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AFLEVERING 2

STUDY OF THE VOLCANO NYIRAGONGO

A PROGRESS REPORT

BY

THURE G. SAHAMA (Helsinki) and ANDRÉ MEYER (Goma).

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Fascicule 2

NATIONAAL ALBERT PARK
VIII. — ZENDING
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INTRODUCTION

The active volcano Nyiragongo is located in the « Parc National Albert » on the eastern border of the Belgian Congo, by 29°15′ E and 1°31′ S. Older literature refers to it under the misspelled names « Niligongo », « Ninagongo » or « Tshaninagongo ».

The mountain is part of the Virunga (Birunga) volcanic region and was discovered in 1894 by the German explorer Count G. A. VON GÖTZEN [10]. The volcano has been studied only in a cursory fashion. Scattered observations by occasional visitors and descriptions of rocks with chemical analyses have been published, without any geological setting or mutual relations of the specimens investigated [6, 7, 9, 10, 12, 23, 26, 44, 45].

Even the authoritative review by HANTKE [11] errs seriously in the description of the main physiographical characters. Published information shows the mountain to be the type locality of the nepheline- and leucite-bearing rocks of the « niligongite » family of A. LACROIX [23].

The authors have explored the greater part of the massif mainly in 1954 and 1956, as part of their respective work on feldspathoidal lavas (TH. G. S.) and general mapping of the Virunga volcanics (A. M.). One of us (A. M.) has mapped in detail the terminal crater of Nyiragongo. The study of the collected material will require considerable time and results of special investigations will be published separately. Some of these studies have already appeared [30, 31, 32, 34, 35, 37, 39].

The present paper is a progress report, providing a general view of the volcano and of its geological setting. No interpretation of the results is attempted. The authors consider that they do not yet possess sufficient facts to warrant a petrogenetical discussion. After completion of the study, the authors intend to publish a monograph on the subject in the « Exploration du Parc National Albert », series of the « Institut des Parcs Nationaux du Congo Belge ».

The authors are indebted to the « Institut des Parcs Nationaux du Congo Belge et du Ruanda-Urundi », and to their respective governments, through the agencies of the « Service Géologique du Congo Belge et du Ruanda-Urundi » and the Government Scientific Council of Finland (Valtion Luonnontieteellinen Toimikunta) for the means put at their disposition. Of the many persons who gave direct or indirect assistance, only Mr. Kai Hytönen, who contributed substantially to the field and laboratory work, will be mentioned at the present time.

GEOLOGICAL SETTING.

South of the Ruwenzori massif, the Lake Edward - Lake Kivu section of the Western Rift Valley opens in the Kivu-Ruanda-Toro plateau a trench directed N 20° E, roughly 300 km long and 30-50 km wide. The rifting is of the block faulting type with secondary blocks disposed at an angle to the direction of the main scarps, providing a saw-tooth pattern for the outer, western edge. The main rifting was completed during the Tertiary time. No important post-Pliocene faulting has been traced in this section. Except in the region immediately SW of Ruwenzori [13], this part of the Rift has not been adequately studied and in the maze of structures, the proponent of any tectonic theory may find local evidence for his pet ideas.

Between Lake Tanganyika and the Ruwenzori massif, the country rocks are :

