonatites are definitely Tertiary (lower Miocene), and it is possible that they are of generally similar age in the Ruri area.

Lavas were erupted at a later date in the Ruri centres than at Kisingiri; the fissures up which the many relatively small lava plugs and dykes rose were probably mostly caused by tectonic disturbances accompanying the up-doming of the complexes and the rift faulting of the Lambwe valley.

Considering the evidence from Rangwa and Ruri the writer reaches the following conclusions regarding the origin of the carbonatites and associated alkaline complexes of South Nyanza.

(1) The process commenced with limited intrusions of alkaline rocks (ijolite, etc.). The alkaline syenites formed by marginal reaction with the country-rock, and also by metasomatic differentiation due to pulsations of fluid through the ijolite body.

(2) The uncompahgrite and turjaite of Rangwa form a later cone-sheet intrusion. Their origin is probably due to the build up of pressure of volatiles, especially carbon dioxide, causing a break up of the remaining silicate minerals to provide the CaO necessary for the formation of melilite.

(3) The carbonatites form cone-sheets, ring dykes and plugs, partly of intrusive and partly of replacive origin, within late explosion vents, which pierce the older complexes. The Rangwa vent is filled with nephelinitic material, much altered, and this suggests a source closely associated with the very widespread nephelinite magma, rather than an origin from the differentiation of a small alkaline intrusion. The proportion of carbonatite to alkaline rocks exposed also weighs heavily against such a derivation.

(4) An up-doming occurred in Rangwa and the Ruri complexes. It is suggested that the build-up of explosive carbonatite supplied the upward pressure involved. Indeed it may be this upward pressure that forced the magma up in a series of cupolas corresponding with the first ijolite bodies of the complexes, and, notwithstanding the relative ages of the surface ijolite and carbonatite, it may well be that the carbonatite is the prime mover in the development of the complex.

(5) The Rangwa vent was the vent of the Kisingiri volcano. Whether the other vents were associated with sub-aerial vulcanicity is uncertain. No remnants of corresponding volcanic piles exist today, nor is there any evidence of surface volcanicity corresponding with the earliest alkaline intrusions.

(6) The Rangwa carbonatite is probably of Miocene age but in part younger than lower Miocene sediments, the alkaline intrusions and uncompahgrite being considerably older, though still Tertiary. There is some evidence suggesting that the four carbonatite complexes in the Ruri area may be older than that at Rangwa, and of early Tertiary age.

(7) Limestone assimilation is virtually untenable as a mode of origin for the carbonatites since calcareous sediments are almost completely absent in the underlying Precambrian formations (Pulfrey, 1949, discussion pp. 457-8). Also a control of the situation of carbonatites by sedimentary trends would be expected, rather than the observed close relation to tectonic structures—the Kavirondo rift valley in the present case.

(8) The situation of six carbonatite complexes and one small vent in the Kavirondo rift valley cannot be coincidental. A further complex can be presumed under Tinderet in the eastern part of the Kavirondo rift from the evidence of ijolitic boulders in its agglomerates and another small explosion vent at Buru hill has recently been discovered nearby so, in all, seven complexes and two small vents are aligned along the rift valley.

The alkaline and carbonatite complexes are all earlier than the post-lower Miocene faulting in the Gwasi area, but from the configuration of the Lower Miocene lake beds, it is clear that a down-warped trough was situated along the line of the graben much earlier than the faulting. There may even have been an earlier fault-trough.

Whatever the origin of the rift valleys, whether tensional or compressional, a pressure build-up beneath them must have occurred, and this perhaps provides a favourable condition for the pushing up of the carbonatites. Carbonatites need not and do not, however, require the presence of a rift valley for their formation—many are not situated anywhere near such structures—but a rift valley provides conditions favourable to diatreme activity.

3. Tertiary-Quaternary Sediments and Superficial Deposits

(1) Tertiary-Quaternary Deposits of Doubtful Age

(a) Homa Bay Clays

A series of red and green stratified clays containing fossil wood and boulders of Precambrian rocks, forms a hundred-foot cliff to the east of Homa Bay pier, near Simenya hill. The age of the whole series is not known. The clays somewhat resemble the lowest Miocene sediments of Mfanganu, but stratified tuffs are absent. Saggerson considers that similar clays further to the east near Homa Mountain are lower Miocene, since they are cut by a tinguaite dyke (Saggerson 1952, pp. 20–23). The nature of the deposits rather favours a lower Miocene age, since deposition would have been very rapid during the Pluvial periods of the Pleistocene and it seems doubtful if such fine-grained deposits could have been laid down so close to the lake shore. Miocene fossils have been obtained from these clays by Dr. L. S. B. Leakey, who considers that they are mainly of Miocene age with, possibly some Pleistocene sediments associated with them.*

(b) Tuige Clays

Clays similar to those near Homa Bay and raised beach deposits with abundant fossil wood outcrop along the coast between Tuige and Sokolo. The clays are cut by a carbonatite dyke west of Tuige and, as they contain nephelinite boulders of Kisingiri type, but none of Ruri or Nyamaji type, for the present these clays must be considered as of doubtful lower Miocene age, but possibly associated with Pleistocene clays. From the facies, it is believed that they will yield fossil evidence on more detailed examination.

