PETROGRAPHY.

ROCK CLASSIFICATION.

The most conspicuous feature in the petrography of the Nyiragongo area lavas is the absence of feldspars, particularly of plagioclases. No phenocrysts of feldspars of any kind have ever been detected in these rocks and potash feldspar occurring as a thin rim around large leucite phenocrysts or interstitially in the groundmass in small amounts has been discovered only in a few of the specimens microscopically studied and is to be considered an unessential constituent. No single occurrence of plagioclase in the lavas of the Nyiragongo area proper is known to the authors.

Of the feldspathoids, leucite and nepheline (kalsilite) are quantitatively important and the amounts of these minerals may be regarded as distinctive for the petrographical classification of the lavas of the area. Other feldspathoids of which only sodalite has so far been identified with certainty are not characteristic. In addition to leucite and nepheline, melilite forms a constituent the presence or absence of which is distinctive to that particular lava type.

Accordingly, the petrographical classification of the Nyiragongo area lavas is to be based on the presence and amount of the three constituents leucite, nepheline and melilite. This classification will be analogous to the classification of the ugandite-mafurite-katungite series from the Bunyaruguru and Katunga areas in SW. Uganda proposed by HOLMES [18]. In chemical and mineralogical composition there are, however, major differences between the Nyiragongo and the Bunyaruguru-Katunga lavas that do not allow the HOLMES' classification and the rock names proposed by him to be applied to the Nyiragongo lavas.

The range of variation of the composition of the Nyiragongo area lavas is illustrated by Table I at the end of this paper that summarizes the results of 30 chemical analyses made of the rocks of the area. Of these analyses, 27 are new and unpublished and three (Nos. 8, 9 and 13) have been previously published by one of the authors (SAHAMA) [31 and 32]. For convenience of the reader, Niggli values and molecular norms are also given in Tables II and III, respectively. In this progress report, chemical analyses of Nyiragongo area rocks published by previous authors will not be summarized.

For a general petrographical characterization of the Nyiragongo area rocks, it is of some importance to compare the Nyiragongo rocks on the basis of the analyses contained in Table I with the Bunyaruguru and Katunga area rocks of which chemical analyses have been given by HOLMES [15, 16, 17, 18], HOLMES and HARWOOD [20], COMBE and HOLMES [3], HIGAZY [14], NEUVONEN [28] and SAHAMA [33].

In literature that will not here be referred to in detail, the Nyiragongo rocks have been often characterized as being predominantly potassic. This statement is certainly true as far as a comparison of the Nyiragongo area with many other areas with nepheline and melilite rocks is concerned. The preponderance of potassium over sodium in Nyiragongo rocks is, however, not as pronounced as is often imagined. A calculation of the average alkali ratio from the analyses of Table I, that may be regarded as representative for the Nyiragongo area, gives the following results :

NYIRAGONGO LAVAS.

Average ratio (weight %) $Na_2O : K_2O = 1 : 1.12$.
Average atomic ratio $Na : K = 1 : 0.74$.

For the Bunyaruguru-Katunga lavas that represent the ugandite-mafurite-katungite series, the alkali ratio is :

BUNYARUGURU-KATUNGA LAVAS.

Average ratio (weight %) $Na_2O : K_2O = 1 : 4$.
Average atomic ratio $Na : K = 1 : 2\frac{1}{2}$.

The figures presented above show a very striking difference in the alkali ratio between the two groups of lavas mentioned. This difference in alkali ratio between the Nyiragongo and the Bunyaruguru-Katunga rocks results in the fact that lavas containing kalsilite as virtually the only leucocratic constituent and, accordingly, corresponding to mafurite, have not been found in the Nyiragongo area. In all rocks of this area in which kalsilite has been discovered, this mineral is by far less abundant than nepheline. In addition, rocks analogous to ugandite of the Bunyaruguru lavas, viz. strictly nepheline-free leucitites, are not included among the lava types known so far from the Nyiragongo area. Further, a feature characteristic of the Nyiragongo area is the fact that lava types containing melilite virtually without leucite or nepheline (kalsilite), corresponding to katungite, have not been discovered.

The leucocratic rock types found in the lava family of the Nyiragongo area are schematically presented in figure 3. On studying the figure, the reader may be reminded that the pure leucitite as well as the pure nephelinite end member of the family are not actually represented among the lavas of the area. These extreme rock names have been marked in the figure only for clarity. A greater part of the lavas having a groundmass either cryptocrystalline or fine-grained, modal compositions of rocks based on accurate planimetric analyses can not be given. For that reason, the scheme presented in figure 3 must be taken only in a qualitative or semi-quantitative manner.

In addition to the alkali ratio, there is another major difference between the Nyiragongo and the Bunyaruguru-Katunga lavas. In the last-named lava group of which a good collection of representative specimens has been at the authors' disposal, olivine is the most important melanocratic constituent. This mineral is characteristic of the entire ugandite-mafurite-katungite series and, unlike melilite, is not distinctive to any rock species

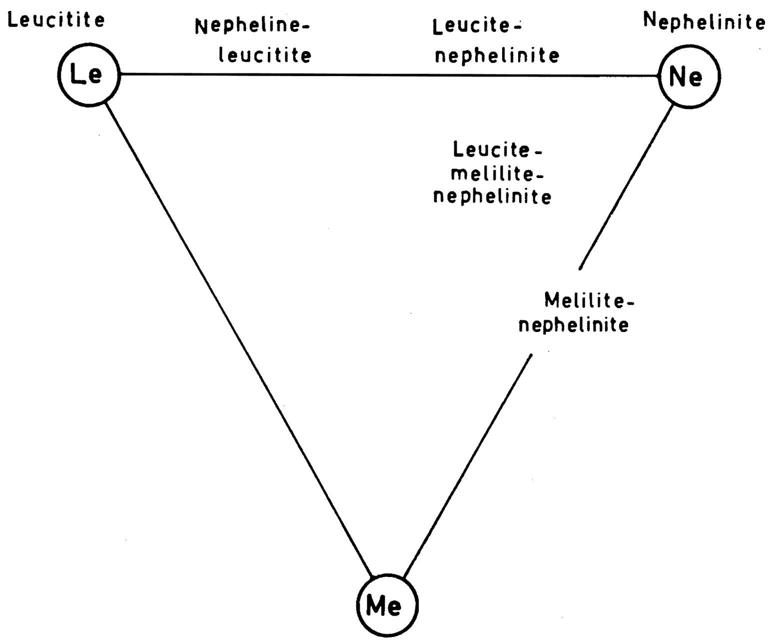

FIG. 3. — The Nyiragongo area rocks.
Schematical presentation of the nomenclature used in this paper.

within the series. Clinopyroxene is present but, in amount, is second to olivine. In the Nyiragongo area the quantitative importance of olivine and clinopyroxene is reversed. The latter mineral is virtually always present either as a titanian variety or as a type colorless to slightly greenish in transmitted light. Olivine plays a much less important role. This fact is especially conspicuous in the more melanocratic lava types.

The petrographic classification and naming of lavas found in the Nyiragongo area that is summarized in figure 3 needs a few comments. The terminology in designating rocks in this paper follows partly JOHANNSEN [22] but deviates from the system put forward by him mainly in two points. First, the use of the designation « basalt » as an indication of the olivine content of leucite-, nepheline- or melilite-bearing lavas free from plagioclase as recommended by him was rejected. As has been pointed out by several previous authors, such rocks deviate in composition from true basaltic lavas. The use of terms like « leucite-basalt », etc. for Nyiragongo lavas would probably be apt to cause confusion as to the petrographically exceptional character of these rocks. Second, no rock designations derived from locality names have been used. As has been discussed above, the rock names referring to the Bunyaruguru-Katunga lava group are not applicable to the Nyiragongo area lavas. Several of the analyzed rocks listed in Table I, have their closest counterparts outside the Nyiragongo area, in the leucite-nephelinites from Etinde on the flank of Mt. Cameroon, West Africa. These lavas, called etindites by ESCH [8] and later re-investigated by TILLEY [48], deviate from the Nyiragongo rocks of Table I in being clearly more sodic. For that reason, the name etindite was not adopted in designating Nyiragongo lavas. The rejecting of the designation etindite in this progress report must, however, be considered only tentative. The conception of the term niligongite originally proposed by A. LACROIX for an ejected block from the top of Nyiragongo has been revised and redefined by DENAEYER [6]. Also that designation was not adopted in this paper. The authors feel that they do not yet master the entire range of compositional and textural variations in the Nyiragongo lavas sufficiently well in order to propose the most suitable limits for the rocks that should be included into the niligongite family. Even after DENAEYER's welcomed redefinition, the conception of niligongite is still based only on a few specimens collected more or less arbitrarily. Unfortunately, the feldspathoidal lavas in general and certainly not least in the Nyiragongo area, display such a maze of varieties that an application of a separate designation derived from locality names for each variety would burden the petrographic nomenclature too heavily. For that reason, the authors like not to take any definite standpoint as to the term niligongite in this paper. For the same reason, the term ankaratrite or potash ankaratrite as used by HOLMES [19] was tentatively omitted.