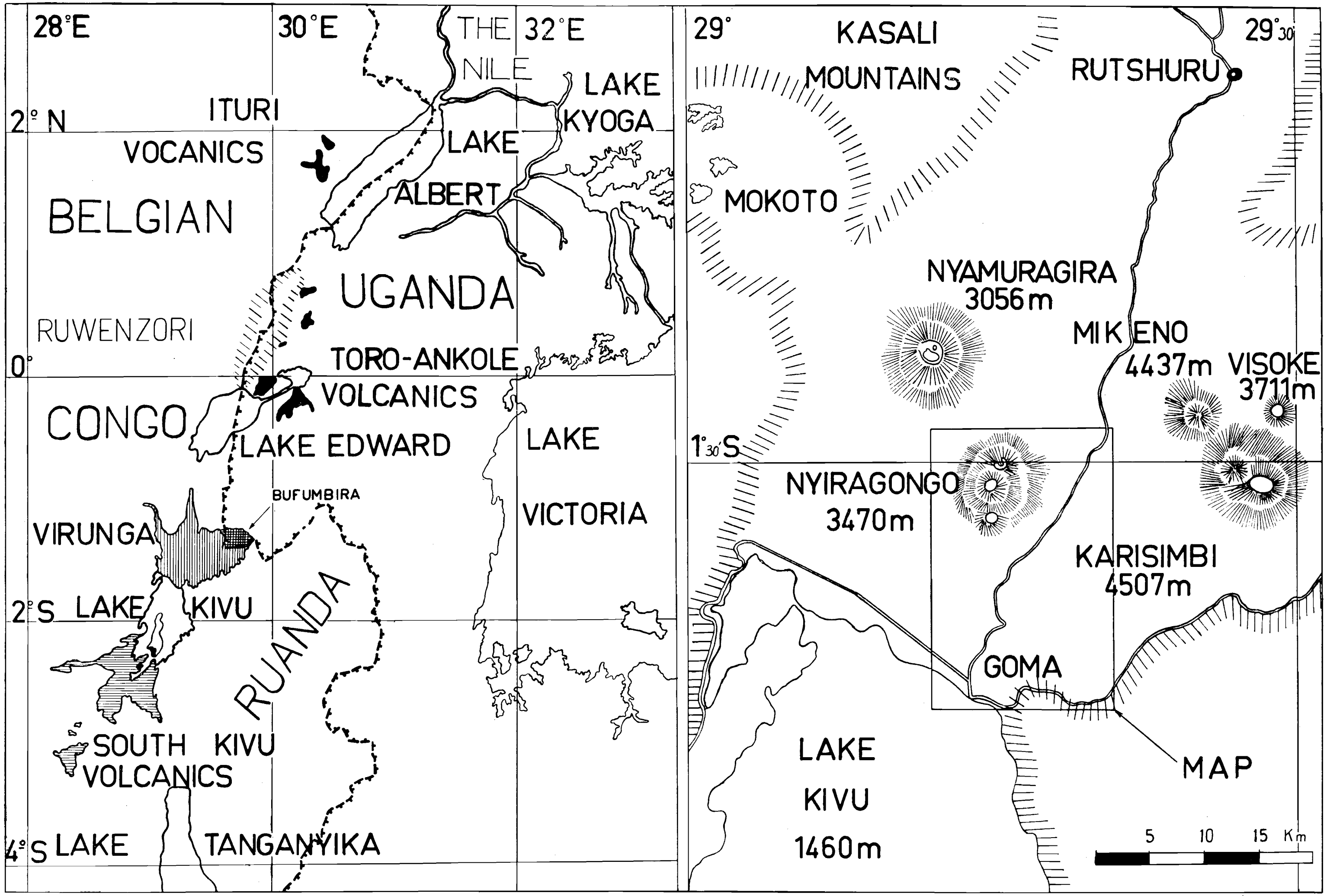
A. — SEDIMENTS AND OLDER IGNEOUS ROCKS.

a) Rift Valley sediments : gravels, sands and clays of Pleistocene age. Their thickness is unknown, but must be considerable. Along Lake Albert, drilling for oil has disclosed a sediment filling at least 1.200 m thick.

b) « Urundi system » correlated with the « Karagwe-Ankole » system of Uganda. Schists, quartzites and dolomitic limestone lenses of pre-Cambrian age, subjected to considerable tectonic disturbances. Dating of minerals related to intrusions give results ranging between 900×10^6 and 1.400×10^6 years.

c) « Ruzizi system » : quartzites, variously metamorphosed schists and gneisses.

d) Younger granites and minor intrusions of basic rocks cutting the Urundi sediments.



A B

Fig. 1. — A : Volcanic areas associated with the Western Rift.
B : The central and western part of the Virunga.

e) Older granites, intrusive into the Ruzizi sediments alone, as is demonstrated by the existence of granitic pebbles in the basal conglomerate of the Urundi system.

f) At least one major carbonatite intrusion of hitherto unknown age has been discovered in the scarp SW of Lake Edward [1, 2].

B. — **VOLCANIC FORMATIONS** (fig. 1, A).

Late-Tertiary to recent volcanics occur in sizable quantities on the Ituri plateau W of Lake Albert, at the foot of Ruwenzori, between Lakes Kivu and Edward (Virunga-region) and around the southern end of Lake Kivu (South Kivu volcanics). The three last regions are related to major disturbances in the Rift : the Ruwenzori horst, the Bufumbira bay and the intersection of the Kivu-Edward section of the Rift with the Tanganyika section. The fascinating relations between rift tectonics and volcanism will not be discussed here and the subject will be treated elsewhere.

The characteristics of these regions may be summed up as follows :

a) The Ituri volcanics are formed by basalts extruded from numerous fissures. Advanced erosion leaves only two small occurrences of flows between Bunia and Djugu but many doleritic dykes are found in the region between Irumu and Mahagi, testifying to the former extent of the volcanics.

b) Toro-Ankole volcanics. Along the E foot of the Ruwenzori range six small fields are found that consist of recent explosion craters, tuffs and rare flows of potash-ankaratrite-melaleucitite and related rock types (katungite with melilite, mafurite carrying kalsilite, ugandite with leucite). The rocks have been studied by HOLMES [15, 16, 17, 18, 19, 20] who proposed to account for their genesis by the interaction of a carbonatite magma and granitic basement rocks.