(2) Quaternary and Recent Deposits

(a) The Lambwe Valley Alluvials and Lake Beds

The flat floor of the Lambwe valley apparently marks an extension of Lake Victoria during Pleistocene times. Samples from bore-hole C.1269 in the centre of the valley have been examined by the writer and indicate the following section:—

	Feet	
	from	to
Black cotton soil	0	20
Buff-coloured clay	20	70
Diatomaceous lake beds, with well-rounded fragments	70	343

Similar sections of lake beds were disclosed by shallow bore-holes at the eastern end of the valley. This extension of the lake matches that east of Kisumu in the Kano plains where over 500 feet of Pleistocene lake beds accumulated.

(b) The Kaksingiri and Karungu Alluvial Gravels

Unconsolidated gravels form deep sections in the plains surrounding Rangwa and in the adjacent valleys. The gravels contain scattered boulders, and were apparently rapidly accumulated during the Pleistocene pluvial periods, with subsequent deposition continuing more slowly to the present day. The thickness of these gravels is striking—sections 50 ft. deep are exposed in ravines south and west of Rangwa. This deep incision of the alluvial plain indicates a recession of the lake level in very recent times, causing the incoherent alluvials to be rapidly excavated by storm torrents from Rangwa, Gwasi and Gembe. A notable feature of the gravels is the local origin of the detritus contained in them. Over the Kaksingiri granite near Sagurumi and Omutageti the gravels are largely made up of quartz and granite detritus. Near the uncompahgrite, south of Rangwa, black sands composed mainly of magnetite and perovskite predominate, and in the central valley of Rangwa red alluvials derived from the carbonatite are piled up. This is a promising indication that the Rangwa alluvials may yield concentrations of pyrochlore and apatite, and possibly of columbian perovskite.

*Verbal communication.

(c) *Talus*

Talus mantles the lower slopes of Rangwa and Ruri hills. The bouldery rubble has in many places been cemented by carbonate solutions to form a calcareous breccia. On South Ruri rounded aggregates of perfectly formed calcite crystals up to several inches in length have been deposited, probably by hot underground streams in cavities in the talus. Similar calcite aggregates are a feature of Homa Mountain where hot springs are still active.

(d) *Soils*

Black cotton soil covers poorly drained areas of the volcanic rocks, and the greater part of the plains around Ruri and Rangwa. The Lambwe valley is mantled by black cotton soil. Dark reddish brown soils occur in the better drained areas of volcanic rocks.

The Nyanzian and Kavirondian rocks usually have a mantle of lateritic soil or murram

4. Tectonics and Structures

(1) Pre-Tertiary Structures

The structures in the older rocks of parts of South Nyanza have been described by Shackleton (1946, pp. 38–43) and Huddleston (1951, pp. 46–47) who mapped the Migori and Kisii areas, where the Nyanzian and Kavirondian rocks are extensively exposed and a detailed study of the structures was possible. In the Gwasi area the older rocks are exposed only in the south-east part, to the north of the Sare-Oyani porphyritic andesite mass, and in three further very limited areas at Homa Bay, Ruri and Kaksingiri (Fig. 8).

The comparatively simple folding of the Kavirondian (post-Kavirondian orogeny) can be made out and is shown on the natural section (C–C_3) accompanying the geological map. The folding of the Nyanzian and Kavirondian is certainly very complicated at Kaksingiri, and probably more or less isoclinal; the Nyanzian east of Homa Bay is also probably tightly and intensely folded, as the cleavage is invariably very steep.

The history of pre-Tertiary folding generally accepted for South Nyanza is that it occurred during two periods, one post-Nyanzian and the second post-Kavirondian.

(a) *Post-Nyanzian Orogeny*

Intense folding of the Nyanzian rocks took place prior to the deposition of the Kavirondian conglomerates, syntectonic granites (G_2) being injected into the folded rocks. The folding was mainly on north-west—south-east axes.

A long period of erosion during which the older granites were exposed intervened before the post-Kavirondian orogeny, and the Kavirondian conglomerates were laid down unconformably over the Nyanzian.

(b) *Post-Kavirondian Orogeny*

Folding of both the Kavirondian conglomerates and the already folded Nyanzian rocks took place adopting, to a large extent, the older Nyanzian trends. This second episode of folding movements compressed, ruptured, and sheared the Nyanzian rocks, but the massive Kavirondian conglomerates did not undergo a comparable disruption. The later granites, typically leucogranites (G_3) and including the Nyagongo, Muhoro and Kaksingiri-Takivere granites rose by stoping through the now highly disturbed formations. For illustrations of the folding, and the succession of tectonic events the reader is referred to the illustrations in the reports on the Kisii area (Huddleston, 1951) and the Migori area (Shackleton, 1946).

Faulting.—Nyanzian and Kavirondian rocks mapped by Shackleton and Huddleston in the Migori and Kisii areas are cut by faults and quartz-filled fractures (buck veins) running in a north-north-west to south-south-east direction. Faulting, however, is not seen on any large scale in these older rocks. Some minor fractures running in the same direction and filled by quartz veins can be detected on and near Nyagongo, but elsewhere no faulting or fracturing was noted.