Recently, RITTMANN [29] has proposed a petrographic nomenclature for volcanic rocks giving determinative tables for naming the rocks. Most of the rocks the compositions of which are given in Table I of this paper, fall within RITTMANN's groups D5 or D6 and, accordingly, should be called nephelinites or potash-nephelinites. It seems to the authors that a strict application of RITTMANN's nomenclature to the naming of the Nyiragongo rocks would probably not give sufficient justice to the variations in mineralogical composition. Therefore, also his classification was tentatively rejected.

DESCRIPTION OF SPECIMENS.

In the following, the Nyiragongo area rocks will be petrographically described. To provide the specimens with their geological setting within the area, brief notes on the main rock units are added to the descriptions.

The order of description is purely geographical. Starting with Shaheru, Baruta and with the main cone of Nyiragongo, the description proceeds down the mountain to E and follows the lava plain clockwise to Lake Kivu.

In addition to optical methods, mineral determinations were largely made by X-ray methods using Philips Norelco diffractometer for powder pattern and Philips Weissenberg camera for single crystal work. The composition of nepheline, kalsilite and olivine were determined by powder pattern using the method by SMITH and SAHAMA [41] for nepheline, that by SAHAMA, NEUVONEN and HYTÖNEN [34] for kalsilite and that by YODER and SAHAMA [51] for olivine. The specific gravities of bulk lavas were made on powdered material with the « Notari » volumeter. Thus the result indicates the specific gravity of the rock excluding vesicles. In several instances, the presence of kalsilite in parallel growth with nepheline and, on the other hand, the presence of zoning in olivine, nepheline, etc. was detected and checked with a Leitz rotating (elliptical) mica compensator.

For brevity, the grain size of the rock is given in brackets in a way used by HOLMES [19] as follows :

Groundmass :

vf (very fine)	average grain diameter	0,02 mm or less.
f (fine)	average grain diameter	0,02-0,07 mm.
m (medium)	average grain diameter	0,07-0,2 mm.
c (coarse)	average grain diameter	0,2-0,5 mm.
vc (very coarse)	average grain diameter	0,5 mm or more.

Phenocrysts :

S (small)	maximum length	3 mm or less.
M (medium)	maximum length	3-6 mm.
L (large)	maximum length	6 mm or more.

The letter symbols of the specimens have the following significance :

FEAE : The Finnish East African Expedition, 1952.
S : Collected by SAHAMA in 1954.
VM : Collected by MEYER in 1954 and 1956-1957.
R.G. : Specimen from older collections, stored in the Musée Royal du Congo Belge, Tervuren.

A few specimens, collected jointly, have both S- and VM-numbers.

The zeolites found in many of the specimens have not yet been subjected to closer study.

Reviews dealing with the variation of composition, etc. and with the mode of occurrence of the constituting minerals will not be included in this paper but will be published later. The following chemical analyses of minerals from the Nyiragongo area lavas are added at the end of this paper : four clinopyroxenes in Table IV, three melilites in Table V, one leucite in

Table VI, one apatite in Table VII. None of these analyses has been published previously. A number of previously published mineral analyses from the Nyiragongo lavas are not reproduced here.

SHAHERU.

Exposures are few and poor. The general physiography is outlined above (p. 9). The following specimens will be described :

Specimen S. 79 = VM. 396. E wall of crater, near to the rim. Flow that fills a former valley incising the rim.

Specimen S. 80 = VM. 395. NE wall of crater. Loose block found embedded in the ground.

Specimen S. 81 = VM. 398. Foot of S wall of crater. Fallen block.

Specimen S. 83 = VM. 397. S wall near to the rim. Flow filling an ancient valley.

Specimen S. 79 = VM. 396.

Olivine-leucite-nephelinite. (vf, S). Dark grey, very vesicular lava with a few phenocrysts of titanian clinopyroxene and, more scarcely, of olivine and leucite. Very strong preponderance of nepheline over leucite. Accessorily yellow melilite. Nepheline occurs in micrographic intergrowth with clinopyroxene and melilite. Abundant magnetite.

Specimen S. 80 = VM. 395 (1).

Complex kalsilite-bearing melilite-nephelinite. The rock is of outstanding mineralogical interest. In hand specimen, it is dark grey with irregular cream-colored spots. The rock is holocrystalline, phaneritic and massive, without vesicles. Under the microscope, the rock shows a few fair-sized aggregates of subhedral nepheline crystals, up to 4 mm in diameter, embedded in a medium-grained (average 0,1 mm) mesostasis. The size of the nepheline crystals is larger in the margins of the aggregate and decreases towards the core. The following minerals have been identified in the rock : clinopyroxene, nepheline, kalsilite, melilite, götzenite, sodalite, kirschsteinite, combeite, magnetite, perovskite, apatite, brown hornblende, pale biotite and an unknown mineral in sparing amounts the investigation of which has not yet been completed. Despite this unique mineralogical composition, no new name for the rock will be suggested. In this paper, the rock will be simply called complex kalsilite-bearing melilite-nephelinite.

(1) VM.395 = M. 2 and 3. The M-numbers were given in the field during the mapping in 1954 and were later changed into VM-numbers that refer to the whole collection, made by the Geological Survey of the Belgian Congo.

The result of a bulk chemical analysis of the rock is presented in Table I, No. 1. Chemically the rock is characterized by its low content of aluminum in relation to the alkalis and by its relatively high content of calcium. The very high contents of fluorine and chlorine are especially noteworthy.

The quantitatively most important mafic constituent of the rock is a non-pleochroic clinopyroxene, very slightly greenish in transmitted light. Brownish violet tints typical of the titanian variety are lacking. Zoning very slight, almost absent. The mineral was separated and chemically analyzed. The result of the analysis with optical data are summarized in Table IV, No. 4. According to the analysis, the atomic ratio (Fe + Mn) : Mg : Ca = 18,3 : 33,9 : 47,8. The mineral represents a salite. The optical properties agree with those of salite. It is worth noting that the clinopyroxene is free from aluminum and relatively poor in alkalis.

Nepheline is the most important salic constituent. The crystals are euhedral to subhedral. No zoning is visible by any optical means. For determining the composition of the nepheline, a small amount of the mineral was separated from the rock. The powder pattern taken of the fraction showed strong lines of both nepheline and kalsilite. Centrifuging the fraction in Clerici's solution resulted in an almost complete separation of the two minerals from each others. The composition of nepheline yielded 31,5 mol. % Ks. The powder pattern of kalsilite proved the mineral to be entirely free from the sodium component. So far, the kalsilite of this specimen is the only sodium-free kalsilite found in natural rocks. Careful examination of several thin sections cut of the rock revealed no sign of perthitic exsolution texture in nepheline. All crystals are completely clear and homogeneous. Accordingly, nepheline and kalsilite must occur as separate crystals, not in parallel growth with each others. Unfortunately, nepheline and kalsilite may be microscopically distinguished from each others only if they occur in parallel growth. If in separate grains, their identification is very difficult. For that reason, it is not possible to tell the mode of occurrence of kalsilite in the rock on the basis of a microscopic study.

Melilite occurs as stout prisms, sometimes with visible crystal forms. It is optically negative with a positive sign of elongation. $\varepsilon = 1,632$, $\omega = 1,637$. The crystals are often zoned with higher birefringence in a thin margin. The crystals show clear signs of being under resorption and have been altered wholly or partly into a granular aggregate of kirschsteinite and clinopyroxene.

The mineral götzenite that is rather abundant in the rock represents a new species found in this specimen. It is triclinic with a formula approximating to $(Ca, Na, Al)_7(Si, Ti)_5O_{15}F_{3.5}$. A detailed description of the mineral has been published by SAHAMA and HYTÖNEN [37] and will not be repeated here. The mineral shows a prismatic habit, elongated along the crystallographic b-axis. Strong dispersion with abnormal bluish interference colors, prismatic cleavage and twinning are diagnostic for the mineral in thin section. Formally, the mineral is related to the mosandrite-johnstrupite-rinkite group. As has been recently shown by SAHAMA and HYTÖNEN [38], the unit cell dimensions of götzenite differ clearly from those of that mineral group. Owing to lack of material for calcium rinkite available to the authors, a comparison of that mineral with götzenite could not be made.