c) Virunga volcanic region, including the Bufumbira area. This later name covers the part of the region that falls within the political boundaries of Uganda and that amounts to ca. 10 % of the bulk of volcanics in the entire Virunga field while ca. 90 % is in the Belgian Congo and Ruanda. The Bufumbira region was mapped by A. D. COMBE during the years 1925 to 1929 and the collected material studied by A. HOLMES. The work of these geologists [4, 21] remains the main source of information on the Bufumbira, but much new evidence has been recently collected from the other parts. Plio-Pleistocene basalts in the Mokoto area, olivine-leucitites (Mikeno) and potash trachyandesites (Sabinyo) were followed by a suite of rocks ranging in composition from olivine-leucitite and melilite-nephelinite to trachyte. The Virunga region (fig. 1, B), comprises eight major massifs and more than a hundred minor cones. The activity was mainly of the effusive type. Some confusion seems to have crept into recent literature as to the relative amounts of the Toro-Ankole and Virunga volcanics. The total bulk of the Toro-Ankole volcanics is probably less than the volume of any one of the major Virunga massifs.

d) South Kivu volcanic region : Plio-Pleistocene trachytes, basalts derived from fissure eruptions, followed by recent rhyolites and basalts.

An up-to-date summary of the main relations and new data has been given by one of us (MEYER, in press).

Around 1°30′ S, the Rift Valley presents an important embayment to the east, roughly 45 km long and 25 km wide. That is the « Bufumbira Bay », a tectonic feature badly known and even less understood. By 1°15′ S, a smaller bay to the west is believed to represent a cauldron subsidence. It is the « Mokoto depression » communicating with the main Rift Valley through the « Kamatembe Gap ». Of the eight major Virunga volcanoes, three (Muhavura, Gahinga, Sabinyo) are aligned along the axis of the Bufumbira Bay, three (Visoke, Mikeno, Karisimbi) cluster at the junction with the main Rift, while the two western massifs (Nyiragongo, Nyamuragira) straddle squarely the main Rift depression.

In pre-volcanic time, one single lake occupied the Rift from Ruwenzori until the S end of what is now Lake Kivu. This former lake drained into the Semliki valley, W of Ruwenzori and was part of the Nile drainage system. The Ruindi and Rutshuru plains S of Lake Edward are the ancient bottom of this lake. Mapping of the bottom of Lake Kivu by echo-sounding has shown it to be a remarkably flat surface at an average altitude of 1.000 m. As this is also the average altitude of the plains N of the volcanoes, it is concluded that the top of the Plio-Pleistocene sediment filling of the Rift Valley under the two western volcanoes probably also is a nearly flat surface at the same altitude of 1.000 m.

Flows pouring out from the basaltic vents on the crest of the western scarp and from the Mikeno massif in the east have invaded at least part of the main Rift Valley, covering the pre-existing sediments. These flows were probably followed by Karisimbi lavas invading the valley more to the south. As the level of the greater Lake Edward sunk, drainage still remained directed northwards. Sections drawn across the Rift Valley show that these older flows have probably not completely blocked the valley, even if the drainage was progressively shifted westwards.

In comparatively recent times, vents opened along the floor of the main Rift Valley and their lavas formed a dam, causing the waters to accumulate in the southern part of the depression and thus creating Lake Kivu with the jagged shorelines characteristic of a drowned topography. This fact was already noticed by MOORE as long ago as 1900 [27].

The dispersal of vents is shown not only in the visible topography but also by the presence of basin-topped mounds up to 150 m high on the bottom of Lake Kivu. The waters of this lake rose to about 110 m above the present level of 1.460 m. Around the 1.570 m level the mounting lake reached a notch in the watershed south of Bukavu and started flowing towards Lake Tanganyika which is part of the Congo River basin. The eruptions thus caused a migation of the Mediteranean-Atlantic watershed and diverted a sizable portion from the Nile to the Atlantic basin. Rapid erosion of the valley by the resulting Ruzizi river lowered the level of Lake Kivu to 1.460 m.

The volume of igneous material between the top of the lacustrine sediments and the present level of Lake Kivu amounts to about 500 km^3.

Unpublished C^{14} datings carried out on fossil shells from terraces on the north shore of Lake Kivu show that the high level of the lake occurred between 10.000 and 15.000 years ago and that the lake sank at the average rate of about 1 m per 100 years.

The visible part of the Nyiragongo massif is thus posed on a pile of lavas erupted from the eastern volcanoes, from its own vents and from an aureole of satellites. Below the 1.000 m level there are lacustrine sediments of unknown thickness.

The older basement rocks cannot be observed directly. The nearest outcrops are granites and pegmatites, 13 to 20 km S and SE from Nyiragongo. Towards SW, Urundi sediments are found in the Mbuzi peninsula, 22 km from the mountain. Quartzites, schists, dolomitic limestones and pegmatites on the western scarp are found 22 to 25 km from it. Ejected blocks of sedimentary material, while abundant in the Nyamuragira, are completely absent in the Nyiragongo. This fact suggests a granitic substratum under the Nyiragongo.

THE VOLCANO NYIRAGONGO.

PHYSIOGRAPHY.

The Nyiragongo massif is formed by three major volcanic cones welded together and disposed along a N-S trending arc, slightly concave towards E. Their alignment is exactly on the continuation of the main eastern scarp of the Rift. The cones are :

A. — Shaheru, elevation 2.800 m.

B. — Baruta, elevation 3.100 m.

C. — Terminal cone of Nyiragongo, elevation 3.470 m.

Seen from N or S, the profile is that of a steep-sloped truncated cone while seen from W or E, the outline shows a massive smoking cone, flanked by two lower buttresses.