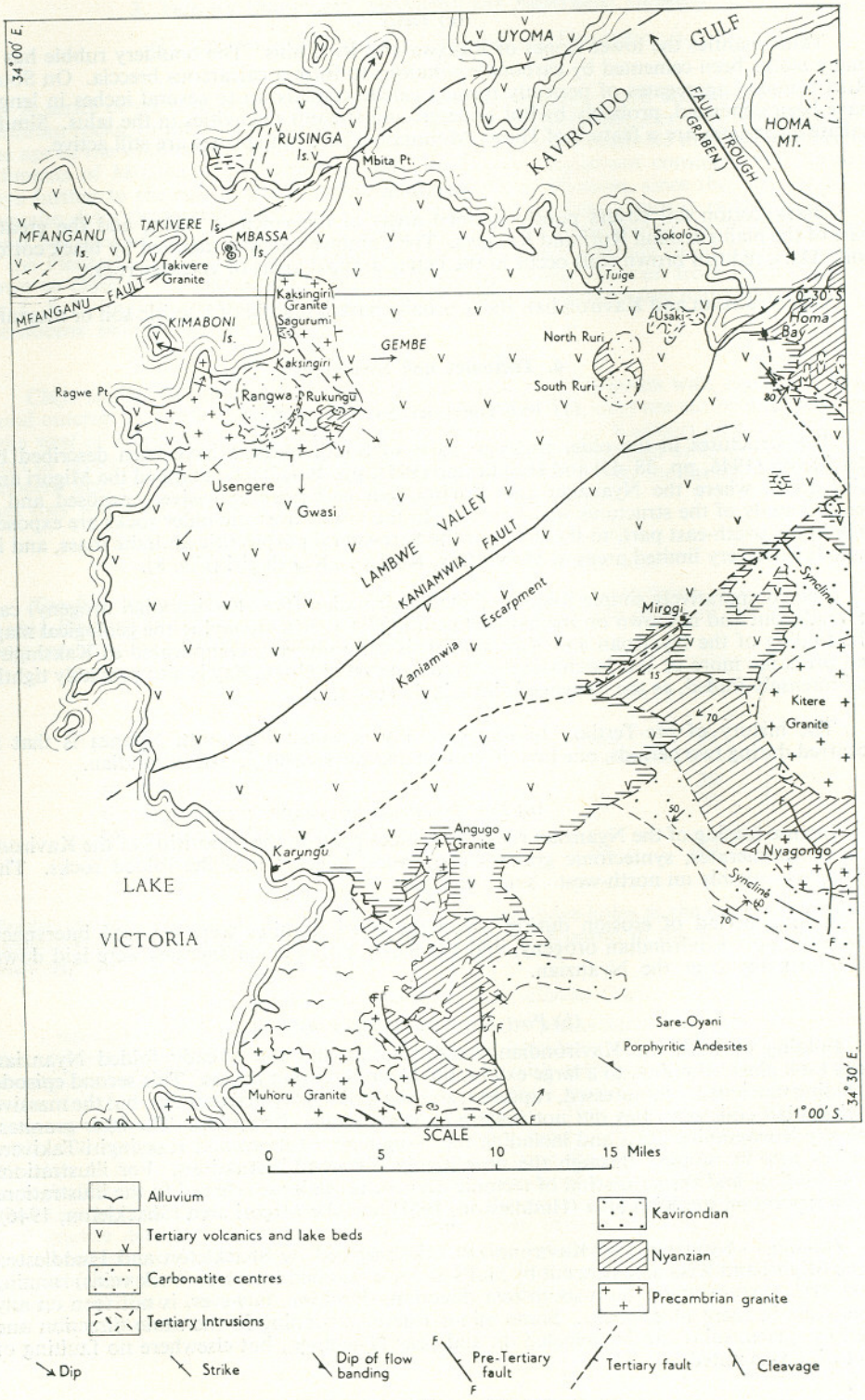


Fig. 8.—Structural map of the Gwasi area.

(2) Tertiary Structures

The only folding in the Tertiary rocks is gentle warping of the Lower Miocene lake beds of Rusinga and Mfanganu. These structures are considered by Shackleton (1951, p. 382) to have their origin in slumping rather than compression.

There are two major Tertiary faults, the Kaniamwia fault and the Mfanganu fault. The Kaniamwia fault is apparently a normal fault down-throwing to the north-west. The line of the fault bears no relation to the strike of the underlying schists, being north-east to south-west. The estimated throw in the centre section, opposite Kaniamwia and Kiambo, is over 1,500 feet. In the north-east opposite Ruri the throw is much less and the fault bifurcates into two rather insignificant displacements, the more southern of which dies out in a distance of about five miles. In the south-west, near Uganju, the fault again diminishes. The displacement here is small but the fault forms a definite feature passing out into the lake immediately south of Uganju. The escarpment of the Kaniamwia fault is eroded, and the state of dissection corresponds with the old marginal fault-line escarpments of the Gregory Rift Valley. It is a fault-line scarp, the actual fault line being obscured by the Lambwe alluvium. The probable age of the faulting is suggested as late Pliocene or early Pleistocene by Shackleton (1951, p. 386) but the eroded state of the phonolitic nephelinite plugs of Ruri and Nyamaji which were emplaced later than the faulting, suggests that it is perhaps rather earlier—possibly upper Miocene.

