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A suite of volcanic rocks from south-west Uganda containing kalsilite (a polymorph of $KAlSiO_4$).

(With Plate VI.)

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CONTENTS.

1. INTRODUCTION.

DURING the last few years large collections of rock specimens from the Toro-Ankole volcanic fields, east and south-east of Ruwenzori, have been sent to Durham by the Geological Survey of Uganda for petrological investigation. The specimens recently studied include representatives of a suite of highly potassic ultrabasic lavas. Some of these resemble melanocratic olivine-nephelinites or olivine-rich ankaratrites, but the nepheline-like felspathoid which they contain, instead of being nepheline, is a polymorph of $KAlSiO_4$. For chemical reasons this mineral was at first thought to be kaliophilite. Other types, closely related, contain leucite, biotite, or melilite, in addition to the supposed kaliophilite.

Natural kaliophilite is an extremely rare mineral and is known with certainty only from certain ejected blocks of biotite-pyroxenite and augite-melilite-calcite-rocks from Monte Somma (Bannister, 1931, p. 569). Hitchcock (1900, p. 47) recorded 'a multitude of acicular crystals of kaliophilite' from pegmatitoid veins occurring in a Hawaiian nepheline-olivine-melilitite, but provided no evidence for his identification. The pegmatitoids have since been exhaustively studied by Dunham (1933, p. 372), who finds the only acicular crystals present to be apatite and hydronephelite. I am indebted to Dr. Dunham for his opinion that Hitchcock's 'kaliophilite' is almost certainly hydronephelite.

As neither kaliophilite nor any other polymorph of $KAlSiO_4$ had previously been detected as a constituent of volcanic rocks, it was obviously desirable that the mineral in question should be studied by X-ray methods. I was fortunate in being able to enlist the expert co-operation of Mr. F. A. Bannister, who has skilfully and successfully tackled the very difficult problems involved in such an intricate investigation. Mr. Bannister's results, supplemented by micro-chemical analyses made by Dr. M. H. Hey, are recorded in the communication which follows this paper. The new data indicate that the mineral is not kaliophilite, but a hitherto unrecognized polymorph of $KAlSiO_4$ for which the appropriately mnemonic name *kalsilite* is proposed. The present communication is devoted to the mode of occurrence and petrology of the newly discovered kalsilite-bearing lavas.

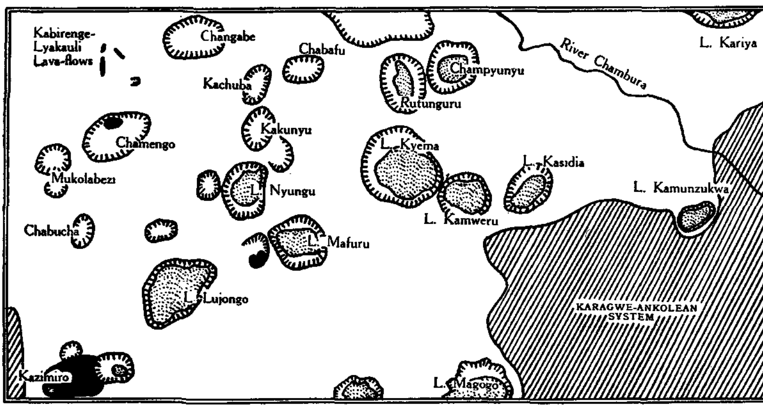

FIG. 1. Sketch-map showing the explosion craters and lava occurrences of part of the Bunyaruguru volcanic field of south-west Uganda. The area illustrated is $7\frac{1}{4}$ by $3\frac{3}{4}$ miles. Topographical and geological details from an unpublished field map by A. D. Combe, Geological Survey of Uganda.

Karagwe-Ankolean system—inclined shading; lava occurrences—black; tuffs—unshaded; crater lakes—dotted.

Field work in the Toro-Ankole volcanic areas was begun in 1929 by Wayland and Combe (Combe, 1930), and a preliminary account of the tuffs, ejected blocks, and bombs then collected was published a few years later (Holmes and Harwood, 1932). During the 1932, 1933, and 1938 seasons more extensive and systematic geological exploration was carried out by Combe, and some of his observations have been briefly described in the Annual Reports of the Survey (Combe, 1933, 1934, and 1939). Detailed accounts of the isolated Katunga volcano and its rocks have also appeared (Combe, 1937; Holmes, 1937).

The specimens now to be considered are from the volcanic area of Bunyaruguru, which stretches southwards from the south shore of Lake George, partly over the floor of the western Rift depression and partly over the adjacent plateau to the south and east of the Rift. The area, part of which is shown in fig. 1, is a typical field of multiple vents, characterized by closely spaced explosion craters of late Pleistocene to Recent age, many of which are now occupied by lakes. The vents have been drilled through sediments—locally more or less metamorphosed—of the Karagwe-Ankolean system and, in many cases, through an overlying mantle of 'older' tuffs, dating from the Middle Pleistocene, the volcanic topography of which has been largely obscured by the later explosions. The Karagwe-Ankolean rocks, which contribute abundantly to the tuffs and volcanic breccias, are mainly argillites or phyllites, accompanied by grits and quartzites. Ejected blocks of limestone occur in the tuffs about the craters of Lakes Mafuru, Kamweru, and Kasidia and probably represent impersistent lenticles of limestone in the Karagwe-Ankolean (Combe, 1934, p. 65; 1939, p. 19), since the occurrences lie along a line that is roughly parallel to the regional strike of the Karagwe-Ankolean formations. To the east and south of the volcanic area there are widespread exposures of granite (Simmons, 1939). Ejected blocks from several of the vents, e.g. those of Lake Nyungu and Chamengo, indicate that similar granite also occurs locally beneath the volcanic area.

Occurrences of lava in bulk are known in only four localities: Kabirenge-Lyakauli, Chamengo, Mafuru, and Kazimiro (see fig. 1). The western of the two Mafuru craters truncates what appears to be a lava flow. The latter and most of the ejected blocks of lava found in and around the Mafuru craters are composed of a new rock-type composed of olivine, pyroxene, kalsilite, perovskite, and black ore. Following current fashion, the rock could be called 'olivine-rich mela-kalsilitite', but as leucite and biotite varieties also occur and require distinguishing names, such a term would be unduly awkward. The name *mafurite* is therefore proposed for the new type, and the varieties alluded to then become *leucite-mafurite* and *biotite-mafurite* respectively. As ejected blocks, biotite-mafurite also occurs in and about the crater of Lake Nyungu. *Melilite-mafurite* is found as ejected blocks in and near the crater of Lake Kamunzukwa, which lies about four miles to the east of Lake Mafuru. On the north-west side of Chamengo crater the truncated edge of a dome- or plug-like mass is exposed (Combe, 1934, pp. 66 and 68). The specimens representing this lava-dome range from mafurite poor in leucite, through leucite-mafurite to *kalsilite-ugandite*, ugandite being melanocratic olivine-leucitite (Holmes and Harwood, 1937, p. 11).

Apart from the local occurrences of lava mentioned above, the volcanic products are pyroclastic. The dominant volcanic material of the tuffs, represented by well-preserved, essential and accessory, lapilli and occasional bombs and blocks, is *katungite* (potash-rich olivine-melilite lava: Holmes, 1936 and 1937). Lapilli of *kalsilite-katungite* have recently been detected and are described on p. 210. Ugandite, mainly the olivine-rich variety, also occurs, sparingly as lapilli in some of the tuffs and more conspicuously as ejected blocks and bombs. One of the latter, from the old rest-camp of Kichwamba, adjoining Kachuba crater, has already been described under the name melanocratic olivine-leucitite (Holmes and Harwood, 1932, p. 415).