Because of gradual passage into the surrounding lava plain, the apparent base of the massif is hard to define. It can be considered as roughly following the 2.200 m contour line. The flows have advanced 6-7 km E before having been diverted to S by the older Karisimbi flows and 12-15 km to S untill the shore of Lake Kivu. To W and N, they disappear under the younger Nyamuragira lavas. Flows derived from the Nyiragongo massif are not much younger than the last flows originating at the SW foot of the Karisimbi massif.

The length of the massif between the N foot of Baruta and the S foot of Shaheru is nearly 10 km. The absolute age cannot be given. The only sure element is the fact that flows from Nyiragongo cover previous flows incrusted by fossil-bearing sinter at the 1.560 m stand of Lake Kivu.

Compared with such giants as the Mauna Loa, the Nyiragongo massif is not impressive. But it's features make up for the lack of size.

A. — Shaheru.

The cone of Shaheru has remarkably steep slopes inclined at 28° and is covered by dense forest growing on a thick layer of soil derived from weathered ash. Exposures are few and deeply weathered. The top holds a steep-sided crater, 700 m across and 80 m deep. A flow of « Nepheline Aggregate lava » from the main cone has filled the saddle between Shaheru and Nyiragongo and, cascading down the N wall, has invaded the W half of the Shaheru crater. The walls display ash and coarse cinder with a few ejected blocks. These blocks are of variable composition and most often massive. They are supposed to derive from older intercrateral flows cut by later vents and ejected during phases of explosive activity rather than representing bombs of ejected molten material. V- and U-shaped outcrops of vesicular lava along the rim are believed to represent fillings of valleys cut in the old cindercone and filled by later flows from a central vent. The older crater must have been considerably enlarged in the later stages of activity while the main lava column was withdrawn. The base of the Shaheru is ringed by satellite cones and disappears under their flows. At the end, activity migrated from the terminal cone to the foot of the mountain.

B. — Baruta.

Baruta is a massive complex cone whose slopes rise at 15° in the lower parts and at 30°-32° above the 2.600 m level. The main crater is 1.100 m across and 300 m deep. Exposures on the outer slopes are few and poor. The inner sub-vertical walls display good outcrops of massive lava, partly covered by thick vegetation. The NW wall is breached along the whole height by several smaller craters. The breach is exactly in line with the « weakness zone » [24, 49] of the Nyamuragira massif.

The thickly forested floor of the Baruta crater carries at least six big crescent-formed depressions whose steep walls are lined by benches of glassy lava. Except for a bigger size, they are similar to the lava lake of