The Mfanganu fault has the same trend as the Lambwe fault but throws down to the south. On Mfanganu Island a sheer cliff rises on the south side. Small faults can be detected in the field running in the same direction. In spite of the sheer nature of the scarp, it is considered to be a fault-line scarp and that the fault itself lies well out into the lake. Takivere island must lie on the north and upthrow side of this fault, which is responsible for the Kaksingiri granite dome here re-emerging. Further proof of the recession of the scarp is seen in the fact that the valleys of the high plateau of Mfanganu run back southwards into wind gaps (Kent, 1942, p. 26). The fault has a throw of well over a thousand feet opposite Mfanganu, but dies away opposite Rusinga where the throw is estimated from the position of the lava on Hiwegi hill and on Mbita as about 150 feet. The fault passes through the deep and narrow Mbita channel, and can again be recognized to the north-east on Uyoma by the south scarp of Naia.

Taking the wider aspects of the rift faulting in the Lambwe valley graben, many points of interest can be noted. The graben shows none of the post-Tertiary lavas seen on the floor of the Gregory Rift Valley and, as would be expected, none of the secondary grid-faulting in the Lower Pleistocene. The grid-faulting took place immediately after the welling out of extensive plateau lavas during a period of tension. It is likely that the faulting of the Kavirondo and Lambwe rift valleys may also have a close connexion with vulcanism, for the greatest displacements in these two rifts are seen, first in the Kiambo-Kaniamwia and Mfanganu escarpments exactly opposite the Kisingiri volcano, and secondly in the sector east of Kisumu containing the vast Tinderet nephelinite volcano. Between these foci of vulcanism the faults displacements are proportionally small. It is suggested that the Lambwe rift-faulting was immediately subsequent to and genetically connected with the eruptions of the extensive Upper Kisingiri plateau lavas during a period of tension, and that the faulting occurred during the Miocene era. It is clear from the field evidence that the history of this Tertiary rift valley commenced with the emplacement of a chain of diatremes along a linear zone prior to the Lambwe faulting. Down-warping or faulting may have taken place previously and no doubt some surface volcanics were produced, but these have been completely obliterated. It is the cause of the development of such linear zones in the continental shield, characterized by recurrent episodes of diatreme activity, surface volcanic activity and downwarping or faulting that still presents a problem.

Minor fractures running north-westwards can be detected from the orientation of aligned phonolitic nephelinite plugs near Ruri. They are possibly a posthumous reflection of older lines of weakness in the Precambrian rocks, or may be due to complex fracturing near the junction of the Kavirondo and Lambwe troughs. A few minor normal faults trending slightly east of north are seen on Rusinga Island, and near Rangwe point, while a few minor dislocations, in the nature of major joints, traverse the Rangwa vent.

Thrust dislocations were described on Rusinga in the Kiahera, Hiwegi, Kulu and Waregu beds by Kent (1944, pp. 95–98) but were not accepted by Shackleton (1951, pp. 381–382). They have again been described from the sediments at Gumba by Whitworth (1953, pp. 88–89) who thinks that they are of no great tectonic significance. No further definite evidence of post-Miocene compression has been noted throughout the Gwasi area. Some cleavage (or closely spaced fracturing) is seen in the tough compact upper Kisingiri lavas, on the edge of the Kaniamwia fault, near the African Land Development headquarters; there are two directions of hade, towards and away from the scarp. Elsewhere along the fault-scarp the lava near to the fault shows only fragmentation into a breccia of angular fragments.

VI—ECONOMIC GEOLOGY

1. Mineral Development

Only one mineral deposit has been developed in the area—the *Macalder Mine* at Masara in the Migori gold-belt. The mine was originally worked for gold and silver and between 1935 and 1950 (excepting 1949 when no production was made) 42,438 oz. of gold valued at £356,322 were produced, and more than 50,000 oz. of silver worth more than £6,000. It was subsequently taken over in October, 1951, by the Colonial Development Corporation, operating as Macalder-Nyanza Mines Ltd., to work the cupriferous sulphide ore-bodies. The occurrence has been described by Shackleton (1946, pp. 53–56).

In 1950 a geophysical survey was carried out by consulting geophysicists using magnetic and electrical methods and a number of anomalies were detected, which, however, are mostly directly related to geological structures. No additional ore was located in relation to the anomalies. A further geophysical survey by means of a gravimeter was carried out by J. M. Brown of the Geological Survey of Uganda (1954). The survey suggested that there is a small structural culmination related to the swing of the Masara fault near Copper hill. Since no similar anomaly was found elsewhere in the area it was deduced that the main sulphides are restricted to that locality. A "Slingram" survey by Brown using the induction method revealed one area in which a promising anomaly was recorded, and it was recommended that further geological examination of this area should be carried out.

The ore reserves at the mine have been estimated as follows (Anonymous, 1955, p. 927):—

	Tons	Copper	Gold	Silver	Zinc
		per cent	*dwts./ton*	*dwts./ton*	*per cent*
Proved reserves ..	718,000	2·27	2·24	1·81	3·45
Indicated ore ..	119,000	2·09	2·75	1·25	2·00
Inferred ore ..	637,000	1·89	1·60	0·92	2·49
Transition zone ..	36,000	3·88	2·52	1·46	1·82

The mine will go into operation as a copper producer on completion of the precipitation plant now in course of construction*. Concentrates obtained by flotation and tabling will be roasted in a fluo-solids reactor to produce soluble sulphates, which will be leached, followed by precipitation of the copper on sponge iron produced at the mine from the iron oxides recovered after roasting, by reduction with charcoal. The cement copper precipitated will be sent to the Kilembe Mines smelter at Jinja, Uganda, which is expected to begin operations in 1956. It is proposed to treat 10,000 tons of ore monthly, with gold and silver being obtained as by-products, both from tabling and as a result of cyanidation of the roaster residues before they are converted into sponge iron. Gold will also be produced from small free-milling veins on the same property.