The following classification shows the mineralogical relationships of the volcanic rocks of Bunyaruguru, with the exception of one or two rare olivine-free types, of which *proto-katungite* (mineralogically like katungite, but without olivine) is the chief.

TABLE I. Kalsilite- and leucite-bearing volcanic rocks of Bunyaruguru, south-west Uganda.

Olivine, Perovskite, and Black ore + ; +	Leucite	Leucite > Kalsilite	Kalsilite > Leucite	Kalsilite
Augite	Olivine-rich ugandite UGANDITE	Kalsilite-ugandite	Leucite-mafurite	MAFURITE Biotite-mafurite
Augite > Melilite	Melilite-ugandite (Melilite-poor alnöite)	—	—	Melilite-mafurite
Melilite > Augite	(Alnöite)	—	—	—
Melilite	Leucite-katungite; KATUNGITE* Biotite-katungite		Kalsilite-katungite	

*Leucite is rarely developed in katungite, but computed estimates of the composition of the glass indicate that, on an average, the glass is potentially leucitic, being slightly less silicic in two examples and slightly more in a third.

The tuffs also invariably contain mineral fragments and ejected blocks of a cognate sub-volcanic suite of rocks composed essentially of one or more of the minerals biotite, augite, and olivine, and comprising such types as glimmerite, biotite-pyroxenite, and biotite-peridotite. As elsewhere in the Toro-Ankole fields, these rocks are of earlier formation than any of the volcanic types, since they invariably appear in the latter as xenoliths and xenocrysts in various stages of corrosion and disintegration.

2. SOURCES OF MATERIAL.

The Mafuru craters.—Lake Mafuru is of elliptical outline, about 600 yards long by 100 yards across. Immediately to the west of the lake crater, and separated from it by a narrow rib about 70 feet high, is an older dry crater, about 300 yards long by 100 across, which is open at its south-western end, where it is truncated by a swampy depression that extends towards Lake Lujongo. The surface of the water in the lake crater is lower than the floor of the dry crater. Reporting on his first visit, Combe (1934, p. 66) writes: 'The south wall of the older crater is about 400 feet high and is formed mostly of tuffs and agglomeratic rocks. About half way up is a sheet of lava exposed for a thickness of 15 feet or so, but the bottom is not seen. The lava can be observed for a length of about 70 feet along the crater wall but it probably extends farther.' In 1938 Combe again visited the crater and found that much clearing had been done as a preliminary to banana cultivation. The lava sheet was then seen to extend along the wall for at least 150 yards, the exposed thickness increasing from 6 feet at the eastern end, near the rib, to about 120 feet at the western end. The upper part of the sheet is scoriaceous and slaggy and is overlain by 30 feet of tuff and agglomerate packed with ejected blocks of various types of mafurite up to 4 feet across. The upper surface of the lava was not exposed, a 20-foot slope of black soil intervening between the highest exposure of lava and the lowest of the overlying tuffs. It was observed, however, that the top of the sheet drops in height towards the west, suggesting that it originated from a source in the direction of the lake crater.

The following specimens were collected serially from bottom to top of the exposures towards the western end of the sheet. It will be noticed that leucite-mafurite is represented as well as mafurite.

Feet.		
160	Highest exposure of tuffs:	
	C.6078	Ejected block of mafurite with glassy base.
	C.6077	Katungite-tuff.
130	Lowest exposure of tuffs:	
	C.6076	Ejected block of mafurite.
	C.6075	Katungite-tuff (containing lapilli of mafurite, some of which are enclosed in katungite lapilli).
	C.6074	Katungite-tuff (containing lapilli of leucite-mafurite).
	C.6073	Ejected block of mafurite.
110	Highest exposure of lava sheet:	
100	C.6072	Scoriaceous mafurite, typical of the upper 25 feet.
85	C.6071	Altered mafurite with irregular spidery vesicles.
65	C.6070	Altered leucite-mafurite with irregular vein-like vesicles.
55	C.6069	Altered mafurite riddled with vermicular vesicles.
35	C.6068	Mafurite with a finely vesicular band.
16	C.6067	Leucite-mafurite.
0	C.6066	Mafurite from lowest exposure of lava sheet.

Relatively coarse-grained mafurite from blocks fallen from an exposure of the same sheet at the north end of Ndeke Ridge, immediately south of the dry crater, is represented by C.6143.

Other specimens of the tuffs and ejected blocks of Mafuru are listed below:

Locality.	Katungite tuffs.	Ejected blocks.	
NW. wall of lake crater ...	C.4071	C.4069	Biotite-mafurite
		C.4070	Glassy mafurite
		C.4078	Biotite-mafurite
		C.6051	Biotite-pyroxenite
NE. rim of lake crater ...	C.6037 (katungite poor in olivine)	C.6042	Mafurite
N. wall of lake crater, 75 feet below rim	C.6043 (abundant lapilli of proto-katungite)	C.6045	Biotite-pyroxenite
Rib between the craters ...	C.6079 (contains mafurite enclosed in katungite)		

Lake Nyungu crater.—The crater occupied by Lake Nyungu is situated to the north-west of Lake Mafuru. On the north side the wall rises only 60 feet above the water level, but towards the east it rises to over 200 feet and on the other side to about 150 feet. From the NE. corner cliffs about 30 feet high can be followed to the eastern side, and above and below this main exposure smaller outcrops can be traced along the steep crater wall. These are all of katungite tuffs and volcanic breccias containing abundant fragments of quartzite, fewer of phyllite, occasional blocks of granite, and sporadic blocks of biotite-mafurite and olivine-rich ugandite. The specimens studied are as follows:

Locality.	Katungite tuffs.	Ejected blocks.
NE. wall of crater, 40 feet above lake	C.4046	C.4042–45 Biotite-mafurite C.4047 Olivine-rich ugandite
Road cutting, E. of crater, 200 feet above lake	—	C.4049 Mafurite
Road cutting, NW. of crater	C.4066–67	
SW. flank of crater	C.6135 (contains leucite-katungite and kalsilite-katungite)	
50 feet below SE. rim of crater	C.6136	

Chamengo crater.—Chamengo crater (Combe, 1934, pp. 67–68) is of elliptical outline, the floor being about 350 by 120 yards. The walls are of layered tuffs, except on the NW. side, where the wall reaches its maximum height of 250 feet. Here, under a 100-foot cover of tuffs, crags of dark massive lava, with a talus of fallen blocks at the base, can be seen up to a height of 150 feet. At its western end the lava cuts sharply across the tuffs. The occurrence is interpreted by Combe as a plug- or dome-shaped mass that failed to break through to the surface, but was subsequently exposed by the explosions responsible for the present crater.