Sodalite forms a rather abundant interstitial constituent of the rock. It is completely isotropic with $n = 1{,}490 \pm 0{,}002$. The identification was made by powder pattern from a small batch separated from the rock.

Kirschsteinite, the second new species found in the rock, represents a magnesium-bearing Ca Fe-orthosilicate of the olivine group. It is the closest natural analogue to synthetic iron monticellite known so far and contains 69,4 mol. % $CaFeSiO_4$. A detailed chemical, optical and X-ray study has been published by SAHAMA and HYTÖNEN [39]. The mineral never shows crystal forms but occurs as irregular grains. It often forms coronas around the melilite crystals.

Combeite is the third new species found in the rock. It is rhombohedral with a formula approximately $3\,[Na_4Ca_3Si_6O_{16}(OH, F)_2]$. A detailed description of the mineral and of its alteration has been published by SAHAMA and HYTÖNEN [37].

The magnetite crystals are mostly euhedral. Perovskite is less abundant than magnetite. It occurs as well-developed cubes sometimes with small octahedral faces. The crystals are dark violet brown, isotropic. Sp. gr. = 4,1. The identification was made by powder pattern. The powder lines show a marked zoning for the mineral. Average $a_0 = 7{,}67 \pm 0{,}01$ Å. Apatite prisms are not uncommon.

Brown hornblende and pale biotite occur in sparing amounts. The following optical properties were determined for the hornblende : $\alpha = 1{,}629$, $\beta = 1{,}636$, $\gamma = 1{,}644$, $2V_\gamma = 86°$, $c\Lambda\gamma = 33°$, $b//\beta$. The color is pale yellowish brown. Pleochroism weak. The pale brownish biotite, weakly pleochroic, shows $\gamma = 1{,}586$ and $2V_\alpha = 28°$.

It seems evident that the complex kalsilite-bearing melilite-nephelinite from Shaheru represents a rock crystallized at a low temperature range. Two facts in the mineralogical composition favor this interpretation. First, heating experiments made with götzenite (SAHAMA and HYTÖNEN, 37) indicate that the mineral is decomposed at $955° \pm 10°$ C. Accordingly, the rock must have crystallized below that temperature. Second, a joint crystallization of the relatively potassium-poor nepheline with the sodium-free kalsilite in separate grains is possible only at a very low temperature range. These facts together with the exceptionally high contents of fluorine and chlorine make it possible that the entire rock was formed under conditions comparable with the filling of amygdules that are often found in lavas and that contain a relatively low temperature association of minerals. As long as the origin of the loose complex kalsilite-bearing melilite-nephelinite block from Shaheru remains unknown, this interpretation must be considered tentative.

Specimen S. 81 = VM. 398.

Olivine-melilite-leucite-nephelinite. Non-porphyritic, phanerocrystalline, remarkably coarse-grained (grain size up to 2 mm), grey vesicular rock. Nepheline, clinopyroxene (pale-colored, non-pleochroic with slightly greenish tint), melilite, leucite, olivine, magnetite, apatite and perovskite. Olivine was separated from the rock and subjected to chemical, optical and X-ray study. The results of this study that will be published elsewhere indicate that the mineral contains slightly more calcium than the ordinary olivines of the forsterite-fayalite series and shows a ratio Mg : (Fe + Mn) = 67 : 33.

Specimen S. 83 = VM. 397.

Pheno-leucitite. Abundant small phenocrysts of titanian clinopyroxene and some leucite in a dark vesicular, cryptocrystalline matrix, probably partly glassy. A few small olivine phenocrysts visible.

BARUTA.

SOUTHERN UPPER PART.

The old crater above the saddle between Nyiragongo and Baruta, incorporated into the S part of Baruta proper, is filled with ash and is drained towards E by a small stream fed by a group of springs. In the valley of this stream cutting the rim, there occur a number of loose blocks. The following specimens collected from these blocks will be described :

S. 86 = VM. 356	S. 90
S. 87 = VM. 360	S. 91 = VM. 357
S. 88 = VM. 358	

NE of this valley, a notch occurs in the rim of the main crater. Specimens VM. 362 and VM. 363 were taken from blocks in the notch and are probably lying in situ.

Specimen S. 86 = VM. 356.

Melilite-nephelinite. (f-m, S). Porphyritic, dark grey, massive rock. Microscopically, the rock consists of very abundant melilite laths and clear, subhedral to euhedral nepheline (34,9 mol. % Ks) crystals in a mesostasis rich in colorless clinopyroxene. Melilite is slightly more abundant than nepheline. Melilite shows a steel grey, not anomalous, interference color and is optically negative with positive sign of elongation. The larger crystals are very slightly zoned. Especially at both ends, the laths are often hollow, filled by the mesostasis. The hollow development is still more pronounced for the relatively abundant apatite prisms in which the core regularly consists of the mesostasis. In addition, apatite is characteristically full of tiny inclusions the presence of which is diagnostic for the mineral. The very few olivine phenocrysts are always surrounded by coronas of clinopyroxene. Olivine is apparently not in equilibrium in the rock but was undergoing resorption. Magnetite occurs in two generations, as a few phenocrysts and as a constituent of the mesostasis. Small amounts of violet perovskite are detectable. Along with apatite and the first generation of magnetite, melilite and nepheline evidently represent early crystallizates of the rock. The crystallization of clinopyroxene belongs to the final consolidation of the lava.

Specimen S. 87 = VM. 360.

Nepheline-leucitite. (vf, L). The rock is characterized by numerous large (up to 2 cm) crystals of leucite and aggregates of nepheline in a slightly greenish, very fine-grained groudmass. A few smaller phenocrysts of titanian clinopyroxene are present. The groundmass consists of the same minerals and, in addition, of apatite and magnetite. The clinopyroxene of the groundmass is mostly green in color, sometimes with a brownish core. Especially around some of the leucite phenocrysts and in sparing amounts in the groundmass, an optically negative uniaxial potash feldspar may be detected. Perovskite is scarce. No melilite nor olivine were found. The closest counterpart for the rock elsewhere in the Nyiragongo area is represented by specimen S. 97 from the E slope of the mountain.

Specimen S. 88 = VM. 358.

Kalsilite-bearing olivine-melilite-nephelinite. (f, L). Large aggregates of turbid nepheline and phenocrysts of dark yellow melilite in a brownish grey vesicular groundmass. Under the microscope, the nepheline crystals of the aggregates are seen to consist of non-perthitic kalsilite cores surrounded by a nepheline margin. The specimen was the first one in the Nyiragongo area in which this mode of occurrence was observed for kalsilite. For that reason, the complex phenocrysts were subjected to a closer study. The results have been published by SAHAMA, NEUVONEN and HYTÖNEN [34] and will not be repeated here in detail. The following compositions were found for the two phases : nepheline 31,1 mol. % Ks and kalsilite 98,3 mal. % Ks. Further X-ray work is in progress.

A bulk chemical analysis of the rock is reproduced in Table I, No. 2. The chemical composition of this rock is not very different from that of specimen S. 96, the main difference being in the contents of aluminum, calcium and potassium. The mineralogical compositions of these two specimens are so similar that a separate microscopic description of specimen S. 88 seems not necessary. The only notable difference is the absence ot titanian clinopyroxene phenocrysts in specimen S. 88.

Specimen S. 90 = (No VM.).

Olivine-leucite-nephelinite. (f. L). Numerous large (up to 2 cm) euhedral phenocrysts of leucite and aggregates of subhedral to euhedral nepheline (18,9 mol. % Ks) in a fine-grained, grey, slightly vesicular groundmass. The leucite crystals are often surrounded by a crust of potash feldspar. The groundmass consists mainly of titanian clinopyroxene, nepheline, leucite and relatively abundant potash feldspar. A small amount of dark-colored greenish yellow subhedral olivine is characteristic of the rock. The olivine is very iron-rich. The mineral was separated from the rock and subjected to chemical, optical and X-ray studies. The results will be published elsewhere.

Specimen S. 91 = VM. 357.

Dark olivine-nephelinite. (vf, M). The rock is dark grey, vesicular. Abundant phenocrysts of pale-colored titanian clinopyroxene and less olivine in an almost cryptocrystalline groundmass. Small phenocrysts of magnetite and apatite. Nepheline was identified in the groundmass and as a few small phenocrysts. The groundmass is very rich in clinopyroxene and magnetite.