2. Minerals of Economic Value

(1) Radio-active Anomalies in the Gwasi Area and Associated Columbium Deposits

Radiometric measurements were made throughout the area during the survey, using Labgear (Model No. 1048A) and Victoreen instruments. No abnormal radio-activity was noted except in the carbonatite complexes. The nature of the anomalies observed are described below.

*Production started in August, 1956.

Ruri.—The most striking anomalies were found on the North Ruri and South Ruri carbonatite complexes, and are mainly localized around ironstone segregations in the carbonatite, networks of ironstone veins, and outcrops of iron-impregnated volcanic breccia. Elsewhere no increase on the normal background was observed. The normal background reading was 1·5 to 2 micro-amperes on the Labgear instrument and 1·5 to 2 micro-amperes on the sensitive scale of the Victoreen instrument. The highest recording was 25 micro-amperes, i.e. more than 15 times background, on the north margin of North Ruri. The β–γ ratio is indicative of a high thorium-uranium ratio. At this locality a lenticular mass of iron-stained breccia cut by ironstone veins passes inwards into equally iron-rich carbonatite. Over an area of about 350 yards square recordings of 10 times background or higher were obtained. Many smaller bodies of a similar type giving high readings on the ratemeter were found on the Ruri hills, mainly at the margins of the vents. The persistence of these bodies in depth is a question not yet solved though, if the vent is indeed of cylindrical form with nearly vertical walls, persistence seems possible. Deposits near to the margin of the vent, where cone-sheets predominate, will probably extend inwards towards the centre in depth.

Investigations of radio-active concentrations at Sukulu (Campbell, 1952) have shown that such hydrated iron ores in breccia and carbonatite owe their radio-activity partly to uranium and thorium and partly to radium and its daughter elements. The radio-active daughter elements are present in quantities in excess of those found under conditions of equilibrium. It is possible that by drilling to several hundred feet the source of the radio-active products in the ironstones might be discovered, and yield workable quantities of the primary minerals. Pyrochlore is scattered in schlieren in the carbonatite on Ruri but there is no evidence yet that it is of any economic importance. It is probably responsible for a very small part only of the radio-active anomalies. In view of the greater pyrochlore content of the Rangwa carbonatites, that complex obviously merits first attention in the search for pyrochlore deposits.

Soils and alluvial deposits around Ruri are neither deep nor extensive. L. M. Bear (1952) found doubtful euxenite, pyrochlore, and a little monazite in soil samples from Ruri. Analyses by W. P. Horne of soil samples without concentration yielded the following results:—

	R4	R19
	per cent	*per cent*
Rare Earths	Trace	0·04
Nb_2O_5–Ta_2O_5	0·20	0·10

R4. Magnetite-rich soil, from a gully running northwards, west of North Ruri summit·

R19. Magnetite sand, from a gully 1½ miles south-south-west of South Ruri summit.

While there are many exposures of radio-active ironstone on Ruri, it is doubtful if there are sufficient alluvial deposits or soil mantle to be of economic value. The Achol valley and the valley south-east of South Ruri summit offer the most promise of soil and alluvial concentrations.

Tuige.—Luwala hill, south of Tuige but part of the same vent, consists of iron-stained breccia resembling closely boulder material from Mrima Hill (Baker, 1953, p. 44). Radio-activity is abnormally high and values up to 10 times background were recorded. Similar values are obtained over ironstone bands in the carbonatite on Tuige hill itself though the light-coloured carbonatite gives low readings. The occurrences on Tuige are exactly similar to those on Ruri and prospecting, especially by drilling, might prove deposits of economic value. Pyrochlore is present on Tuige, but not enough samples have yet been studied to assess the value of the occurrence.

Sokolo.—The highest values recorded on Sokolo were 2 times background. The general state of the explosion breccia there is fresh as compared with Tuige and Ruri and, though the examination during the present survey was cursory, the vent appears to be the least likely to yield economic deposits. No pyrochlore has yet been detected on Sokolo, but few samples were studied, as the central plug ("Sokolo Point") is difficult of access owing to dense bush mantling the almost sheer marginal slopes.

Rangwa.—The radio-activity anomaly around Rangwa is far less pronounced than at Ruri and Tuige—readings of 4 times background were the highest recorded. A slight increase was noted towards the centre and over the deep red alluvial deposits of the central valley, and an increase was also found near carbonatites carrying pyrochlore. Ironstone veins are small and sparse. The breccia which forms most of the vent shows on the north part a yellow discoloration reminiscent of the Mrima hill explosion breccias and may well show high rare earth and columbium content, though no pyrochlore or monazite is apparent. It is doubtful if the pyrochlore concentrated in schlieren in the carbonatites in the central part of the vent could be worked economically, though if the schlieren are persistent they might be followed as "lodes". The pyrochlore is visible as numerous yellow specks on rock surfaces but its occurrence is sometimes localized. The thick deposit of alluvium in the central valley will, however, almost certainly contain pyrochlore as well as columbian perovskite and apatite. A deep drill-hole in the centre of Rangwa might also reveal carbonatites with a workable pyrochlore content. Official prospecting was begun on the central valley at Rangwa in the second half of 1955.