Although in the field the lava-dome appears to be of homogeneous composition, the three specimens collected from its outcrop are only superficially alike. C.4006 is mafurite with traces of leucite, C.4007 is leucite-mafurite, and C.4008 is kalsilite-ugandite with much more leucite. It is noteworthy that the ejected blocks lying on the surrounding tuffs are identical with C.4008. The associated tuffs and blocks are as follows:

Locality.	Katungite tuffs.	Ejected blocks.
S. wall of crater	C.4002–4 (containing ugandite and mafurite)	C.4005 Kalsilite-ugandite
Foot of rift escarpment, NW. of crater	—	C.4805 Kalsilite-ugandite (containing olivine-leucitite)
Above the lava-dome ...	C.5995	

Lake Kamunzukwa crater.—Lake Kamunzukwa crater lies about four miles east of Lakes Mafuru and Nyungu, near the SE. margin of the volcanic area. At its SW. corner the lake drains by way of a small stream into the Lubale, which is a tributary of the Chamburu river. The Karagwe-Ankolean formations that border the crater on three sides are mainly blue-grey phyllites, and most of the accidental blocks of tuffs are of similar material. The specimens available for study are as follows:

Locality.	Katungite tuffs.	Ejected blocks.
SW. shore of lake	C.3519 C.3520 (contains melilite-mafurite)	C.3521 Melilite-mafurite
Near outlet of lake	C.6109	C.6107–8 Melilite-mafurite

3. Mafurite.

The specimens from the lower exposure of the Mafuru lava and those of the ejected blocks derived from it are compact, fine-grained porphyritic rocks of grey colour, containing abundant phenocrysts of lustrous light-green olivine, 1 or 2 mm. long, and occasional xenocrysts of olivine, biotite, and augite up to 4 or 5 mm. across. Other xenolithic inclusions, of all sizes up to 2 cm., consist of biotite-pyroxenite, glimmerite, and biotite-peridotite in various stages of resorption, some of them being brightly crystalline, while others are dull black with yellowish spots and margins. Xenoliths of phyllite have been detected, but are extremely rare and very small. Oval and somewhat porous light-coloured patches, up to 1·5 cm. long, occur sporadically. These are found under the microscope to be segregations of coarser crystallization of the type to which the term 'pegmatitoids' has been given by Lacroix (1928). Vesicles are rare, such as do occur being irregular cavities, 1–4 cm. across, lined with calcite and zeolites, including phillipsite. About fifty feet above the lowest exposure small vermicular vesicles with similar linings become conspicuous (C.6069); 30 feet higher the rock is scoriaceous (C.6072) and most of the cavities are free from linings. These specimens are internally altered and have a fawn or brownish hue, with orange or reddish-brown pseudomorphs after olivine, and brick-red altered xenoliths of biotite-pyroxenite.

In section the minerals found are those listed in table II. The micrometric measurements were made on sections free from xenoliths and pegmatitoids. Apart from the altered specimens just referred to, the rocks are beautifully fresh and of uniform composition and texture, xenoliths and pegmatitoids being rarely encountered except in sections specially cut to reveal their characters. A typical field is illustrated in pl. VI, fig. 1.

Table II. Mode of Mafurite, C.6073.

	Volume %.	Average grain-size.
Phenocrysts:		
Olivine	20·6	1·2 mm.
Diopside and augite	6·3	0·9
Groundmass:		
Diopside	26·0	0·07 × 0·01
Kalsilite	23·7	0·12
Perovskite	6·2	0·02
Black ore	5·7	0·03
Olivine	4·4	0·07
Biotite	2·3	0·25
Glass	4·1	—
Apatite	n.d.	—
	99·3	

Olivine occurs as somewhat rounded euhedral phenocrysts, some of which, especially the larger examples, are deeply corroded and even eviscerated by tongues of groundmass material crowded with black ore and perovskite. From the ends of the tongues strings of isolated grains of ore continue into the olivine. Occasional polysomatic aggregates of olivine occur and are penetrated by similar tongues, generally along intergranular boundaries. Such aggregates are probably xenolithic, as they are commonly traversed by tiny replacement veinlets of biotite and by sinuous trains of gas bubbles like those in the olivine of the peridotite xenoliths and ejected blocks of the area (cf. Holmes and Harwood, 1937, p. 21). In all cases the olivine is optically negative, but with a nearly straight isogyre in β-sections. Inclusions of ore, and less commonly of perovskite, are confined to a marginal zone, except for rare internal groups of these minerals which probably mark the terminations of penetrating tongues. In the groundmass, olivine occurs as tiny blebs. Throughout the whole suite of mafurite and its varieties no trace of serpentinization has been detected.

Pale-green *diopsidic augite* is present as stumpy euhedral microporphyritic crystals, some of which contain irregular or corroded cores of bright or greyish-green augite identical with the pyroxenes of the ejected blocks of peridotite and biotite-pyroxenite. Large xenocrysts and aggregates of these augites also occur sparingly, in every case bordered in optical continuity with a narrow fringe of the diopsidic type normal to the rock. In the groundmass the same type of diopsidic augite is present as microliths which are generally crowded together, either as an open felt or in stream-lined swarms.

Perovskite is conspicuously and uniformly distributed through the groundmass as golden-brown or yellow octahedra and twinned groups, and as greenish-yellow grains of smaller size. Black ore, probably *titaniferous magnetite*, also occurs abundantly as octahedra and grains.

Kalsilite forms a clear interstitial background of anhedral to subhedral crystals which poikilitically enclose the above-mentioned minerals of the groundmass, together with rare minute needles of apatite. In a fallen block from the Mafuru sheet, C.6143, there are streaks of relatively coarse grain in which poikilitic kalsilite is unusually conspicuous and sometimes euhedral. A similar variety of mafurite occurs as lapilli in the tuffs above the sheet (pl. VI, fig. 2). In the normal, finer-grained type, the kalsilite background is interrupted here and there by patches of slightly turbid glass. Kalsilite generally occurs as stout prisms, but in some specimens—especially those of the more glassy varieties—the prisms are longer and have skeletal terminations like double-pronged forks; the 'prongs' often consist of parallel bundles of fibres of which the outermost are the longest.

Adjacent to olivine the kalsilite occasionally merges almost imperceptibly into ragged patches of phlogopitic biotite, pleochroic from faintly greenish-yellow to pale reddish-brown. The mica is clearly a synantetic mineral and its occurrence where kalsilite and olivine would otherwise meet first suggested the possibility that the nepheline-like mineral might be kaliophilite. Moreover, it was noticed that where the mineral is in contact with pyroxene and black ore no sign of aegirine appears, as might be expected if it were nepheline. From the chemical composition and norm of mafurite it became certain that the nepheline-like mineral contains very little soda, and that chemically it is probably a potassium end-member of the nepheline series. The analysed rock contains 6·98 % of K_2O and only 0·18 % of Na_2O. As the potash must be almost entirely in biotite, glass, and the mineral under discussion, it can easily be estimated that the latter contains at least 25 % of K_2O. As a further check on the chemical identity of the mineral, a small sample of a pegmatitoid occurring in mafurite from Nyungu crater (C.4049) was submitted to Dr. H. F. Harwood for determination of the alkalis. The sample contained rather more diopside than kalsilite and also a little calcite. The results were K_2O 11·37, Na_2O 1·33 %. Pure kalsilite contains 29·7 % of K_2O.

Finally, X-ray and micro-chemical investigation of the separated mineral by Bannister and Hey (recorded in the paper that follows) led to its recognition as a polymorph of $KAlSiO_4$ which differs in its cyrstal-structure from both nepheline and kaliophilite. A distinctive name being therefore necessary, *kalsilite* is proposed. Optically, kalsilite cannot be distinguished from nepheline, the refractive indices being about the same or slightly higher than that of Canada balsam. On separated material Bannister obtained the values ω 1·542, ϵ 1·537$\pm$0·002; these are higher by about 0·01 than the corresponding values for kaliophilite (Bannister, 1931, p. 601).

Pegmatitoids (Lacroix, 1928; Dunham, 1933) are segregations of pyrogene minerals occurring in veins, cavities, lenticles, and streaks in basic volcanic rocks, to which they bear a relationship analogous to that of the pegmatites associated with plutonic rocks. The minerals are generally the same as those of later crystallization in the enclosing rock, but of coarser grain; with them zeolites and calcite may be associated, representing a later hydrothermal phase in the cooling history.