Specimen VM. 362.

Melilite-nephelinite. (vf, M). Large aggregates of nepheline and phenocrysts of smoky melilite in a massive, greyish, very fine grained groundmass. Melilite always contains tiny inclusions that cause the turbidity of the crystals. The mineral is optically negative with a positive sign of elongation. In habit and in optical properties, the melilite of this rock differs from the melilite of specimen S. 86 (p. 27). In sections parallel to the optic axis, the melilite crystals of specimen VM. 362 are seen to represent no thin laths but stout prisms with a ratio length/width averaging to $\frac{2}{3}$. The crystals are invariably very heavily zoned with a rather large homogeneous core surrounded by a relatively thin mantle in which the interference color rises rapidly towards the margin. A measurement of the birefringence with Berek compensator yielded 0,004 for the core and 0,011 for the outer margin. These optical properties indicate that the core is rich in åkermanite. The gehlenite content increases in the marginal zones and the outermost zones are very rich in it, probably with an increased content of alkali melilite. The nepheline crystals contained in the specimen S. 96, the main difference being in the contents of aluminum, calcium and potassium. The mineralogical compositions of these two specimens are so similar that a separate microscopic description of specimen S. 88 seems not necessary. The only notable difference is the absence ot titanian clinopyroxene phenocrysts in specimen S. 88.

Specimen S. 90 = (No VM.).

Olivine-leucite-nephelinite. (f. L). Numerous large (up to 2 cm) euhedral phenocrysts of leucite and aggregates of subhedral to euhedral nepheline (18,9 mol. % Ks) in a fine-grained, grey, slightly vesicular groundmass. The leucite crystals are often surrounded by a crust of potash feldspar. The groundmass consists mainly of titanian clinopyroxene, nepheline, leucite and relatively abundant potash feldspar. A small amount of dark-colored greenish yellow subhedral olivine is characteristic of the rock. The olivine is very iron-rich. The mineral was separated from the rock and subjected to chemical, optical and X-ray studies. The results will be published elsewhere.

Specimen S. 91 = VM. 357.

Dark olivine-nephelinite. (vf, M). The rock is dark grey, vesicular. Abundant phenocrysts of pale-colored titanian clinopyroxene and less olivine in an almost cryptocrystalline groundmass. Small phenocrysts of magnetite and apatite. Nepheline was identified in the groundmass and as a few small phenocrysts. The groundmass is very rich in clinopyroxene and magnetite.

Specimen VM. 362.

Melilite-nephelinite. (vf, M). Large aggregates of nepheline and phenocrysts of smoky melilite in a massive, greyish, very fine grained groundmass. Melilite always contains tiny inclusions that cause the turbidity of the crystals. The mineral is optically negative with a positive sign of elongation. In habit and in optical properties, the melilite of this rock differs from the melilite of specimen S. 86 (p. 27). In sections parallel to the optic axis, the melilite crystals of specimen VM. 362 are seen to represent no thin laths but stout prisms with a ratio length/width averaging to 2/3. The crystals are invariably very heavily zoned with a rather large homogeneous core surrounded by a relatively thin mantle in which the interference color rises rapidly towards the margin. A measurement of the birefringence with Berek compensator yielded 0,004 for the core and 0,011 for the outer margin. These optical properties indicate that the core is rich in åkermanite. The gehlenite content increases in the marginal zones and the outermost zones are very rich in it, probably with an increased content of alkali melilite. The nepheline crystals contained in the aggregates are slightly zoned as indicated by the regular arrangement of inclusions. Kalsilite in intergrowth with nepheline could not be detected under the microscope. A few phenocrysts of titanian clinopyroxene have clearly been undergoing resorption and are mantled by a homoaxial growth of colorless clinopyroxene with sharp boundaries against the titanian clinopyroxene core. Some phenocrysts of olivine also occur in the rock. They are partly or wholly transformed into a fine-grained mixture of colorless clinopyroxene and magnetite and, accordingly, represent a relictic constituent. Apatite prisms are characteristically turbid. The groundmass consists of nepheline, colorless clinopyroxene, magnetite and perovskite.

Specimen VM. 363.

Olivine-melilite-nephelinite. (vf, S). A few small phenocrysts of clinopyroxene and olivine in a massive, dark, steel-grey groundmass. The clinopyroxene is a pale-colored titanian variety. Small melilite laths with very low anomalous interference colors reach a grain size above that of the almost cryptocrystalline groundmass. The groundmass consists of colorless to slightly greenish clinopyroxene, magnetite, nepheline and very sparing amounts of pale biotite.

NORTHWESTERN BREACH.

The NW breach of the main crater of Baruta is caused by at least two smaller craters perforating the side of the main cone. Specimen S. 92 was collected on the NW external rim at an elevation of 2.850 m and represents a pile of flows probably filling an old valley that has been cut in the main cone. Specimen S. 93 comes from the NW inner wall at the 2.725 m level where brown-red piled flows form a conspicuous landmark.

Specimens VM. 365 to VM. 368 are bombs embedded in the coarse ash of the E wall, about 15 m above the crater floor.

Specimen VM. 369 comes from a big (1 m^3) block on the bottom of an extinct lava lake located in the SE part of the breach.

Specimen S. 96 is part of several big massive blocks lying at the foot of the rocky wall immediately NW of the threshold to the main crater. The wall itself is formed by piled vesicular flows not described here. The level from which the buried blocks originate is not yet known. The rock is described because of its mineralogical importance.

Specimen S. 92 = VM. 352.

Dark olivine-nephelinite. (vf, S). Abundant small phenocrysts of olivine, titanian clinopyroxene and, very rarely, of nepheline in an almost opaque, cryptocrystalline, very vesicular groundmass.

Specimen S. 93 = VM. 353.

Dark olivine-nephelinite. (vf, S). Phenocrysts of olivine and titanian clinopyroxene in a cryptocrystalline, vesicular groundmass. The olivine crystals are strongly altered to a reddish brown mass, probably through steam action. Minute amounts of nepheline could be identified in the groundmass.

Specimens VM. 365-368.

Dark olivine-nephelinites. (vf, S-M). These specimens are so similar to each others that they may be described together. Phenocrysts of olivine and pale-colored titanian clinopyroxene in a very vesicular dark grey groundmass. Only in one of the specimens (VM. 365) a few clots of nepheline are visible to the unaided eye. Small amounts of leucite are contained in the clots. The groundmass is cryptocrystalline, very dark, with sparing amounts of detectable nepheline. Specimens VM. 366 and VM. 368 contain pale biotite as an accessory.

Specimen VM. 369.

Olivine-leucite-nephelinite. (f, S). Titanian clinopyroxene and euhedral zoned olivine in a fine-grained, dark grey, vesicular, holocrystalline groundmass. The groundmass consists of the same minerals and, in addition, of nepheline with small amounts of leucite.

Specimen S. 96 = VM. 355.

Kalsilite-bearing olivine-melilite-nephelinite. (f, L). The rock is porphyritic and contains large aggregates of perthitic nepheline-kalsilite crystals and separate phenocrysts of melilite, clinopyroxene and olivine in a dark grey vesicular groundmass.

The result of a bulk chemical analysis of the rock is quoted in Table I, No. 3. The high state of oxidation of iron is especially noteworthy and is apparently a result of volcanic steam action. The rock is not weathered but looks fresh.

A chemical, optical and X-ray study of the perthitic nepheline-kalsilite phenocrysts has been published by SAHAMA, NEUVONEN and HYTÖNEN [34]. The detailed results of that study will not be repeated here. Only the compositions of the kalsilite and nepheline phases of the complex perthitic crystals will be mentioned : nepheline 30,2 mol. % Ks and kalsilite 95,0 mol. % Ks. Further X-ray work with the perthitic nepheline-kalsilite crystals is in progress. Nepheline occurs in the rock also as separate homogeneous phenocrysts outside the large complex aggregates. The composition of the separate nepheline phenocrysts is 32,3 mol. % Ks. Refractive indices are : $\varepsilon = 1{,}542$ and $\omega = 1{,}546$.