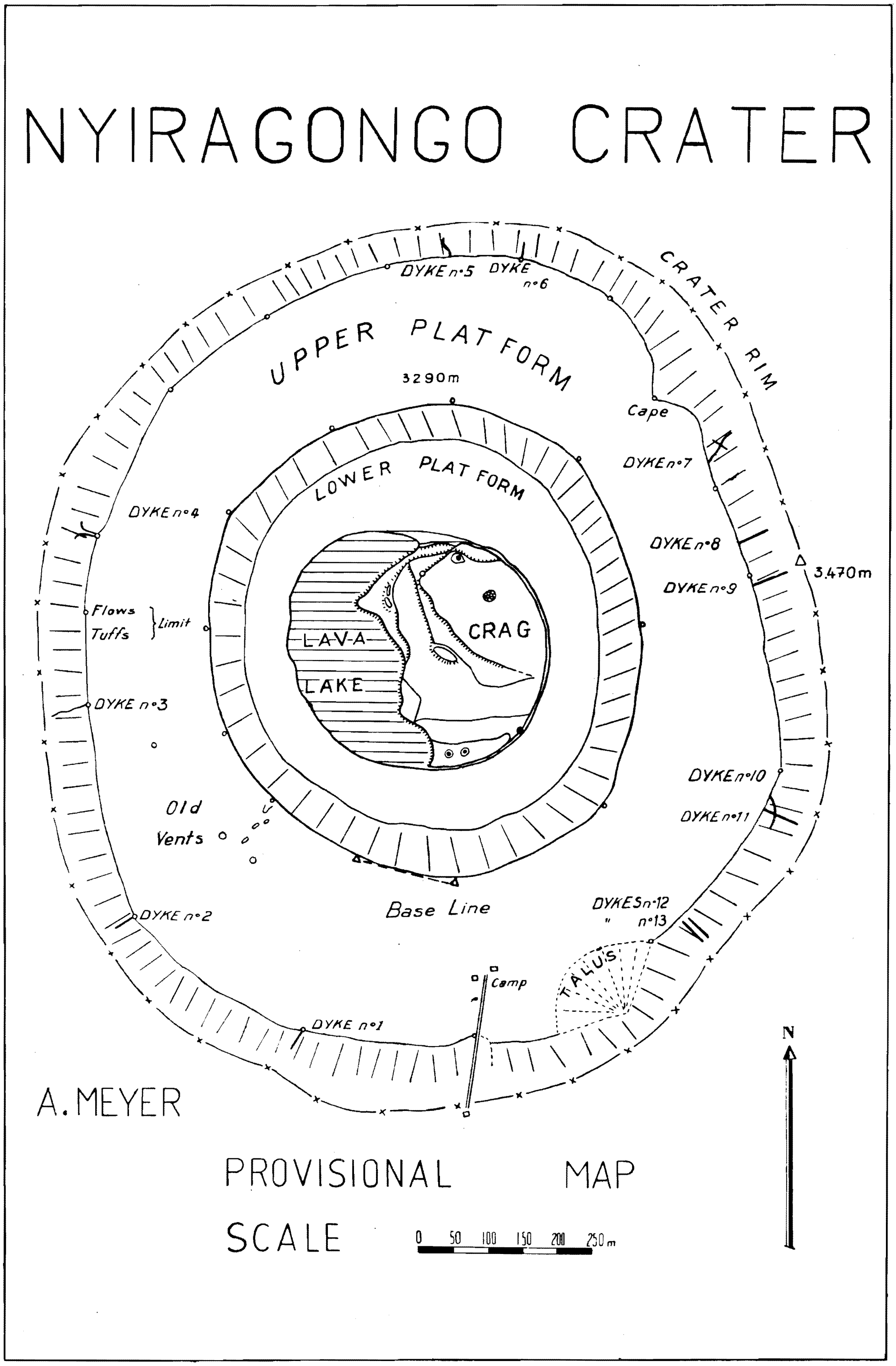


FIG. 2. — The crater of the Nyiragongo.

the Tshambene eruption of 1938-1940 on the SW foot of Nyamuragira [24]. In the upper S part of Baruta, there is an older crater, partly incorporated into the rim and providing a good shelter for visitors. This crater is drained towards the east through a small valley.

There is no trace of any recent activity in the Baruta, nor are there any native traditions on the subject. The statement found in HEIM [12] (p. 54) : « Nach einer Aufnahme des Herzogs zu Mecklenburg in 1908 war der Baruta in Eruption » is contested. The quoted photograph shows usual clouds and on no other photograph are there any signs of activity. No reference to such an event is found in the text — on the contrary, both lateral craters are stated as long extinct.

C. — TERMINAL CONE OF NYIRAGONGO.

When seen from a distance, the terminal cone of Nyiragongo appears very regular. The flanks rise at 31° on the W side, 32° on the N side and 28° on the E side, respectively. The SSW slope is irregular and displays a lava-covered spur whose sides dip up to 40°. The W slope is completely barren, probably because of the prevailing sulphur-bearing winds along this flank. The other flanks are covered by the giant heather *Hagenia abyssinica*, followed upwards by a mixed vegetation of *Ericacea*, *Lobelia* and *Senecio*.

The slopes are covered by flows of what the authors term « Nepheline Aggregate lava ». Below 3.000 m, the pahoehoe prevailing near the summit frequently grades into « aa »-type flows. Scattered outcrops of leucitite occur as windows in this main type of flow. In the upper part, numerous trenches lined with glassy lava represent old channels. Some of the channels originate in visible tunnels, others may be followed untill notches in the rim of the crater and their origin must be sought at higher levels and inside the present outline of the crater. These interrupted channels are convincing proof of the recent enlargement of the terminal crater. At the time of emission of these flows, the upper part of the cone probably displayed an activity similar to the present « Sciara del Fuoco » of Stromboli.

The flow channels play an important role in the erosion of the volcano. As built-in trenches, they canalise the run-off from the heavy rains and are quickly changed into erosion guillies.

TERMINAL CRATER OF NYIRAGONGO (fig. 2).

The terminal crater has been named « Graf Götzen Krater » by the german expedition of 1907-1908.

The components of the crater are : the walls, the upper platform, the sink, the lower platform, the fire-pit with the lava lake and the crag. The upper platform is located at the 3.285 m level. The section of the crater, measured along this plaform, is an ellipse with a N-S axis of 1.140 m and an E-W axis of 960 m. The terminal crater has been called a caldera but the use of this term seems to be incorrect because authorities agree that a characteristic feature of a caldera is a diameter multiple of the biggest vent enclosed.

The first man to try the descent was the Oberleutnant WEISS in 1907, and the first man to succeed was R. D. BURTT in 1930.

a) **The walls.**

The height of the crater walls of Nyiragongo varies between 160 and 185 m. In the rocky parts, the slope is regular, averaging 70°, and is very irregular in the tuffs. The walls are subjected to active erosion. After strong rains, the loosely consolidated tuffs discharge torrents of water exercising a strong caving action, dislodging loose boulders and overhanging slabs of interstratified flows. The net effect is one of widening the crater by recession of the walls and subsequent lowering the rim. Granted sufficient time, such an erosion is apt to produce effects of astonishing size. Provided the eroded material is periodically removed, it is believed that this « creeping » process can be as potent as the two violent processes of explosion and engulfment.