In mafurite the pegmatitoids occur as lenticles, sometimes slightly cavernous or drusy, most of which contain (in order of crystallization) diopside, kalsilite, and calcite. Except that it may be heavily charged with tiny globular inclusions of low refractive index, the diopside is identical in its properties with that of the enclosing rock. Euhedral crystals are characteristic, having about the same size as the microporphyritic diopside of the rock, but aggregates of subhedral forms and groups of slender prisms are also common. In one case (C.4007, Chamengo) the diopside is entirely of microlithic habit and associated with a little biotite. Near the walls, which are generally lined with diopside, the latter mineral contains tiny inclusions of black ore and perovskite. Kalsilite increases in abundance towards the interior, where it forms continuous masses of euhedral crystals and anhedral grains, the former being stumpy prisms giving nearly square or hexagonal sections up to about 0·2 or 0·3 mm. across (pl. VI, fig. 3). In the diopsidic areas kalsilite is interstitial. In turn, calcite is interstitial to both diopside and kalsilite, and near the middle it may occur in patches 1 or 2 mm. across. Occasionally a little phillipsite is associated with the calcite.

In a few examples phlogopite or biotite occurs interstitially in addition to the minerals normally present (pl. VI, fig. 4). In others both mica and olivine may be found, the olivine being of early formation and confined to the walls of the pegmatitoid. The coarse variety of mafurite (C.6075 and C.6143) is remarkable in containing globular or lenticular inclusions of exceptionally fine grain, composed of a background of kalsilite and rare phlogopitic biotite, which is crowded with blebs of olivine, granules of perovskite, and sporadic grains of dark-green augite and black ore. The paucity of the usual diopsidic augite is a notable feature. These granulitic inclusions are probably related to the pegmatitoids. Similar granulitic areas, but almost devoid of black ore, occur in parts of an otherwise normal pegmatitoid found in C.6073. Another example, occurring in the same rock, is unusually rich in black ore; it has a rim of kalsilite and pale diopside, and merges imperceptibly into the groundmass of the rock.

It is noteworthy that the vesicular specimens from the upper part of the Mafuru sheet are free from pegmatitoids. The *vesicles* of mafurite are generally thinly encrusted with zeolites and calcite. Phillipsite can be detected in small radiating groups, often forming spherules, but the chief zeolite has not been identified. It occurs in globular groups of prismatic crystals and has properties like those of heulandite, but with refractive indices below 1·497. The vesicular varieties of mafurite are internally altered. Olivine is rimmed with iddingsite, fibres of which penetrate the crystals at right angles to the edges. Kalsilite becomes cloudy, and fibrous isotropic material commonly occupies the interstices between the other minerals.

The *xenoliths* in mafurite include the following varieties:

(*a*) Biotite-pyroxenite of the same type as the associated ejected blocks (C.6045 and C.6051). These are coarse-grained and consist of green augite and biotite with accessory black ore and sphene. For an analysis of a similar variety from Katwe, north of the Kazinga Channel, see Holmes and Harwood, 1937, p. 30. The dull black xenoliths already mentioned are altered biotite-pyroxenite in which the biotite is mainly represented by black ores and obscure cloudy by-products, while augite has become turbid through separation of minute grey specks. The yellowish spots and rims of these xenoliths are found to consist of iron-stained isotropic material, the spots being bulbous areas connected with the rims by intergranular channels. Both biotite and augite have contributed to the isotropic material, and from parts of the latter acicular diopside, minutely granular olivine, and an interstitial zeolite, probably phillipsite, have crystallized.

(*b*) Glimmerite and olivine-bearing glimmerite with a little augite. The red xenoliths are altered examples of the latter type in which the biotite is partly changed to black ore, but mainly to deep reddish-brown iddingsite identical with that which rims the olivine phenocrysts of the enclosing rock (C.6070).

(*c*) Biotite-peridotite and small olivine aggregates. In some cases the olivine is replaced by biotite along intergranular channels communicating with the groundmass of the enclosing rock. Alteration to iddingsite is again seen in examples from the vesicular specimens.

(*d*) Karagwe-Ankolean sandy argillite or phyllite. Such material is rare and when found is generally surrounded by a turbid grey isotropic zone of low refractive index. Small patches of similar isotropic material are occasionally seen in thin sections and are probably vitrified or transfused scraps of pelitic origin.

Chemical composition.—The results of an analysis of mafurite (sample free from megascopic xenoliths and pegmatitoids) are listed under C in table III (p. 212). The 'norm' (table IV) is calculated with priority given to diopside, after computing the minor constituents, so that some approach to the mode is attained. It will be noticed that leucite appears as a normative constituent, although no trace of leucite can be detected in the analysed specimen. This is partly accounted for by the presence of biotite and glass in the rock, and partly, perhaps, by the inclusion in the analysed sample of scraps of pelitic or other siliceous material too small to be seen in the hand-specimen. In this and other 'norms' similarly calculated (table IV) perovskite is much lower than the modal amount, ilmenite being correspondingly high. Suitable correction for this discrepancy would liberate FeO (at the expense of CaO) for distribution between diopside and olivine.

The rock differs from all the previously analysed rocks from the Toro-Ankolean province (Holmes and Harwood, 1932; Holmes, 1937) in its exceptionally high

K_2O and low Na_2O. No close analogues from other regions have been traced. Further discussion and comparisons are deferred to a later section (p. 211).

4. Biotite-Mafurite.

Most of the specimens of mafurite contain a little interstitial biotite, the proportion being less than about 5 %. Certain ejected blocks from Mafuru and Nyungu are, however, conspicuously richer in biotite and are therefore distinguished as *biotite-mafurite*. The specimens of this type have a general resemblance to those of mafurite, but are of brownish-grey colour. Olivine is invariably coated with biotite and consequently looks yellow-brown, except on freshly broken surfaces. Small xenocrysts of biotite and xenoliths of glimmerite are common, and inclusions of altered phyllite and mica-schist are more conspicuous than in mafurite.

In section (pl. VI, fig. 5) the minerals are seen to be almost the same as those of mafurite and it will suffice to draw attention only to the differences, which are mainly those of proportion and habit. Microporphyritic diopsidic augite, often with bright green pleochroic cores, is less abundant, and in some specimens quite rare; microliths and small bladed prisms, however, make up a higher proportion of the groundmass. Biotite is uniformly distributed as ragged interstitial patches with γ 1·580; as a 'reaction' mineral bordering and penetrating olivine; and as small euhedral crystals. It constitutes about 15 % of the rock. Perovskite is less abundant, and black ores, which must be highly titaniferous, judging from the chemical composition, are more thickly distributed, especially as inclusions in olivine. The interstitial background contains a higher proportion of pale-brown fibrous isotropic material, probably glass, which clears to kalsilite over considerable areas. Kalsilite also occurs as small laths, often with forked skeletal terminations. The analysis of C.4043 suggests the presence of a little nosean, but none has been detected.

Pegmatitoids are small and very different from those already described from mafurite. One type (C.4069) is lined with tangential, radial, and criss-cross blades of biotite, rare radiating groups of diopside microliths, and innumerable needles of apatite; all embedded in calcite, which entirely occupies the interior, except for a little fluorite. C.4078 contains many micro-amygdales of calcite; some of these, transitional to pegmatitoids, have biotite growing in from the walls. Another type of pegmatitoid, developed on a microscopic scale only, consists almost wholly of kalsilite, with rare prismoids of diopside against the walls.

Xenoliths, as already indicated, are mainly of glimmerite, the biotite of which has γ 1·631 and is thus of different composition from the new biotite of the groundmass. Biotite-peridotite occurs sparingly and, as in mafurite, xenolithic aggregates of olivine are common. Among the pelitic inclusions, a much corroded fragment of mica-schist (in C.4069) shows some features of interest. The original biotite is a dull, pale-brown, bleached-looking variety, but towards the margin of the xenolith it is made over to a variety closely resembling that of the enclosing rock. Surrounding the xenolith is a zone of turbid isotropic material in parts of which pockets of zeolites occur, together with prismoids of diopside and rounded grains of leucite. Within the schist, which is penetrated by tongues of groundmass, the felsic constituents are locally replaced by streaks of similar turbid material, clearing here and there to zeolites.