The abundant melilite phenocrysts, up to 3 mm in size, show a characteristically yellow color thus differing from the two other analyzed melilites from the Nepheline Aggregate lava (specimen FEAE No. 93) and from the Kabfumu lava (specimen FEAE No. 83). Table V, No. 3 presents composition, physical and optical data for the melilite from specimen S. 96. The melilite from this specimen represents a ferrian variety thus differing from the two other analyzed melilites mentioned above. The contents of the åkermanite and of the alkali melilite components, on the other hand, are approximately the same for all three melilites. The higher state of oxidation of iron is apparently the cause of the somewhat higher refractive indices of the Baruta melilite and, in addition, of the dark yellow color not common for the members of the melilite family. Under the microscope, the optically uniaxial negative melilite phenocrysts are always euhedral with positive sign of elongation and are often zoned with higher interference colors along the margin. Extremely weak pleochroism, with absorption $\omega > \varepsilon$. The crystals are full of tiny transparent inclusions with a refractive index higher than for melilite. These inclusions are too small in size to be identified microscopically.

The phenocrysts of titanian clinopyroxene show color, hour-glass texture and twinning of this pyroxene variety. Chemical composition and physical and optical data are summarized in Table IV, No. 3. The phenocrysts of olivine are less abundant than those of clinopyroxene. The olivine crystals show a thin crust of a dark brown, strongly pleochroic alteration product, probably iddingsite. As for melilite, the olivine crystals are not clear but contain tiny inclusions. The composition of olivine is 82,7 mol. % Fo.

Numerous apatite prisms reach a size well above that of the groundmass. The crystals are often hollow containing groundmass in the core. The color is very slightly yellowish, in thin section colorless. The common zoning may be detected in loose crystals under the binocular microscope or, in thin section, with a rotating mica compensator. Table VII presents the composition, physical and optical data.

The groundmass is fine-grained, not cryptocrystalline, containing nepheline, greenish clinopyroxene, yellow melilite, magnetite, hematite, perovskite, calcite, apatite.

Main crater.

In the W wall of the main crater of Baruta, the most conspicuous outcrop is a massive-appearing rock about 120 m high. No banding nor horizontal flows appear on its face. In the top of the talus, ca. 30 m high, that gives access to the foot of the wall, proper, specimen VM. 370 was taken from a fallen block. The lower part of the rock wall is a light grey, slightly vesicular lava carrying numerous crystals of pyroxene up to 1 cm long and flattened so as to appear acicular in section. Specimens VM. 371 and VM. 376 represent this rock.

Specimen VM. 372 was taken from a bomb embedded in tuff at the shore of the southernmost extinct lava lake.

Specimen VM. 374 comes from a big massive block of violet-colored lava, at the foot of a conspicuous spur in the SE wall, probably fallen from an unknown level.

Specimen S. 94 = VM. 354 is a vesicular ropy lava from a flow that forms the threshold into the main crater. This is the last lava emitted in the main crater.

Specimens VM. 375, VM. 377 and VM. 378 come from the E wall, where a massive blue lava forms an outcrop symmetrical to the W main outcrop.

Specimen VM. 370.

Dark olivine-leucite-nephelinite. (vf, M). Numerous large phenocrysts of pale-colored titanian clinopyroxene, less numerous and smaller phenocrysts of zoned olivine and a few small aggregates of leucite in a dark grey, almost cryptocrystalline groundmass in which small amounts of nepheline could be identified.

Specimens VM. 371 and VM. 376.

Olivine-leucite-melilite-nephelinites. (f, L). These two specimens are very similar. In hand specimen, large and numerous pyroxene crystals are seen in a light grey, slightly vesicular groundmass. Under the microscope, the clinopyroxene proves to be a titanian variety. Small olivine phenocrysts are strongly altered into a dark reddish brown material. The groundmass is holocrystalline, fine-grained. It consists of nepheline, leucite, zoned melilite, slightly yellowish green clinopyroxene and magnetite. Melilite occurs only in the groundmass, not as phenocrysts and fills the interstices between the nepheline crystals. Melilite shows a relatively strong yellow color with absorption $\omega > \varepsilon$. It is optically negative with positive sign of elongation. The birefringence, measured with Berek compensator from specimen VM. 376, is remarkably high, viz. 0,03. $\omega = 1{,}661$ and $\varepsilon = 1{,}630$. These optical properties and the mode of occurrence as one of the later crystallizates of the rock seem to indicate that the composition of the mineral deviates from the compositions of the melilites found in most melilite-bearing rock types of the Nyiragongo area. The melilites of these two specimens are probably very rich in the alkali melilite component.

Specimen VM. 372.

Melilite-nephelinite. (m, M). Massive, grey lava with a few black spots of titanian clinopyroxene. Under the microscope, the clinopyroxene is found to be strongly corroded. Melilite occurs as phenocrysts that sometimes reach the size of 3-4 mm. Despite their considerable size, the melilite crystals are hardly seen in hand specimen. This circumstance is caused by the poikilitic development of the melilite crystals that enclose patches of the mesostasis of the rock. The birefringence of melilite is remarkably high, like in specimens VM. 376 and VM. 371. The melilite of specimen VM. 372 evidently belongs to the later crystallizates of the rock. The mineral will be subjected to closer study. Nepheline occurs in the groundmass as subhedral crystals. No nepheline phenocrysts were found. The holocrystalline mesostasis between the melilite and nepheline crystals consists mainly of colorless clinopyroxene, magnetite and perovskite. Turbid apatite prisms are common. A few granular aggregates of colorless clinopyroxene with magnetite show contours of former olivine phenocrysts that have been completely transformed into a mixture of these two minerals.

Specimen VM. 374.

Olivine-melilite-leucite-nephelinite. (vf, S). Dark grey vesicular lava with a few phenocrysts of yellow melilite and pyroxene. Under the microscope, the rock shows abundantly phenocrysts of yellowish turbid melilite with low, slightly anomalous interference colors. Only the largest of these crystals are visible to the unaided eye. Phenocrysts of titanian clinopyroxene and olivine are less abundant. Small aggregates of nepheline and a few leucite crystals are found. Some apatite is present. The groundmass is dark, cryptocrystalline.

Specimen S. 94 = VM. 354.

Dark olivine-nephelinite. (vf, S). The result of a bulk chemical analysis of the rock is presented in Table I, No. 4. The rock is very vesicular with olivine and clinopyroxene phenocrysts in a dark grey groundmass. Under the microscope, the rock is seen to be very melanocratic with only minor amounts of nepheline in the groundmass. The composition of the olivine phenocrysts is 84,5 mol. % Fo. The clinopyroxene is very pale-colored with slightly violet tints of the titanian variety. Not pleochroic. Hour-glass texture, twinning and zoning very marked. The clinopyroxene of the groundmass is pale greenish. Clinopyroxene is quantitatively the dominant constituent of the rock. Magnetite occurs in the groundmass partly as euhedral crystals and partly in skeletal development. Also hematite and apatite were found in the almost cryptocrystalline groundmass.

Specimens VM. 375, VM. 377 and VM. 378.

Olivine-melilite-nephelinites. (vf, M). These three specimens are very similar to each others and may be here described together. The rocks contain large rounded aggregates of nepheline-melilite and separate phenocrysts of titanian clinopyroxene, olivine, melilite and apatite. The core of the aggregates is usually rich in melilite and is surrounded by a mantle of nepheline crystals. No kalsilite could be detected microscopically. The groundmass is rich in magnetite and almost cryptocrystalline.

TERMINAL CONE.

MAIN CRATER OF NYIRAGONGO.

Petrographic descriptions of rocks from the main crater of Nyiragongo will be limited in this paper to the specimens listed below. These specimens have been chosen from a bulk of 84 sets of samples collected during systematic geological mapping of the crater that was carried out in February and June, 1956. The specimens here described are arranged according to the localities at which they have been collected, starting from the talus of fallen blocks at the foot of the SSE wall that forms a convenient landmark and turning clockwise around the crater.

The oldest flows exposed in the crater above the upper platform occur as thin lenses in the tuffs of the lower walls in the SW and W parts of the crater. The layers dip slightly towards NE and, accordingly, the flows outcropping in the N and E parts of the crater represent higher horizons. In establishing a rough stratigraphy of the flows, dykes visible in the walls are useful when their connection with flows as feeding channels is observable. Cone sheets and ring-dykes occur and their true nature is sometimes difficult to recognize.

The following specimens will be described :

VM. 246, VM. 147, VM. 163 and VM. 165 come from blocks in the SSE part of the talus mentioned above and represent flows in the upper third of the wall.

VM. 201 is from the border of a small ring-dyke outcropping ca. 6 m above the top of the said talus.

VM. 208 comes from an injected mass of lava, 50 m E of dyke No. 1. VM. 210 was taken from a horizontal lava bed related to the injected mass.

VM. 212 and VM. 213 come from the composite dyke No. 1 that is formed by greenish leucite-nephelinite with clinopyroxene phenocrysts injected into an older dyke of leucite-nephelinite with large aggregates of leucite and nepheline.