In the SW and S walls, coarse tuffs with blocks of all sizes up to 1 m contribute up to 90 % of the material. Some interstratified flows occur as thick lenses and, in the uppermost 15-20 m, there is a capping of flows. The other walls display up to 80 % flows and only a minor amount of relatively thin tuff beds. There are two distinct formations in the tuffs, the upper resting unconformably on the lower one and dipping towards the centrum of the crater. It is believed that the upper formation is derived from an adventive cone located on the SSW slope and now buried under subsequent flows. The rounded spur of the SSW flank would be the topographical expression of this buried mound. The upper surface of the tuff beds shows U-shaped notches filled by piles of horizontal flows. This feature represents valleys cut in the tuff cone and filled by overflowing lava from an ascending column. The contact between tuffs and overlaying lavas plunges towards NE and disappears under the platform. From the geometrical characters of the contact it is inferred that the oldest feature of the top of Nyiragongo probably was a tuff cone erected around a relatively small crater centered in the SSW part of the present crater. The erection of this cone occurred during a phase of explosive activity. A change in the type of activity took place, the lava column climbed and frequent overflows occurred, mainly towards NE and E. The change from explosive to effusive activity was marked by a change in the mineralogical composition of the flows (see below). At a later stage, the center of activity migrated northwards, perhaps in several stages with intermediate breakdowns of the successive craters.

To account for the present features, a substantially higher cone must be postulated. If the upper extensions of flows on the outer flanks are drawn on profiles across the cone, the extended slopes meet above the present fire-pit at a height near to 3.850 m. This elevation is assumed to represent the maximum possible level of the lava column. A crater 400 m across (diameter of the present fire-pit) would have its rim located around 3.720 m high, and this is considered a reasonable assumption. The lava column withdrew later and the crater took the present shape by successive breakdowns and engulfments of the walls. That such a process occurred, is clearly demonstrated by the presence of numerous dykes and cone-sheets now seen in the walls, the injection of which could not be conceived under the present conditions. Thirteen main dykes and numerous small feeders are visible, with steep conesheets outlined in irregular outcrops. At a very recent stage, glassy lava was ejected from the fissure surrounding the upper platform plastering the wall in several places with the coating reaching a height of about 140 m in the ENE wall.

b) **The upper platform.**

The upper platform is a horizontal annular surface with a net extension of 52 ha covered by ropy or cellular lava and littered with blocks fallen from the walls. In the SW part, half a dozen small lava domes, 2-3 m high, appear approximately at the place where the old « tuff phase crater » is supposed to have been located. Flows have also come from fissures in the NW part. Frozen « waves » of lava along the base of the walls mark the true level of emitted flows. A circular crack, up to 3 m wide, separates the platform from the wall. Shrinkage of the plug during cooling has lowered the platform by around 2 m as compared with the level of the « waves ».

The denivellation between platform and rim was measured in 1907 by the German Oberleutnant WEISS, topographer of the Duke of Mecklenburg's expedition. His figure of 155 m is close enough to our measure of 160 m as to warrant the conclusion that no substantial changes in level of the platform have occurred since 1907.

c) **The sink.**

The sink is cylindrical, 180 m deep, with a nearly circular section, 680 m across in N-S direction and 620 m in E-W direction. The walls are sub-vertical, built up by horizontal flows with an average thickness of 1 ½ m. Important changes have occurred during the last 60 years. In 1894, VON GÖTZEN found two distinct vents separated by a wall. On a photograph taken in 1905, the wall is seen crumbling and the two vents start uniting. On later photographs, the process is seen to go on and in a panoramic view taken in 1918 one single big vent is visible. The outline of this central vent has undergone no important changes during later years.

Easily identified blocks and fissures visible on the 1918 photograph can still be found today. Reports of the crater taking a clover-leaf form during the years 1930-1940 are based on hearsay evidence and are contradicted by the facts mentioned.

d) **The lower platform.**

The lower platform is a horizontal annular surface with a net area of 22,7 ha littered by blocks fallen from the walls of the sink. This platform is most probably the remnant of the plug formed during withdrawal of the lava column and the temporary extinction of the volcano around the year 1924.

e) **The fire-pit.**

The fire-pit is a cylinder with an elliptical section of 10 ha. The major axis is directed N 70° W and is 400 m long. The minor axis is 330 m long and trends N 10°-20° E. The W part holds a crescent-shaped lava-lake 320 m long and 160 m across in the broadest part. The lake covers a little more than 40 000 m^2. The E part of the pit is occupied by a tilted and partially broken block of solid lava covering 6 ha and is similar to the « crag » in the Halemaumau during the years 1916-1917. The sides of the fire-pit are draped by sheets of black lava and display narrow horizontal benches showing former levels of the fluctuating lake.