Chemical composition.—An analysis of a typical specimen of biotite-mafurite from Nyungu has been made by Dr. H. F. Harwood and is recorded under D in table IV. The 'norm' is calculated as before to give the maximum amount of diopside. The analysis is closely similar to that of mafurite. The slightly higher SiO_2 and the higher proportion of normative leucite reflect the higher biotite and glass contents of the rock, and may also be symptomatic of contamination by pelitic inclusions, such as the mica-schist described above.

5. Leucite-Mafurite and Kalsilite-Ugandite.

The leucite-mafurite (C.6067) of the Mafuru lava-sheet is megascopically indistinguishable from the associated mafurite, while C.6070 is an altered variety showing the same modifications as altered mafurite. Under the microscope the only new feature is the presence of rounded grains of leucite in the groundmass. These are often turbid and of pale buff colour: in the altered rock entirely so. There can be little doubt that leucite has developed as the result of the incorporation of a small proportion of pelitic or siliceous material. C.6067 contains small xenoliths of phyllite changed marginally, like the mica-schist in biotite-mafurite, to a buff-coloured isotropic substance of low refractive index which closely resembles the altered leucite of the groundmass. One example is riddled with tongues of groundmass and is now almost entirely represented by isotropic material containing patches of which some are crowded with olivine grains in a zeolitic matrix, others with diopside granules, and others, reminiscent of resorbed biotite, with grains of black ore.

The leucite-mafurite (C.4007) and kalsilite-ugandite (C.4008) of the Chamengo lava-dome are fine-grained blue-grey rocks containing sparse phenocrysts of yellow-green olivine, up to 5 mm. across, but generally much smaller; some small blades of augite; and occasional xenocrysts of biotite. In section these rocks are seen to be members of a continuous series, differing only in the relative proportions of leucite and kalsilite. C.4007 contains abundant microporphyritic crystals of olivine and pale-green diopsidic augite in a groundmass which is exactly like that of mafurite, but with the addition of small, sparsely distributed grains of clear leucite. A narrow ill-defined band occurring in one slide contains larger and more abundant leucites and is identical with the kalsilite-ugandite described below. Poikilitic patches of biotite occur sporadically, in each case moulded around numerous blebs of olivine, and also including microliths of diopside and granules of perovskite and black ores. The specimen contains excellent examples of pegmatitoids of the normal type, with marginal concentrations of diopside surrounding aggregates of euhedral kalsilite.

The rocks to which the term kalsilite-ugandite is applied (C.4005 and C.4008) contain much more conspicuous leucite and would at first sight be called ugandite. The interstitial material, however, though not abundant, is largely composed of kalsilite in tiny poikilitic areas, some of which are euhedral, the kalsilite being interrupted here and there by biotite and fibrous buff-coloured glass. Leucite occurs as colourless grains, generally about 0·1–0·2 mm. across, and in clusters of similar or even larger grains which may exceed 1 mm. in diameter. Here, again, there is evidence that the leucite owes its existence to silica introduced by pelitic xenoliths. One of the latter is now represented mainly by turbid isotropic material containing biotite, diopside granules, and a zeolite. It is surrounded, without any definite boundary, by a zone of groundmass which is highly charged with minute grains of leucite.

C.4805, occurring in the tuffs near the foot of the neighbouring Rift escarpment, is identical in all respects with C.4005. It is of interest in containing vaguely defined inclusions of beautifully fresh olivine-leucitite and ugandite.

Chemical composition.—The results of an analysis of leucite-mafurite, C.4007, are listed under E in table III. The 'norm', in table IV, is calculated as in the previous cases. Comparison with C shows that the composition is close to that of mafurite, except for higher Na_2O and much lower K_2O, in which respects it approaches that of melilite-ugandite, G. The most striking difference between the 'norms' of mafurite and leucite-mafurite is the fact that mafurite, with no modal leucite, has much more normative leucite than leucite-mafurite. The most probable explanation of this discrepancy is that the analysed sample of mafurite may have been slightly contaminated by silica-rich xenolithic material. A determination of the alkalis in kalsilite-ugandite, C.4008, gave Na_2O 1·12 and K_2O 4·72 %.

6. Melilite-Mafurite.

So far, this variety has been found only as ejected blocks and accessory lapilli occurring in the katungite-tuffs of Lake Kamunzukwa crater. The blocks are of dark-grey porphyritic lava, containing small phenocrysts of yellow-green olivine in a very fine-grained groundmass. Xenolithic inclusions are more abundant than in mafurite, and include xenocrysts of biotite, up to 1 cm. across, and of olivine and augite in smaller grains, together with aggregates of these minerals, singly and in combination, glimmerite and biotite-pyroxenite being most characteristic. Phyllite of the type exposed around the crater also occurs sporadically.

In section, the rocks differ from mafurite in the following respects. Biotite is present only as xenocrysts. The margins are corroded and heavily sprinkled with black ores in a matrix which, though generally obscure, can here and there be seen to contain minute grains of olivine and calcite in an isotropic base. The groundmass consists of an interlacing network of diopside prismoids, accompanied by grains of perovskite and black ore and rare blebs of olivine, together with small laths of melilite (up to 0·2 by 0·04 mm.) and stumpy or elongated forked prisms of kalsilite (0·04 mm. across); poikilitic patches of kalsilite, interspersed with cloudy glass, occupy the interstices. The melilite shows low but normal polarization colours and is optically negative. In C.6108 it is largely altered to a yellow isotropic substance comparable with the yellow pseudomorphs after melilite described by Brauns (1922, p. 35) from the melilite-nephelinite of Hannebacher Ley in the Eifel.

Tiny amygdales, interconnected by veinlets, are occupied by calcite, either alone, or followed internally by radial groups of phillipsite. In one larger example diopside prisms have grown inwards from the walls and now lie in a matrix of calcite; nothing else suggestive of pegmatitoids has been detected.

Of the xenolithic constituents only phyllite calls for further mention. One or two small corroded fragments with turbid isotropic rims may be seen in most slides; most of the smaller ones are entirely isotropic. The material has a refractive index well below that of Canada balsam and contains black ore and patches of a feebly birefringent zeolite.

Chemical composition.—An analysis of melilite-mafurite is presented under B in table III. As would be expected, the rock is intermediate in composition between katungite and mafurite (cf. fig. 2). As before, the 'norm' is calculated to give the maximum amount of diopside, a procedure which in this case involves allotting all the K_2O to normative kaliophilite, since Ca_2SiO_4—symptomatic of melilite—also appears.

7. Kalsilite-Katungite.

In some of the katungite tuffs from the Kabirenge valley west of Changabe crater (C.5953 and C.5962), and in others from the NW. wall of the crater itself (C.4011–12), beautifully preserved lapilli of kalsilite-katungite have been found, associated with others of ordinary katungite. Similar lapilli occur in the tuffs of Mukolabezi crater SW. of Chamengo (C.5999), Nyungu crater (C.6135), and Lake Chuwera crater (C.3498).