Vast quantities of columbian perovskite containing approximately one half per cent Nb_2O_5 are present in the uncompahgrite of Rangwa. The rock contains on an average about five per cent of perovskite; bands containing 10 to 15 per cent are common and as much as 30 per cent is found in some bands. Though the columbium percentage of the rock is not high, the ease of extraction, and great extent of the body, might make this mass of igneous rock, over 700 feet thick, worthy of more detailed investigation. The rock is coarse- to giant-grained and the perovskite can be concentrated by simple crushing and panning. Apatite is an abundant accessory and could also possibly be extracted fairly simply. Alluvials below the uncompahgrite outcrop might similarly yield workable perovskite and apatite concentrations.

Perovskite is worked in rocks of similar type in Russia, but not apparently elsewhere, since it is normally of sporadic occurrence.

(2) Apatite

Apatite might be recovered from the uncompahgrite or alluvials of Rangwa. It is also present in restricted concentrations in the carbonatites on Ruri and elsewhere at Rangwa but it is unlikely that any of the deposits discovered so far could be worked economically.

3. Other Minerals

(1) Limestone

The limestones of Ruri, Sokolo, Tuige and Rangwa might be worked for lime, though on the whole they are ferruginous and impure. To manufacture cement considerable treatment would be necessary. The Miocene sedimentary limestones are of no economic significance.

(2) Vermiculite

Some vermiculite is present in the carbonatites but it is unlikely to be of any economic value.

(3) Garnets

The melanite garnets that abound on Rusinga and Mfanganu are of no economic value. They are invariably cracked or deformed, and were reported some years ago by firms in England as too soft for abrasive purposes. The dark colour is also unfavourable. Abrasives manufacturers prefer garnets with a warm red or deep pink colour.

(4) Gold

No new gold occurrence has been noted and with the exception of the already developed Migori belt, and possibly the western end of the Kitere granite, conditions are geologically most unfavourable. The Nyagongo and Kaksingiri-Takivere granites are not likely to be mineralizers and, in fact, no mineralization of any kind was noted in the vicinity of these granites.

4. Building Materials

The only building-stone of any sort in the area is the tuff that forms the more fine-grained parts of the explosion breccia at Ruri. It is not of good quality but can be used for the simply constructed housing and stores needed for settlement schemes.

5. Ground-water

Only six deep bore-holes have been drilled in the area:—

P.W.D. Contract Number	Locality	Depth (feet)	Yield (Gallons per 24 hrs.)
C1191	Obuari, Anguga valley	415	50,688
C1239	Luanda, north-east of Karungu	570	48,000
C1268	Chabi-chabi, Gwasi	560	55,200
C1269	Lambwe valley	343	52,800
C1347	Macalder mine	220	2,400
C1348	Macalder mine	331	11,500

Drilling in the Tertiary volcanics and soft sediments of the Lambwe valley, Gwasi and Karungu has been very successful, as is seen from the results of the first four bore-holes given in the table. Numerous shallow bore-holes to depths of 100 to 150 feet have also been sunk by the African Land Development Board in the Lambwe valley and on the slopes of Ruri.

There is a considerable depth of Pleistocene sediments of lacustrine origin under the black cotton soil of the Lambwe valley and conditions are ideal for the natural storage of ground-water. The only controlling factor is the depth of the hydrostatic level, and the few failures experienced by the African Land Development Board must be attributed to too shallow drilling—deeper drilling with a power-operated drill should always be successful in the Lambwe valley.

The southern part of the area is well watered and little recourse to ground-water supplies has so far been necessary. The Nyanzian rocks, owing to their cleavage, easy weathering, and decomposition in general should provide fairly good aquifers, whilst the Kavirondian conglomerates are quite impervious to ground-water and drilling on the conglomerate-covered areas would almost always be abortive.

6. Possibilities of the Area

The radio-active ironstones of Ruri and Tuige, the pyrochlore-bearing carbonatites of Ruri and Rangwa and possibly of Tuige and Sokolo, and the alluvials of Rangwa are worthy of detailed investigations. The Ruri and Tuige ironstone occurrences are most promising since the radio-active bedrock is well exposed without alluvial cover in localities accessible to motor vehicles.

The pyrochlore at Rangwa is far more easily detected than at Mrima hill, being visible under a hand-lens, and there is a likelihood that the alluvials, altered breccias comparable with the Mrima deposits, and the carbonatites themselves might prove of economic value as a source of columbium.

Further investigation of the Migori belt using geophysical techniques might lead to the discovery of ore-bodies akin to the Macalder copper occurrences.