Sometimes big sections, measuring several thousands cubic meters, are detached from the walls and tumble into the lake where the fallen material is quickly engulfed. The fresh section thus revealed shows that the interior of the walls above the lava lake is composed of massive, red glowing material the surface of which darkens quickly through loss of heat by radiation and assumes the external aspect of solid rock. It may be pointed out that the conditions revealed inside the walls are favorable for the development of coarse crystallization and, should this semi-molten rock be broken by explosions, the ejected material would probably be identified as of plutonic origin. It is the authors' opinion that the blocks of « niligongite », defined by A. Lacroix as « ijolite leucitique » and the « leucite-kentallenites » ejected by Nyamuragira have originated in this way. The process is probably rather common and there is a definite possibility of many supposed plutonic rocks ejected by volcanoes having been formed at a depth of only some hundreds of meters.

f) **The lava lake.**

To the knowledge of the authors, Nyiragongo displays the only easily accessible permanent lava lake in the world. The lake is essentially a pasty mass of lava, covered by a thick black « skin » and kept in a molten condition by the heat of ascending gases.

In daylight, the lake appears as a flat, black to dark grey surface cut by pink to cherry red wrinkles. When a cycle of activity starts, the surface undulates slowly and fountains appear, projecting cherry-colored to bright red packages of lava. The fountaining liberates considerable amounts of steam quickly hiding the lake. Night time allows better observations.

Fountaining is the most conspicuous feature. There are two types of fountains : the « fixed emplacement » and the « travelling » types.

The « fixed emplacement » fountains, located at several points, are characterized by the escape of considerable amounts of gas throwing packages of molten lava sometimes as much as 20 m high. As soon as a fountain springs in action a streaming effect occurs in the vicinity. The black crust breaks up, forming rafts that glide towards the fountain like ice-floes on a river. When the rafts reach the turbulent zone at the foot of the fountain they are engulfed. This goes on during several minutes and the process ends abruptly. This type of fountain probably represents the apertures of deep-reaching vertical channels.

The « travelling »-type fountain is distinctly smaller, has a shorter lifetime, the amounts of gas generated are less and the stream effect in the adjacent lake is scarcely noticeable. This type of fountain probably represents the escape of local pockets of gas trapped in the mass of molten material.

One of us (A. M.) has observed and filmed several times the general flow of the lake. The sequence of events has always been the same : appearance of numerous small fountains in the N part of the lake, coalescence of several small fountains into larger ones, progressively accelerated movement towards S of the resulting fountains and of the whole adjoining strip of the lake, disappearance of the fountains, but not of the movement, appearance of a vortex in the S half of the lake with numerous small blisters and fountains, reversal of the movement, the displaced portions of the skin gliding back to the vicinity of the starting point. The horizontal amplitude of the displacement is 100-150 m. No satisfying explanation for this succession of events has been found so far.

From numerous temperature readings taken in night time with an optical pyrometer, the following average figures were obtained :

Glowing cracks of the crust	770°-800° C.
Travelling fountains	850°-870° C.
Fixed emplacements fountains	850°-900° C.

The highest reading recorded in the top of the fixed fountain was 960° C.

The constant upwelling of gas from the lower levels is the driving mechanism of the lake. In the present conditions, it seems that the same lava is stirred over and over by the escaping gases and that the lake remains at a nearly constant temperature. Here also good conditions for crystallization and growth of minerals may be found, especially as very small amounts of a particular substance carried by the gases can produce considerable enrichment of it in the stirred lava. The Nyiragongo lava lake may be compared to a giant-sized crystallization dish. This hypothesis is now developed and tested against all available evidence.

The level of the lake changes frequently, as may be seen by the benchmarks on the walls of the fire-pit. The fluctuations seem to be rather short-timed and range within narrow limits (usually less than 10 m). A major variation occurred during the year 1956. On February 20th, 1956, the level of the lake was 224 m under the upper and 44 m under the lower platform at an elevation of 3.061 m. In the beginning of June, the lake was 12 m higher, at the level of 3.073 m and in November of the same year the level dropped 35 m to the 3.038 m level. In the beginning of 1957, the level was rising.

The gases emitted by the lake and by the peripheral small cones are mostly steam with varying amounts of SO_2. Because of topographic conditions, no sampling of uncontaminated gas has been attempted. The cloud rising from the pit is mainly steam with varying amounts of SO_2. As no flames can be seen in the fountains, oxydation of the combustible fraction of gas must occur during the passage through the molten mass. Gases escaping from small cones around the crag can be seen burning in the darkness with grey, greenish or yellow flames.

g) **The crag.**

The crag is a big triangular block, 180 × 160 m, tilted 20° towards SE and surrounded by horizontal terraces. The fissure between crag and lower platform is filled by broken material and dotted with small cones. During the night, the fissure glows red showing that the crag is surrounded by molten lava. Thus the crag floats on the lake and probably grades downwards into epimagma. That the crag is independent of the lower platform was demonstrated by its behavior during the rise and fall of the lake in 1956. The crag rose 5 m while the lava lake ascended 12 m and sank 20 m while the lake sank 35 m. The crag is a part of the lower platform, broken up and tilted.

h) **Evolution of activity in historic time.**

When von Götzen climbed Nyiragongo on June 11th, 1894, he found two distinct circular vents, one of them belching steam. Judging by reports of various travellers, the volcano was permanently active during the following years. On a good photograph taken by the Swiss topographer Thevoz in 1905, two vents may be seen, distinctly elongated in an E-W direction. The thin wall separating the vents has started crumbling and from the N vent there rises a cloud of steam. Shortly before the arrival of the Duke of Mecklenburg's expedition in 1907, activity stopped, to return in the end of 1908.