The lapilli consist of olivine, melilite, kalsilite, perovskite, and black ore, in a greenish-yellow glass which is interrupted in some occurrences by minute round or sinuous amygdales containing phillipsite (pl. VI, fig. 6). Olivine is present partly as irregular xenocrysts, derived from biotite-peridotite, fragments of which also occur, but mainly as well-developed euhedral crystals. Melilite occurs as tabular crystals which appear as sharply defined laths and occasional eight-sided sections. Polarization colours are low but normal, and the optical character is negative. Minute inclusions of perovskite and kalsilite can be detected. In some of the lapilli the melilite is altered, by development of fibres normal to the base, to a highly birefringent product which is probably cebollite. Kalsilite has crystallized as prisms with forked terminations and the form and optical properties are identical with those of kalsilite of similar habit in mafurite. Golden-brown perovskite is very conspicuous as octahedra and twins and is often concentrated around the microphenocrysts of olivine. Black ore has developed only sparingly and is more abundant as inclusions in the xenocrysts of olivine.

In the description of the type katungite of Katunga (Holmes, 1937, p. 204) nepheline was recorded, with the reservation that 'it may be kaliophilite'; and in the definition of katungite (p. 210) kaliophilite was listed as one of the possible potash minerals. For 'kaliophilite' kalsilite should now be read. It is of some interest that kalsilite-katungite is the only rock type so far recognized in which a polymorph of $KAlSiO_4$ (whether kaliophilite or kalsilite) occurs without diopside or augite. It thus represents one of the most ultrabasic silicate rocks that could exist.

8. Relationships.

Mineralogical.—The classification tabulated on p. 200 clearly shows the mineralogical relationships of the olivine-bearing volcanic rocks of Bunyaruguru. The main types are distinguished by the following pairs of the four critical minerals: augite, melilite, leucite, and kalsilite.

Ugandite	= Augite + leucite	with abundant olivine, perovskite, and black ore
Mafurite	= Augite + kalsilite	
Katungite	= Melilite + leucite or leucitic glass	
Kalsilite-Katungite	= Melilite + kalsilite	

There is continuous transition between ugandite and mafurite and probably between katungite and kalsilite-katungite. Augitic varieties of the latter are as yet unknown, and augitic katungite is very rare. The gap between katungite and ugandite is chemically bridged by a series of alnöites from Katwe crater (NW. of Bunyaruguru) which are heteromorphous equivalents of augite-katungite or melilite-ugandite, according as the proportion of melilite present is greater or less than that of augite. Lapilli of melilite-poor alnöite also occur in the tuffs

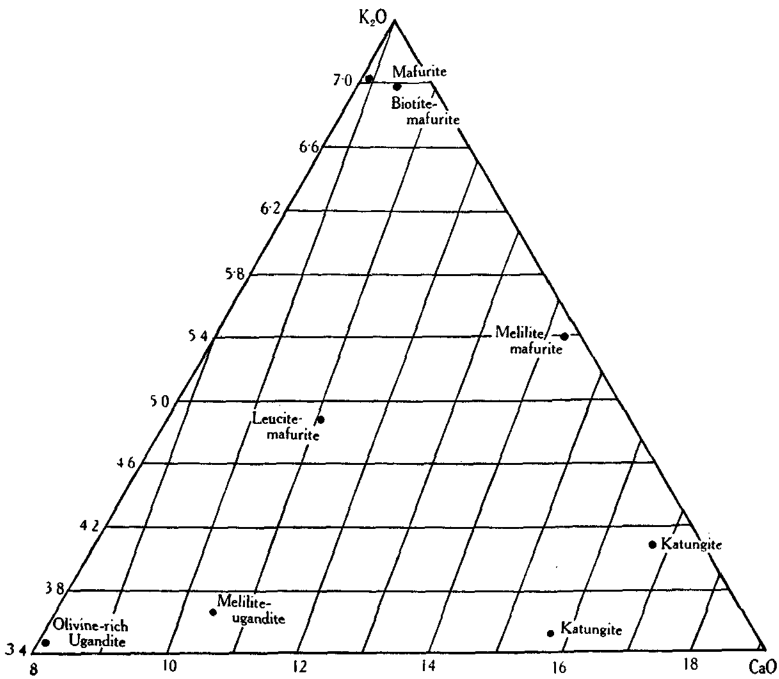

FIG. 2. Triangular part of a field of co-ordinates representing percentages of K_2O (horizontal) and CaO (inclined) to illustrate the relationships between katungite, mafurite, and olivine-rich ugandite and transitional varieties between these three 'corner' types. Biotite-mafurite is represented by the dot just above $K_2O = 7$.

of Chamakumba crater (in Bunyaruguru, but north of the area portrayed in fig. 1). Transitions between the melilite-bearing varieties of ugandite and mafurite—that is to say, rocks containing all four of the critical minerals—have not been detected, but there seems to be no theoretical reason for supposing that such rocks do not exist. Other possibilities of heteromorphism are discussed below.

Chemical.—The chemical relationships can be gathered from inspection of tables III and IV, in which analyses of the mafurite series and related rocks are listed in the order of the same rocks as plotted in fig. 2; that is, from katungite, A, through the mafurite series, B, C, D, and E, to the ugandite series, F and G, and back to katungite, H. The analysis representing ugandite is that of an olivine-rich example, F, from Kachuba crater, which is typical of the variety most characteristic of the area. Melilite-ugandite occurs in intimate association with olivine-rich ugandite at Kachuba and Kazimiro; an analysis of this variety, G, is presented here to complete the suite. H is a new analysis of katungite from Chamakumba crater, where the rock occurs as bombs and lapilli in katungite tuffs; associated bands of tuff contain lapilli of an alnöitic type, and of proto-katungite and melilite-ugandite.

TABLE III. Chemical composition of the Mafurite series (B–E) and related rocks, Bunyaruguru, SW. Uganda.

	A.	B.	C.	D.	E.	F.	G.	H.
SiO_2 ...	35·37	37·05	39·06	40·00	39·28	40·47	38·62	33·22
Al_2O_3 ...	6·50	7·82	8·18	7·68	7·90	5·38	6·34	9·71
Fe_2O_3 ...	7·23	5·11	4·61	5·38	4·88	4·03	4·60	6·68
FeO ...	5·00	5·23	4·98	4·77	5·23	6·47	6·00	5·30
MgO ...	14·08	14·76	17·66	15·46	17·58	24·84	20·06	12·12
CaO ...	16·79	14·28	10·40	9·79	11·03	8·06	10·45	15·64
Na_2O ...	1·32	1·27	0·18	0·65	1·05	0·68	1·27	1·51
K_2O ...	4·09	5·39	6·98	7·04	4·98	3·46	3·66	3·54
H_2O+	2·78	2·29	1·42	1·66	2·36	1·11	2·52	3·28
H_2O-	1·15	0·71	0·50	0·97	0·40	0·57	1·08	0·80
CO_2 ...	0·09	0·58	trace	0·34	0·14	0·36	trace	0·42
TiO_2 ...	3·87	4·09	4·36	4·75	4·29	3·52	4·44	6·08
P_2O_5 ...	0·74	0·76	0·61	0·42	0·36	0·29	0·45	1·12
Cl ...	0·02	—	—	trace	—	0·01	—	—
F ...	0·16	0·12	0·13	0·18	0·09	0·10	0·10	0·08
S ...	0·35	0·16	0·13	0·09*	0·12	0·04	0·18	—
V_2O_3 ...	0·03	—	—	0·03	—	0·03	—	—
Cr_2O_3 ...	0·01	0·07	0·08	0·14	0·09	0·11	0·02	—
NiO ...	0·19	trace	trace	0·05	0·08	0·13	0·08	—
MnO ...	0·24	0·25	0·26	0·15	0·27	0·23	0·09	0·52
BaO ...	0·25	0·26	0·32	0·34	0·21	0·27	0·22	0·17
SrO ...	0·04	0·21	0·18	0·18	0·22	0·02	0·16	0·05
	100·36	100·41	100·04	100·07	100·56	100·18	100·34	100·24
Less O	0·24	0·11	0·10	0·07	0·09	0·05	0·11	0·03
	100·12	100·30	99·94	100·00	100·47	100·13	100·23	100·21
				$*SO_3$				

A. Katungite, C.4407. Near end of western lava-flow of Katunga, 12 miles SSE. of the main Bunyaruguru field. Analyst, A. W. Groves (Holmes, 1936, p. 414, and 1937, p. 205). Total includes ZrO_2 none, CuO 0·06, Li_2O none.