VM. 217 was taken from a lenticular flow, 5 m thick, located half-way between dykes Nos. 1 and 2.

VM. 157 represents the border and VM. 220 the heart of dyke No. 2.

VM. 158 is from the heart of dyke No. 3 that is visible on a vertical distance of more than 120 m.

VM. 230 comes from a small ring-dyke immediately N of dyke No. 3.

VM. 232 represents the highest of three horizontal flows outcropping in a spur 200 m N of dyke No. 3.

Specimens VM. 233 and VM. 234 come from dyke No. 4.

VM. 235 was taken 10 m above platform, 400 m N of dyke No. 3 and is typical of the main mass of flows overlying the tuffs in the NW part of the crater.

VM. 239 is a fallen block from a higher level of the N wall.

VM. 241 is the border phase of the important dyke No. 6 that feeds the flows occurring 100-120 m high in the N wall.

VM. 243 represents the big (sometimes nearly 1 m^3) blocks carrying conspicuous giant leucite phenocrysts found in the SW part of the upper platform, fallen from the upper third of the wall.

VM. 268 was taken from an isolated lava lens interstratified in a tuff bed half-way between dyke No. 6 and the « cape » jutting from the NE wall.

VM. 269 represents the lava flow capping the tuffs at the base of the « cape ».

VM. 270 comes from the coating of glassy lava that covers the NE wall and that has been erupted from the circular fissure running around the upper platform.

VM. 271 represents dyke No. 7 that may be followed up to a height of 130 m above the platform and perhaps extends even higher.

VM. 273 represents dyke No. 10. This dyke is older than dyke No. 11 and feeds flows located 25-30 m above the platform.

VM. 274 comes from the heart of dyke No. 11. This dyke cuts dyke No. 10 and feeds a massive flow underlying the highest tuff bed in the wall of that locality, at a height of 50-60 m.

R.G. 22770 was taken by the Reverend Van der Auwera in 1948 at a height of about 115-120 m (40 m below the rim). It is a bomb embedded in the main tuff layer.

From the relations observed, the following succession of flows from bottom to top is inferred :

Specimens VM. 208, VM. 210, VM. 217, VM. 232, VM. 235 and VM. 268 represent the oldest flows visible above the upper platform. The rocks are olivine-melilite-nephelinites.

Specimens VM. 269 and VM. 273 are melilite-nephelinites, following the olivine-bearing lavas, with olivine very scarce or absent.

Specimens VM. 157 and VM. 220 are melilite-leucite-nephelinites that, by appearance of leucite in the rock, represent a transition towards the leucite- and nepheline-bearing rocks of the higher levels. These last-named rocks can be conveniently split into lower and upper leucite-nephelinites.

Specimens VM. 274 (nepheline-leucitite), VM. 241 and VM. 212 (leucite-nephelinites with large leucite-nepheline aggregates) represent a leucite-dominated phase of the lower leucite-nephelinites. The SW and NW parts of the upper platform are littered with big leucitite blocks carrying giant leucite crystals (VM. 243), sometimes up to 15 cm in diameter (Plate III-*b*).

Specimens VM. 271, VM. 213 and VM. 158 are leucite-nephelinites, fine-grained, with some phenocrysts of nepheline and clinopyroxene, devoid of leucite phenocrysts. These flows will be called the upper leucite-nephelinites.

These rocks are followed by the Nepheline Aggregate lava that forms a thin coating op top of the main cone.

The following scheme summarizes the succession of flows visible above the upper platform of Nyiragongo crater, each phase being named after its distinctive mineral :

Top.

Nepheline phase	Nepheline Aggregate lava. Upper leucite-nephelinites.
Leucite phase	Lower leucite-nephelinites. Nepheline-leucitites (sometimes giant-crystal facies).
Transitional phase	Melilite-leucite-nephelinites. Melilite-nephelinites.
Melilite phase	Olivine-melilite-nephelinites.

Bottom.

In a recent paper, DENAEYER and TAZIEFF [7] give a tentative succession of lavas in the Nyiragongo crater that is substantially different from the succession listed here. As the conclusions of the present authors are based on abundant observations and on a map on the scale 1 : 2.000, chances are that the discrepancies are due to the conditions under which TAZIEFF visited the crater and that have been described by him separately [47]. More puzzling is the fact that the blocks containing the giant leucite crystals of Plate III-*b* seem to have been mistaken for Nepheline Aggregate lava as the reference « Des blocs de la même lave, à agrégats parfois énormes, sont éboulés sur le plancher de la caldère » [7, p. 219] can hardly apply to any other rock.

Specimen VM. 246.

Melilite-leucite-nephelinite. (f). Massive, even-grained lava with melilite (low, not anomalous interference color), leucite, nepheline, slightly greenish clinopyroxene, magnetite and apatite. Small amounts of green glass.

Specimen VM. 147.

Leucite-nephelinite. (c). Rather coarse-grained, grey-red lava, non-porphyritic. Under the microscope, the rock is seen to be holocrystalline with titanian clinopyroxene, subhedral nepheline, leucite, apatite and magnetite. Calcite is common, especially as a coating of the vesicles. No melilite.

Specimen VM. 163.

Leucite-nephelinite. (f, S). Aggregates of subhedral nepheline and leucite in a mesostasis very rich in violet to yellowish green clinopyroxene. Magnetite, apatite. No melilite.

Specimen VM. 165.

Leucite-nephelinite. (vf, L). Large phenocrysts of nepheline and leucite in a cryptocrystalline groundmass. A few small phenocrysts of pale-colored titanian clinopyroxene, apatite and magnetite. No melilite, nor olivine.

Specimen VM. 201.

Leucite-nephelinite. (vf, S). Slightly vesicular grey-black lava with a few aggregates of nepheline, leucite and titanian clinopyroxene in a very fine-grained groundmass that consists of the same minerals and, in addition, of magnetite and hematite. The clinopyroxene of the groundmass, partly greenish in color, occurs in small radial clots.

Specimen VM. 208.

Olivine-melilite-nephelinite. The rock is virtually identical with the specimen VM. 210. The only notable difference between the two specimens is the fact that the olivine of specimen VM.208 has been almost completely altered to a dark reddish brown mass.

Specimen VM. 210.

Olivine-melilite-nephelinite. (f, S). This specimen is considered the type rock for the oldest lava beds above the upper platform of Nyiragongo crater. The rock is light brown, sprinkled with dark melilite crystals, up to 2 mm in size. The lath-shaped melilite is optically negative with positive sign of elongation, shows low, not anomalous, interference colors and is very slightly zoned. The zoning becomes clearly visible only on using a rotating mica compensator. Optically the mineral is very similar to the melilites Nos. 1 and 2 of Table V that are both rich in åkermanite. The cores of the melilite crystals of specimen VM. 210 are prefectly fresh. On the margins, on the other hand, the crystals are altered to a yellow, extremely fine-grained material the identification of which is not possible under the microscope. Nepheline is mostly euhedral, clear and never shows any alteration. The mesostasis that fills the interstices between the melilite and nepheline crystals consists of colorless clinopyroxene, small amounts of olivine (large optic axial angle), magnetite, perovskite, calcite, probably zeolite, and, in addition, a slightly pleochroic, optically uniaxial negative mica, very faintly yellowish in color. Apatite prisms are rather common. The clinopyroxene has $c\Lambda\gamma=48°$, $2V_{\gamma}=67°$.

Specimens VM. 212 and VM. 213.

Leucite-nephelinites. Dyke No. 1. The dyke is composite. Specimen VM. 212 is finely vesicular, bluish, with abundant medium-sized phenocrysts of nepheline and leucite and smaller phenocrysts of titanian clinopyroxene in a cryptocrystalline leucite- and nepheline-rich groundmass. Specimen VM. 213, collected from the W border of the dyke, is greenish grey in color and contains acicular crystals of titanian clinopyroxene in a fine-grained, not cryptocrystalline groundmass of leucite, nepheline, titanian clinopyroxene and magnetite.

Specimen VM. 217.

Olivine-melilite-nephelinite. (f, S). Massive, brown lava with black crystals of melilite visible to the unaided eye. Microscopically the rock is similar to specimen VM. 210. The only difference between the two specimens is in the content of olivine that is more abundant in specimen VM. 217. The olivine of this specimen is never euhedral but occurs in poikilitic crystals enclosing nepheline, etc.

Specimens VM. 157 and VM. 220.