On a photograph taken by H. MEYER in 1911, the S vent smokes. The activity has thus migrated and the wall between the vents is breaking down.

Activity slowed down and even disappeared during the years 1915-1916. During the interval 1912-1918, the two vents were united into one single sink, the outlines of which have not changed since. The situation in 1918 is shown on a panorama taken by M. X. DIERCKX, one of the oldest settlers in the region. The statement of HEIM [12] (p. 54) : « ... doch vom April 1927 an ereigneten sich grosse Eruptionen, wobei die beiden inneren Kraterlöcher vereinigt wurden » is incorrect. The 1918 photograph shows that neither lower platform nor crag existed at that time.

The statement of BAILEY WILLIS [50] (p. 128) : « Nina Gongo (Mother of the Congo), the great truncated cone that rolls out cumulus clouds of steam, had two vents up to 1918, when it blew its crater out » apparently originated with A. D. COMBE, whose knowledge of local conditions WILLIS drew upon during their trip in 1929. Nothing more definite is known about the formation of the pit.

Nyiragongo remained active untill the middle of 1924. It is possible that the volcano suffered temporary extinction during the second half of 1922. No activity is recorded from 1924 to the end of 1926 or to the beginning of 1927. It is most probable that the lower platform was formed at that time. The lava column must have sank very deep because witnesses deny any solfataric activity in the crater during that time. This point is important because withdrawals of lava in Hawaii have been supposed to be related to submarine eruptions. Nyiragongo demonstrates that substantial sinking of the lava column can occur without lateral outpourings at the base of the massif.

Since 1927, the volcano has remained permanently active and the situation has changed little during the last years, except for the rise and fall of lava lake and crag in 1956.

D. — THE LAVA PLAINS E AND S OF NYIRAGONGO.

The lower reaches of the Nyiragongo massif grade into long slopes leading towards the foot of the Karisimbi massif in E and towards Lake Kivu in S. These slopes are formed by a multitude of flows and are interrupted by smaller volcanoes of all sizes, from the minute spatter-cone 2 m high to satellite massifs 1-2 km in length and with heights reaching 150 m. Many cones are partly covered by younger flows coming from the Nyiragongo massif or other vents located at higher levels. In extreme cases, the crest alone emerges from the engulfing flows and one or two more flows would completely bury the old formation.

The satellite vents display a definite tendency to occur more frequently in two bands where their agglomeration has produced arcuate crests in the landscape. The first crest runs roughly from Baruta to Mikeno and is marked by the hills Nyamushwa, Guberebya, Gisi and Mushushwe. The second crest runs from Shaheru to the N end of the main E scarp of the Rift Valley, E of Goma. In both cases, individual vents frequently display an elongation roughly parallel to the direction of alignment.

The lava plain may be divided into two distinct parts :

1. The Buhumba plateau, E of Nyiragongo, is a trough limited by the two said ridges and the foot of the Karisimbi massif. The plateau has been filled to the present average level of 2.000 m by Nyiragongo flows. Some small volcanoes and isolated groups of vents are scattered across this plateau.

2. The Bukumu slope falls 550 m in 12 km from the S foot of Shaheru to the shore of Lake Kivu. The upper part of this slope is thickly studded with cones the number of which decreases at lower levels.

When crossing the passes between neighboring cones, the younger flows frequently form very steep slopes up to 30-40 m high. The alignment of several of these slopes was noticed at an early stage of the study and the suggestion was made in an unpublished report by one of the authors (Th. G. S.) that the younger flows may be covering scarps due to recent faulting. This interpretation was disproved by later mapping. This working hypothesis has been introduced into literature as an established fact by M. E. Denaeyer [5] (p. 62). The present authors do not believe any transverse faults exist in the mapped area.

NW of Baruta-Nyiragongo, the saddle joining this massif to Nyamuragira is a part of the Congo-Nile watershed. Here is one of the heaviest concentrations of eruptions in the whole region, the last one occurring in 1954. In spite of the short distance from the Nyiragongo lava lake, only 6 km horizontally, the recent and historical outflows in the saddle are petrographically quite different from the Nyiragongo lavas characterized by the absence of feldspars. The saddle flows are feldspar-bearing, viz. basanites of the kivite type similar to the bulk of the Nyamuragira lavas and the eruptions are related to the main weakness zone of the last-named volcano.

The map reproduced at the end of this paper shows the collection area of the samples described. It must be understood that this map is a provisional document, designed to locate the main units and on which all details are omitted. The definitive map will be established from shortly forthcoming aerial photographs.