B. Melilite-mafurite, C.6107. Ejected block from Lake Kamunzukwa crater. Analyst, W. H. Herdsman.

C. Mafurite, C.6073. Ejected block from the tuffs above the lava-sheet of Mafuru. Analyst, W. H. Herdsman.

D. Biotite-mafurite, C.4043. Ejected block from Nyungu crater. Analyst, H. F. Harwood.

E. Leucite-mafurite, C.4007. Lava-dome of Chamengo crater. Analyst, W. H. Herdsman.

F. Olivine-rich ugandite, C.3052. Volcanic bomb from Old Kichwamba rest-camp, adjoining Kachuba crater. Analyst, H. F. Harwood (Holmes and Harwood, 1932, p. 415). Total includes ZrO_2 none, Li_2O trace.

G. Melilite-ugandite, C.3989. Driblet, near SE. limit of main lava-flow, Kazimiro, 2¼ miles SW. of Lake Mafuru. Analyst, W. H. Herdsman.

H. Katungite, C.3509. Volcanic bomb from tuffs of upper part of NE. wall of Chamakumba crater, 3½ miles N. of Kasidia crater. Analyst, W. H. Herdsman. The 'norm' is calculated to be comparable with the others, but the rock itself contains pyroxene only as xenocrysts.

In fig. 2 the rocks are plotted in a triangular field of a system of co-ordinates representing the distribution of K_2O and CaO, these being the two constituents that give the maximum separation of the types. The three main types—katungite (with high CaO), mafurite (with high K_2O), and ugandite—occupy the corner fields of the triangle. From the katungite corner SiO_2 rises towards mafurite and ugandite as CaO falls. The essential difference between mafurite and ugandite is the higher K_2O of the former.

TABLE IV. Normative compositions.

	A.	B.	C.	D.	E.	F.	G.	H.
Kaliophilite ...	—	18·06	18·06	11·38	13·16	—	—	—
Leucite ...	18·94	—	7·42	16·93	4·93	16·01	16·98	16·40
Nepheline ...	5·80	5·54	0·82	0·23	4·80	3·10	5·82	6·93
Anorthite ...	—	—	0·89	—	2·14	1·50	0·78	9·18
Acmite ...	0·28	0·46	—	3·97	—	—	—	—
Diopside ...	14·96	36·37	34·23	30·49	37·31	24·49	22·88	10·77
Ca_2SiO_4 ...	16·18	4·21	—	—	—	0·89	5·79	10·74
Forsterite ...	19·71	13·92	19·70	17·07	18·55	37·82	27·57	17·66
Magnetite ...	10·37	7·18	6·69	5·81	7·09	5·83	6·66	9·67
Ilmenite ...	3·96	6·42	6·53	6·56	6·79	6·67	8·22	5·96
Chromite ...	—	0·11	0·11	0·20	0·13	0·16	0·02	—
Pyrite ...	0·65	0·30	0·24	—	0·22	0·07	0·34	—
Perovskite ...	3·03	1·21	1·58	2·20	1·22	—	0·18	5·01
Apatite ...	1·75	1·82	1·45	1·01	0·84	0·67	1·08	2·66
Fluorite ...	0·22	0·11	0·16	0·29	0·12	0·20	0·12	—
Calcite ...	0·21	1·32	—	0·77	0·32	0·82	—	0·96
Water ...	3·93	3·00	1·92	2·63	2·76	1·68	3·60	4·08
	99·99	100·03	99·80	99·70*	100·38	99·91	100·04	100·02

* Total includes Na_2SO_4 = 0·16.

The low summations compared with those of table III are due to reckoning BaO and SrO as CaO.

It will be seen that mafurite and biotite-mafurite are closely similar and can therefore be regarded as heteromorphs. The Chamengo leucite-mafurite has less K_2O but more Na_2O and occupies a position in fig. 2 where there should be ample opportunity for heteromorphism, since the combinations leucite-melilite and kalsilite-augite overlap chemically. Inspection of table IV shows that the 'norms' of B, C, D, and E might have been calculated with leucite instead of kaliophilite and Ca_2SiO_4 and Mg_2SiO_4 instead of part of the diopside. The corresponding melilite-rocks, if they existed, would be leucite-rich olivine-melilitites or highly potassic alnöites. So far, however, no such rocks are known, here or elsewhere. The nearest examples all differ in containing more Na_2O and less K_2O. Consideration of all the analyses available indicates that in the field under review kalsilite appears when the ratio of K_2O to total alkalis is high (0·8 or more), and that crystallization of melilite and/or leucite is favoured when there is less K_2O and more Na_2O. The relatively high Na_2O of melilite-mafurite, leucite-mafurite, and melilite-ugandite illustrate this point. It will be recalled that Bowen (1922, p. 17) has demonstrated that melilite tends to form by reaction from early-crystallized diopside in a considerable part of the nepheline-diopside system.

As a whole, the mafurite series shares the characteristic petrochemical peculiarities of the Toro-Ankole province, namely: relatively high Ti, P, F, Ba, and Sr, with notable but fluctuating amounts of S or SO_3, Ni, and Cr (cf. Holmes and Harwood, 1932, p. 420; Holmes, 1937, p. 207).

The only potassic rocks from other regions which are even approximately of analogous composition are venanzite (leucite-rich katungite) from the Roman province (Rodolico, 1937, p. 44), and madupite (diopside-phlogopite-leucitic glass) from the Leucite Hills of Wyoming (Cross, 1897, pp. 130, 134). These have higher SiO_2, Al_2O_3, CaO, and K_2O, and lower iron oxides, MgO and TiO_2. Soda-rich analogues of the mafurite series have not been traced. The nearest comparable types are rocks described under such names as ankaratrite, melilite-ankaratrite, and tannbuschite (Johannsen, 1938, p. 364). All of these have much more Al_2O_3 than mafurite and are conspicuously augite-rich rocks. True analogues would be olivine-rich mela-nephelinites.

Sequence.—From the limited evidence available in 1932 it was thought that the general sequence of the volcanic types in the Toro-Ankole fields was from katungite and related melilitic rocks, through transitional varieties, to ugandite and related leucitic rocks. Though it remains true that this is locally a common partial sequence, it is now clear that it is by no means the whole story. In Bunyaruguru the 'older' tuffs provide ample evidence that some examples of ugandite or olivine-rich ugandite are older than some occurrences of katungite, and that these types alternated, probably several times. The tuffs of Lugazi Hill, to the east of Nyungu crater, contain accessory lapilli of proto-katungite, katungite, and ugandite, as well as essential—and therefore later—lapilli of katungite. These tuffs are older than those of the Nyungu and neighbouring craters, all of which contain still later essential lapilli of katungite. Mafurite has not been detected in the 'older' tuffs.

At Mafuru, mafurite is followed by katungite. At Chamengo, leucite-mafurite and kalsilite-ugandite (associated in one specimen with olivine-leucitite) are followed by katungite. At Kamunzukwa, melilite-mafurite is followed by katungite. In the Nyungu–Kakunyu–Kachuba group of craters bombs of olivine-rich ugandite appear to be the latest products. At Kakunyu, for example, one of these bombs contains a core of katungite tuff. No detailed succession can yet be given, but it can at least be stated that the mafurite occurrences are both preceded and followed by proto-katungite, katungite, and members of the ugandite series.