Melilite-leucite-nephelinite. Dyke No. 2. Large aggregates and separate phenocrysts of nepheline, melilite and leucite in a groundmass mainly consisting of the same minerals and magnetite. In specimen VM. 220 the groundmass is fine-grained and in specimen VM. 157 almost cryptocrystalline.

Specimen VM. 158.

Leucite-nephelinite. Dyke No. 3. (f, L). Compact greenish rock with aggregates of nepheline and phenocrysts of pale-colored titanian clinopyroxene. No leucite phenocrysts were found. The holocrystalline groundmass consists of nepheline, leucite, clinopyroxene and magnetite. DENAEYER and TAZIEFF [7] have published a chemical analysis of a specimen collected from this dyke. It shows a composition similar to that of specimen R.G. 4922 (Table I, No. 11), but is relatively more rich in potassium. In the material available to the authors, no microperthitic kalsilite was detected.

Specimen VM. 230.

Olivine-melilite-leucite-nephelinite. (m). Grey-brown compact rock. The predominating constituents of the rock are a low-birefringent melilite in thin laths and nepheline. Leucite and olivine are less abundant. Titanian clinopyroxene occurs in small quantities. Magnetite, apatite, probably zeolite, calcite and traces of pale brownish biotite.

Specimen VM. 232.

Olivine-melilite-nephelinite. (f, M). Finely vesicular lava. Abundant medium-sized phenocrysts of pale-colored titanian clinopyroxene. Less numerous phenocrysts of olivine, heavily altered melilite and nepheline. Holocrystalline groundmass consisting of the same minerals and magnetite. Apatite prisms. Numerous vesicles filled with calcite.

Specimens VM. 233 and VM. 234.

Olivine-melilite-nephelinites. Dyke No. 4. (m, S). The two specimens are similar to each others. Compact brownish grey rocks. Small phenocrysts of melilite in a medium-grained granular groundmass that consists of subhedral nepheline, melilite, almost colorless clinopyroxene, perovskite, magnetite and apatite. Olivine is scarce and occurs as a few very small phenocrysts. Some calcite and probably zeolite. The rocks are very similar to specimen VM. 210.

Specimen VM. 235.

Olivine-melilite-nephelinite similar to specimen VM. 217.

Specimen VM. 239 (fallen block).

Nephelinite. (vf). Blue-black slightly vesicular lava without phenocrysts. Almost cryptocrystalline. Greenish clinopyroxene, nepheline, magnetite.

Specimen VM. 241.

Leucite-nephelinite. Dyke No. 6. Similar to specimen VM. 165 except that the groundmass is more coarse-grained.

Specimen VM. 243.

This specimen contains gigantic crystals of leucite, up to 15 cm in diameter, in an almost cryptocrystalline groundmass very rich in greenish clinopyroxene and magnetite and containing a few small phenocrysts of violet-colored titanian clinopyroxene and apatite.

Specimen VM. 268.

Olivine-melilite-nephelinite. (f, M). Grey-brown vesicular lava with a few well-formed dark augite and yellow melilite crystals. Microscopically, the rock contains phenocrysts of pale-colored titanian clinopyroxene, low-birefringent melilite, olivine and nepheline in a granular holocrystalline groundmass of the same minerals with magnetite, perovskite and apatite. Numerous calcite veins.

Specimen VM. 269.

Melilite-nephelinite, kalsilite-bearing. (vf, L). Bluish vesicular lava with phenocrysts of melilite and nepheline, partly collected into aggregates. The nepheline crystals often show a non-perthitic core of kalsilite. The very fine-grained holocrystalline groundmass consists of the same minerals and colorless clinopyroxene, magnetite, perovskite. Apatite prisms. Calcite. Olivine is very scarce.

Specimen VM. 270.

Nephelinite. Very vesicular, almost opaque glassy lava with a few very small phenocrysts of nepheline.

Specimen VM. 271.

Leucite-nephelinite. Dyke No. 7. (vf, S). Grey-brown lava. Numerous aggregates of nepheline and leucite too small for detection by the unaided eye. Groundmass very fine-grained with the same minerals and colorless clinopyroxene and magnetite.

Specimen VM. 274.

Nepheline-leucitite. (f, S). Dyke No. 11. A few phenocrysts of pale-colored clinopyroxene. Numerous small crystals of leucite and nepheline in a groundmass of the same minerals and colorless clinopyroxene. Magnetite.

Specimen VM. 273.

Melilite-nephelinite. Dyke No. 10. The rock is similar to specimen VM. 269 except that olivine could not be found in the two thin sections available. Kalsilite cores in some of the nepheline crystals.

Specimen R.G. 22770.

Olivine-leucitite, nepheline-bearing. (f, S). Crystals of leucite, sometimes collected in small aggregates, and olivine in a fine-grained groundmass consisting mostly of titanian clinopyroxene, magnetite, leucite, nepheline and olivine. Apatite and minute amounts of potash feldspar. The chemical composition of the rock is presented in Table I, No. 5.

Ejected blocks.

The rim of the crater and the upper slopes of the cone of Nyiragongo are littered with ejected blocks displaying considerable differences in texture and composition. In spite of keen search, no rocks of sedimentary origin have been discovered. In the neighbouring Nyamuragira, ejected sedimentary material is abundant. The only foreign material found on Nyiragongo is represented by sponges of completely molten quartz. The type rock for « niligongite » of A. LACROIX was collected from an ejected block. No representative of the olivine-biotite-pyroxenite family of A. HOLMES has been found either.

Only two specimens will be described in this paper. Specimen VM. 12 was collected from an inclusion in the Western Spur flow at an elevation of 3.130 m and specimen R.G. 22778, collected on the S rim in 1945 by the native guide ISHAHUNDA.

In the description of the fire-pit, a possible mode of origin was suggested for the ejected holocrystalline blocks.

Specimen VM. 12.

Melilite-leucite-nephelinite with sparing amounts of olivine. (vc). A grey, even-grained, coarse (grain size up to 5 mm), holocrystalline, massive rock. Nepheline (26,0 mol. % Ks) is slightly more abundant than leucite. Melilite has a somewhat higher birefringence than the melilite that occurs in the Nepheline Aggregate lava. The amount of the mineral present in the rock is rather small. The clinopyroxene shows the typical appearance and colors of a titanian variety. Magnetite, apatite and traces of biotite. The result of a bulk chemical analysis of the rock is given in Table I, No. 7. Compared with the Nepheline Aggregate lava, this rock contains less alumina and alkalis and slightly more calcium and magnesium.

Specimen R.G. 22778.

Melilite-leucite-nephelinite. (f). This specimen is of a special mineralogical interest. It is massive to slightly vesicular grey lava without visible phenocrysts. Microscopically, the rock proves to be granular, leucocratic with nepheline, melilite, leucite and some colorless clinopyroxene, magnetite and apatite. The result of a bulk chemical analysis of the rock is given in Table I, No. 6. In the few small cavities that are found in the rock, an olivine-looking mineral was found that was subjected to closer chemical, optical and X-ray study. The results of this study will be published elsewhere. The mineral represents a sub-calcium magnesian kirschsteinite, a member of the olivine group the chemical composition of which lies between the monticellite-kirschsteinite and the forsterite-fayalite series. So far, such a calcium olivine has been recognized only from this specimen.

NEPHELINE AGGREGATE FLOWS.

The name Nepheline Aggregate flows is applied to a large number of flows in which the composition of the lava may vary within rather wide limits but share the common character of carrying conspicuous aggregates of nepheline crystals. The name is used as a field name. These flows cover the terminal cone of Nyiragongo like the icing on a cake. Their bulk is much less than what their areal extension would suggest. Most specimens from Nyiragongo collected by previous visitors represent this lava type, on which undue emphasis is thus placed in collections and literature.

The origine of the Nepheline Aggregate flows has been discussed above (p. 37). The lower ends of the flows are hidden in the dense forest that covers the lower reaches of the mountain. In the upper part, nearly all Nepheline Aggregate flows are of the « pahoehoe » type and grade into « aa » near to the 3.000 m level where a distinct break in the slope occurs. This type of lava must have been highly viscous on emission because some flows stop on slopes inclined at 25°.

The age of these flows is unknown. They are posterior to the extinction of Shaheru and anterior to the collapse of the main crater.

Origins of specimens cited in the text below are as follows :

Specimen R.G. 4922. Specimen No. 1650 of F. Delhaye. Exact locality unknown.

Specimen S. 76. Path on Kanega, SE slope of Shaheru at an elevation of 2.300 m.

Specimen VM. 21. Upper saddle between Shaheru and Nyiragongo at an elevation of 2.810 m.