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Plate X

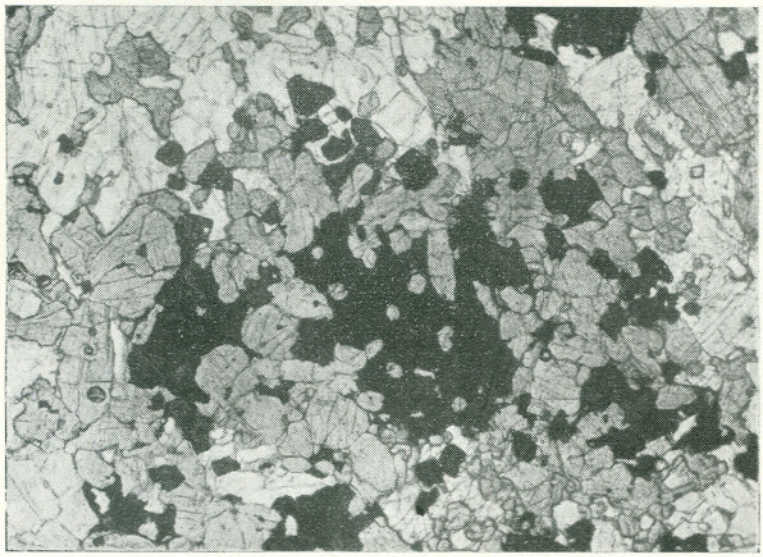


Fig. 1.—Perovskite ijolite, specimen 41/1264, south side of Rangwa. x 25. Magnetite (black), perovskite (dark, with very dark margins), aegirine-diopside (grey) and nepheline (light grey).

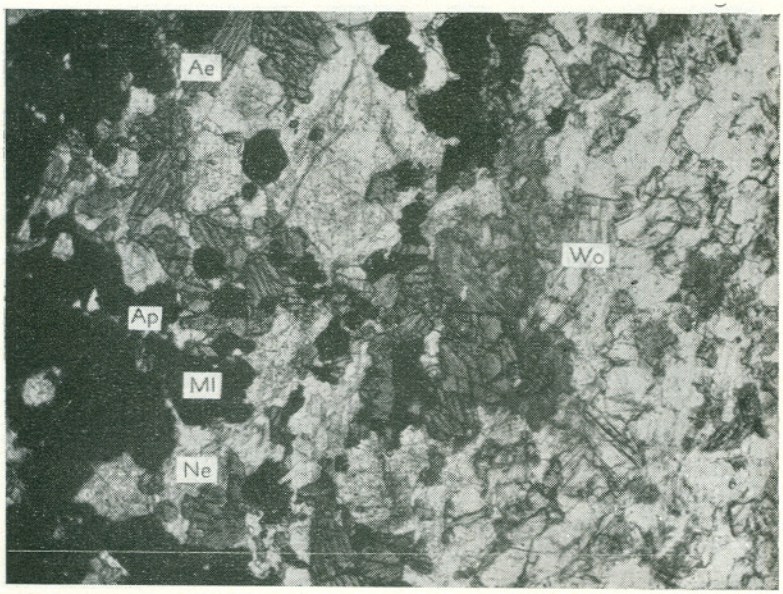


Fig. 2.—Wollastonitic ijolite, specimen 41/1801, Sagarumi. x 20. The photograph shows the compositional banding in the Sagurumi body of ijolitic, melteigitic and urtitic rocks. The right-hand side illustrates an urtitic band composed almost entirely of nepheline and wollastonite (Wo). The left-hand side shows an increasing proportion of aegirine-diopside (Ae) and Melanite (Ml) towards the left, the rock being ijolitic in composition. Ne—Nepheline, Ap—Apatite.

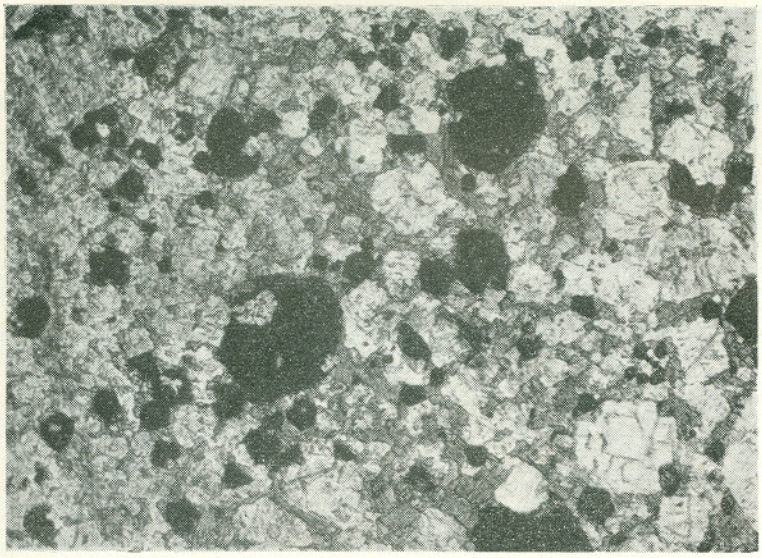


Fig. 1.—Micro-ijolite, specimen 41/1812, Sagurumi. x 25. Melanite (a dark brown variety almost opaque in thin section), aegirine-diopside (grey), and nepheline (white) are present. The metasomatic growth of the pyroxene, as felted aggregates in the interstices between the nepheline crystals, is well illustrated by this photograph.