Associated Xenoliths.—It is clear that the three leading types—katungite, mafurite, and ugandite—are closely related in space, time, and composition. All three types, and also the transitional varieties, contain relics of more or less resorbed xenoliths and xenocrysts belonging to the biotite-pyroxenite–glimmerite–biotite-peridotite suite. The petrological evidence, a little of which is recorded in this and earlier communications, indicates that the volcanic rocks are rheomorphic products due to the action of highly ultrabasic magmatic material on rock material which is represented by the xenoliths. Fig. 3 is a triangular diagram which helps to bring out the chemical relationships between the lavas and the xenolithic rocks.

Biotite-pyroxenite is found to be the predominant associate of katungite (Holmes, 1937, p. 217), and the magmatic ancestry in this case can be traced back as far as proto-katungite. Fig. 3 shows that these three types fall close together. Olivine-rich ugandite, however, falls nearer to biotite-peridotite, and examination of numerous specimens of olivine-rich ugandite shows that the xenoliths consist largely of olivine, olivine aggregates, and bits of biotite-peridotite. In the case of mafurite, biotite-pyroxenite, glimmerite, and biotite-peridotite have all contributed, but the evidence so far collected hardly justifies a statement of the order of relative abundance, except for biotite-mafurite, where xenolithic biotite is invariably important. It is obvious from fig. 3, however, that glimmerite cannot have contributed the whole of the excess potash-content of biotite-mafurite; moreover, had it done so, it would have added much more Al_2O_3 than is present in biotite-mafurite.

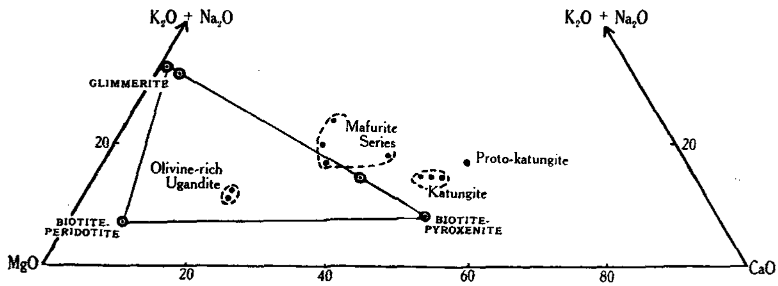

FIG. 3. Triangular diagram (in terms of MgO, CaO, and alkalis) showing the relationships of the volcanic types of Bunyaruguru to the associated cognate plutonic types.

In the mafurite series the dot nearest to the katungite field represents melilite-mafurite, and that nearest to olivine-rich ugandite represents leucite-mafurite. Melilite-ugandite is represented by the dot between katungite and olivine-rich ugandite.

Pelitic and granitic xenoliths also contribute to at least some of the lavas. There is growing evidence, as the collections are examined, that the development of leucite instead of kalsilite, and of augite instead of melilite, is due to the incorporation of such sialic material, especially in the ugandite series. It may be noted here, in passing, that no signs of limestone assimilation have been detected, and that the distribution of what little limestone or dolomite there is in the area is entirely independent of that of the volcanic rocks, both as a whole and as regards the individual types.

There remains for consideration the nature and composition of the magmas or magmatic emanations responsible for the volcanic rocks under review. An attempt has already been made to attack this problem in the case of katungite (Holmes, 1937, p. 214) and, as indicated above, the discovery of proto-katungite has carried this enterprise one stage further back. It is hoped in a later paper to demonstrate that similar magmatic material, acting on a different suite of xenolithic rocks, may have been responsible for the genesis of members of the ugandite series. In the case of the mafurite series the composition of the magmatic material must have been different; but, beyond leading to the almost obvious result that it was much richer in K_2O and very poor in Na_2O, the attempts made to disentangle the composition have so far led to no convincing conclusions. Possibly kalsilite-katungite may provide a clue, but until sufficient material of this type can be separated for complete analysis, the problem must remain unsolved.

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11. Description of Plate VI.

Fig. 1. Mafurite, C.6073. Ejected block from tuffs above lava-sheet, Mafuru dry crater. Microphenocrysts of olivine and diopsidic augite occur in a groundmass containing microliths of diopsidic augite and grains of perovskite and black ore in a mesostasis consisting mainly of kalsilite. ×20.

Fig. 2. Groundmass of coarse variety of mafurite, C.6075, occurring as lapilli in tuffs above lava-sheet, Mafuru dry crater. The field illustrates the occurrence of poikilitic kalsilite as subhedral and euhedral crystals. ×36.

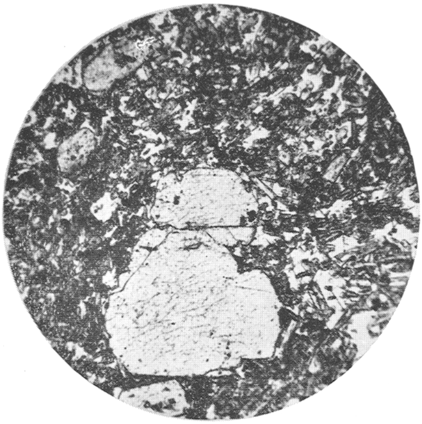
Fig. 3. Pegmatitoid in mafurite, C.6075. The field shows an area rich in euhedral kalsilite with interstitial calcite; a marginal group of crystals of diopsidic augite is seen on the left. ×36.

Fig. 4. Pegmatitoid in mafurite, C.6073. Diopsidic augite occurs in a background of poikilitic kalsilite associated with a little biotite. ×36.

Fig. 5. Biotite-mafurite, C.4078. Ejected block from NW. wall of Mafuru lake-crater. Microphenocrysts of olivine, rimmed with biotite, and a xenocryst of biotite are embedded in a biotite-rich kalsilitic groundmass, the laths and microliths of which are diopsidic augite. ×18.

Fig. 6. Kalsilite-katungite, C.5962, occurring as lapilli in tuffs, north side of Kabirenge valley, about 2000 feet west of Changabe crater. Prismatic and basal sections of melilite, prisms of kalsilite with 'forked' and 'frayed' terminations (including a cross-like intergrowth, possibly a twin), irregular crystals of olivine (NW. and SE. of field), and grains of perovskite are embedded in a matrix of glass. ×120.

Photomicrographs, all in ordinary light, by G. W. O'Neill, University Science Laboratories, Durham.



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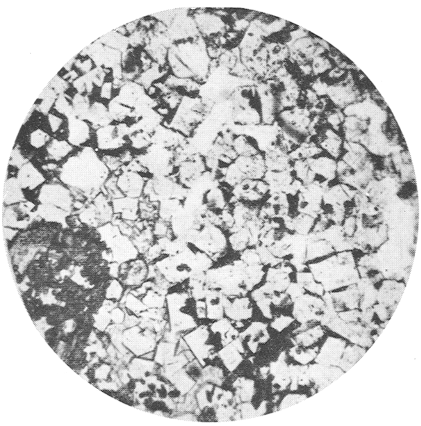

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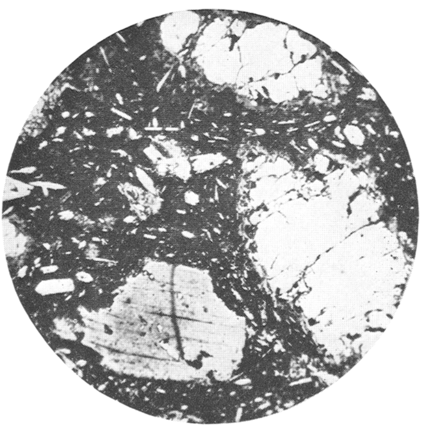

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