Specimen S. 77. NE slope of Shaheru at an elevation of 2.530 m.

Specimen S. 82 = VM. 400. Flow invading the bottom of the Shaheru crater.

Specimen R.G. 4925. Top of Nyiragongo. Exact locality unknown.

Specimen S. 95 = VM. 361. Saddle between Nyiragongo and Baruta at an elevation of 3.045 m.

Specimen S. 84 = VM. 387. NE slope of the main cone of Nyiragongo at an elevation of 3.300 m.

Specimen R.G. 5033. Main crater of Nyiragongo. Collected by J. Fontaine in 1924. Exact locality unknown.

Specimens FEAE No. 87 and FEAE No. 89. Near to km point 224 on the Goma-Rutshuru road.

Specimen FEAE No. 93. S slope of Nyiragongo at an elevation of 2.950 m.

Notes on the mineralogy and petrography of the Nepheline Aggregate flows have been published by Sahama and Wiik [30] and Sahama [31]. In the last named paper two bulk chemical analyses of the lava were given. Since then, two new chemical analyses have been made of rocks probably belonging to the Nepheline Aggregate lava. All these analyses are collected in Table I, Nos. 8, 9, 10 and 11. As will be seen from that table, the lava of the Nepheline Aggregate flows varies remarkably in chemical composition. Despite the variations, some distinct characteristics are in common to these lavas. In addition to the low silica content, the Nepheline

Aggregate lava is characterized by high contents of aluminum, calcium and alkalis and by a low content of magnesium. In weight percent, potash is mostly in excess over soda.

In literature, the Nepheline Aggregate lava has sometimes been erroneously called leucite lava. Such a statement was probably based only on field observations and not on microscopic study of the specimens.

Probably the most characteristic feature in the mineralogy of the Nepheline Aggregate lava is the richness in potassium component of the nepheline phenocrysts. In the two papers mentioned above, seven chemical analyses have been presented of nepheline occurring as phenocrysts in the lava. According to these analyses, that will not be reproduced here, the composition of nepheline ranges from 36,6 to 42,1 mol. % Ks. Original material for the analyzed nephelines have been used by SMITH and SAHAMA [41] in establishing a method for determining the composition of natural nepheline by X-ray powder pattern. Further determination of the compositions of nepheline in Nepheline Aggregate lava are summarized below :

Specimen.	Composition of nepheline.
R.G. 9422	25,6 mol. % Ks.
S. 76	26,7
VM. 21	42,7
S. 77	43,3
S. 82	43,7
R.G. 4925	44,6
S. 95	44,6
S. 84	44,8
R.G. 5033	45,5

With the exception of the two first specimens listed, viz. R.G. 4922 and S. 76, the nepheline compositions found range between 42,7 and 45,5 mol. % Ks. The contents of the potassium components in the nephelines of specimens R.G. 4922 and S. 76 is much lower. Both these specimens look like Nepheline Aggregate lava proper. For explaining the relatively low potassium contents in these two specimens, two alternatives are possible. Either these specimens belong the other flows than the Nepheline Aggregate lava proper or there are locally considerable variations in the potassium content of the Nepheline Aggregate lava nepheline. No matter which one of these possible explanations will prove to be correct, the fact still remains that the potassium content found in the nepheline of the Nepheline Aggregate lava is among the highest recorded so far in natural rocks. At present, such potassium-rich nephelines are not known outside the Nyiragongo area.

According to synthetic studies of the phase equilibrium relationships in the nepheline-kalsilite system by Drs. O. F. TUTTLE and J. V. SMITH at the Geophysical Laboratory of the Carnegie Institution of Washington (both now at the Pennsylvania State College, University City, Penn.), a very large gap in solid solubility exists in the nepheline-kalsilite series in the sub-solidus temperature range. The exact location of the two-phase area in the phase diagram of that system has not yet been published. Preliminary data about the phase diagram of that system has kindly been put at the author's disposal by Dr. SMITH. According to this information, it seems that the composition of the very potassium-rich nephelines of the Nepheline Aggregate lava would fall into the two-phase area of the phase diagram at low temperatures. Accordingly, these nephelines must have crystallized at higher temperatures, say, above 750°-950° C depending on the composition. On cooling below that temperature range, an exsolution into a more sodic nepheline and a kalsilite phase may be expected. In the paper previously published by one of the authors [31], no sign of exsolution was reported for the nepheline of the Nepheline Aggregate lava. Later, Professor C. E. TILLEY, of Cambridge, found one single crystal of perthitic nepheline-kalsilite in a thin section of one of the specimens (personal communication) and, still later, the authors found another similar case in another specimen. These observations prove that exsolution occurs in the nepheline of this lava, and that the exsoluted nepheline-kalsilite crystals are extremely rare and may be found only with good luck. Careful examination of quite a number of thin sections of Nepheline Aggregate lava has revealed no sign of exsolution. The fact that the exsolution is extremely rare may be explained by the rapid cooling of the lava or by a remarkable sluggishness of the exsolution for nephelines of composition around 40 mol. % potassium component.

Strongly exposed single crystal Weissenberg photographs taken of the nepheline from Nepheline Aggregate lava have revealed a complex structure similar to that previously found for the nepheline from Iivaara, Finland [36]. Further X-ray work on this point is in progress. The Weissenberg photographs invariably give a pattern corresponding to the space group $P6_322$ instead of $P6_3$. This fact probably indicates that the nepheline of the Nepheline Aggregate lava is intimately twinned. Of the six nephelines of which chemical analyses have been published by SAHAMA [31], unit cell dimensions have been determined by powder patterns. The results will be published on a later occasion and are not reproduced here. The values for a_0 and c_0 are very slightly lower than those found for synthetic nepheline preparations by SMITH and TUTTLE [43]. Of specimen FEAE No. 87, a prism was ground of a nepheline crystal. Using an optical goniometer and a Leitz monochromator, the refractive indices were measured for a number of different wave lengths. The results are summarized in Table VIII. Of several nephelines from the Nepheline Aggregate lava and of more sodic nephelines from other sources, a number of heat of solution experiments have been made. The nephelines were dissolved in an acid mixture containing 15 % HF and 5 % HCl at a temperature of 75° C. The results that will be published on a later occasion show heats of solution for the nephelines of the Nepheline Aggregate lava that are ca. 10 cal./gram higher than would be expected if the heats of solution found for the more sodic nephelines are extrapolated to the Nepheline Aggregate lava nephelines. This difference is 4-5 times as great as the uncertainties of the measurements.

Of specimen FEAE No. 93, melilite and titanian clinopyroxene were separated and chemically analyzed. The results of the analyses with optical and physical data are summarized in Tables V, No. 2 and IV, No. 2, respectively.

Outcrops surrounded by the Nepheline Aggregate flows.

Two important outcrops of older rocks have been found on the upper slopes of Nyiragongo that are surrounded by the Nepheline Aggregate flows. On the SW flank of the mountain, the spur previously mentioned (p. 12) is covered by leucite-nephelinite flows of the type of dyke No. 3. Specimen VM. 401 was collected on the SW rim of Nyiragongo and represents the spur. On the other hand, on the eastern flank of the mountain, at an elevation of 2.900 m, a small crater is visible in the forest. In the wall of that crater, leucite-bearing lavas and pyroclastics carrying leucite crystals up to 1 cm across are found. Specimen S. 98 represents the flows, while specimen S. 97 comes from a bomb embedded in the lavas.

Specimen VM. 401.

Leucite-nephelinite. (f, L). The rock is very similar to that of specimen VM. 158.

Specimen S. 98.

Leucite-nephelinite. (m, L). The rock is porphyritic. The phenocrysts, mostly collected in aggregates, are leucite, nepheline and titanian clinopyroxene. Apatite prisms are found under the microscope. The dark grey groundmass is holocrystalline medium-grained. It consists mainly of green clinopyroxene, often brownish in the core, nepheline, leucite and magnetite.

Specimen S. 97 = VM. 383.

Nepheline-leucitite. (vf, L). In hand specimen, the rock is characterized by numerous leucite crystals, up to 1 cm in size, and by slightly smaller well-developed nepheline (19,2 mol. % Ks) prisms. Microscopically, titanian clinopyroxene and apatite are also found as small phenocrysts. The nepheline shows an unusually well-developed basal and prismatic cleavage. Further X-ray work with this nepheline is in progress. The groundmass is almost cryptocrystalline with mainly green clinopyroxene, magnetite and nepheline. The chemical composition of the rock is presented in Table I, No. 12.