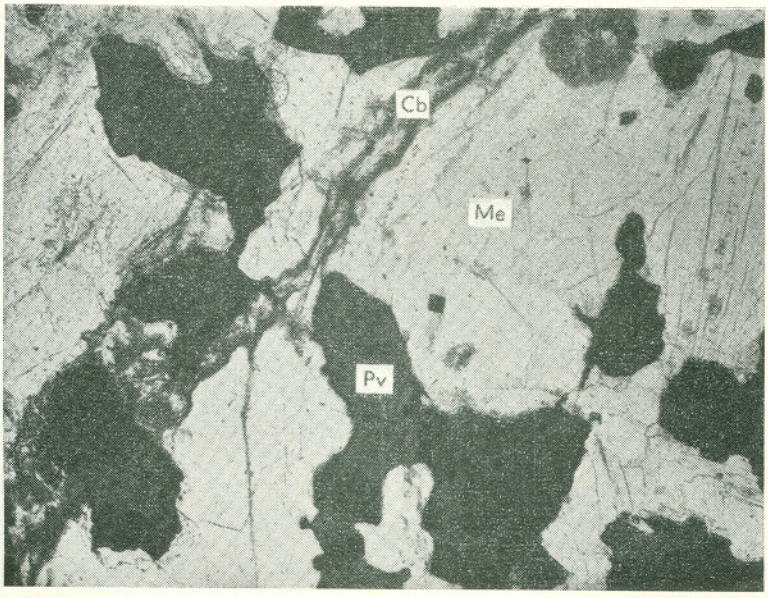


Fig. 2.—Biotite uncompahgrite, specimen 41/1274, south side of Rangwa. x 25. The photograph illustrates a coarse-grained band in the intrusion, composed of xenomorphic crystals of melilite (Me), magnetite (black), perovskite (Pv) and biotite in bottom right corner only, between iron ore grains. The melilite has altered to a fibrous aggregate largely composed of cebollite (Cb)along the diagonal crack.

Plate XII



Fig. 1.—Biotite uncompahgrite, specimen 41/1276, south side of Rangwa. x 20. The photograph illustrates a coarse-grained band showing rims of perovskite and biotite around aggregates of magnetite. Magnetite (black), perovskite (Pv), Biotite (Bi) forming an outer ring outside the perovskite, melilite (Me) and apatite (Ap).

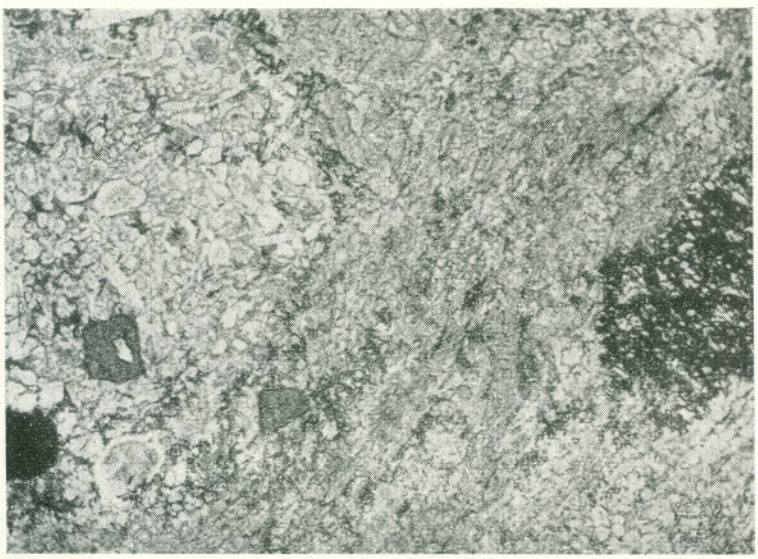


Fig. 2.—Carbonatite, specimen 41/1321, central valley, Rangwa. x 20. Magnetite (black), pyrochlore (cubo-octohedra, lower left), apatite in a round "clot" of short prisms with rounded terminations (upper left). The fine-grained mosaic of calcite and wisps of amorphous iron ore which make up the greater part of the rock fills the right-hand half of the picture. The planar texture or streaming gives the rock an appearance of schistosity.

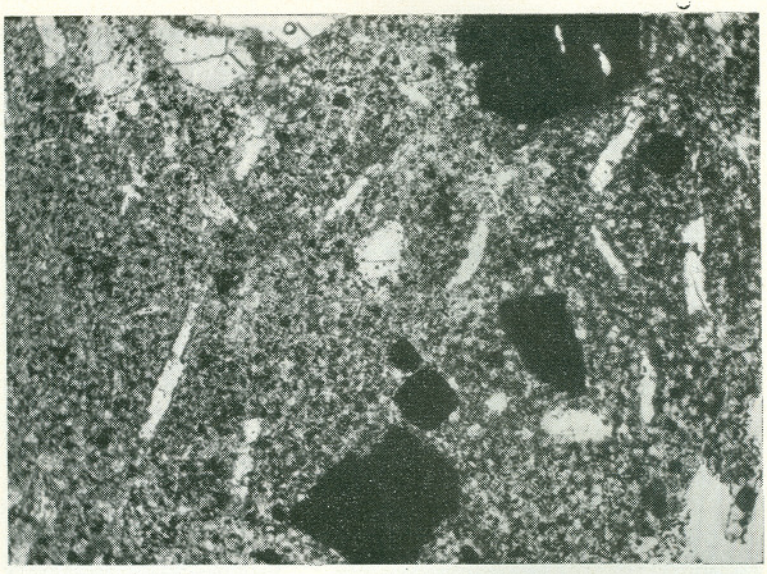


Plate XIII.—Melilitite lava, specimen 41/1708, White Rock Point. x 25. Magnetite (black), and white plates of melilite are set in a microcrystalline groundmass largely composed of augite and melilite.