VOLCANOLOGICAL OBSERVATIONS IN EAST AFRICA.

I. Oldonyo Lengai.

The 1940-41 Eruption.

By J. J. Richard.

Contents.

1. Introduction: Situation, Ascents and History of Oldonyo Lengai.
2. Preliminary Investigations of the Eruption of 1940-41.
3. Observations in the Neighbourhood of Oldonyo Lengai.
4. The Summit of Oldonyo Lengai.
5. Petrographical Notes on the Pyroclastics of the 1940-41 Eruption.
6. Literature.

1. Introduction.

Situation, Ascents and History of Oldonyo Lengai.

About 2,900 m. high, Oldonyo Lengai is situated 2° 45′ S. latitude and 35° 55′ E. longitude, just south of Lake Natron (Fig. 1.) It is the only active member of a group of volcanoes in Northern Tanganyika. This group occurs on either side, on the Western Highlands as well as on the eastern low parts, of that section of the North-South Rift-wall which stretches between Lake Natron in the north and Lake Manyara in the south (Fig 2).

The volcano, according to Barns (1923) first mentioned in the Mombasa Mission map of 1850, was ascended and its summit reached in 1904, by Jaeger (see Uhlig, 1905); in 1913, by Reck (see Reck, 1914); in 1915, by Schulze (see Reck and Schulze, 1921); in 1932, by Reck again (verbal communication from Dr. L. S. B. Leakey); and in 1941, by the writer.

Reck (Reck, 1914, Reck and Schulze, 1921; Reck, 1923; and Reck, 1924) was the first to make a serious study of the geology of Oldonyo Lengai and published a series of papers a list of which will be found at the end of this article. These papers give a valuable description of the situation at the summit which remained more or less unchanged from 1904 when Jaeger visited it to 1913, the time of Reck's first ascent, and until the 1917 eruption.

Schulze (Reck and Schulze, 1921) also wrote on the geology of Oldonyo Lengai and the surrounding cones and craters and, together with Reck, he gave an account of the 1914 and 1917 periods of activity.

The fact that Oldonyo Lengai was at times active had not escaped the notice of the travellers who had visited the neighbourhood in the past. Scholler (1904) reports that according to the natives, steam escapes from the top in the rainy season. Thomsen (1885) describes the mountain as an active volcano. Fisher (1882-83) saw smoke escaping from the summit and the natives who accompanied him spoke of stretches of fire on the flanks and rumbling noises inside the mountain. An eruption with a thunder-like noise and thick smoke seems to have taken place in 1880.

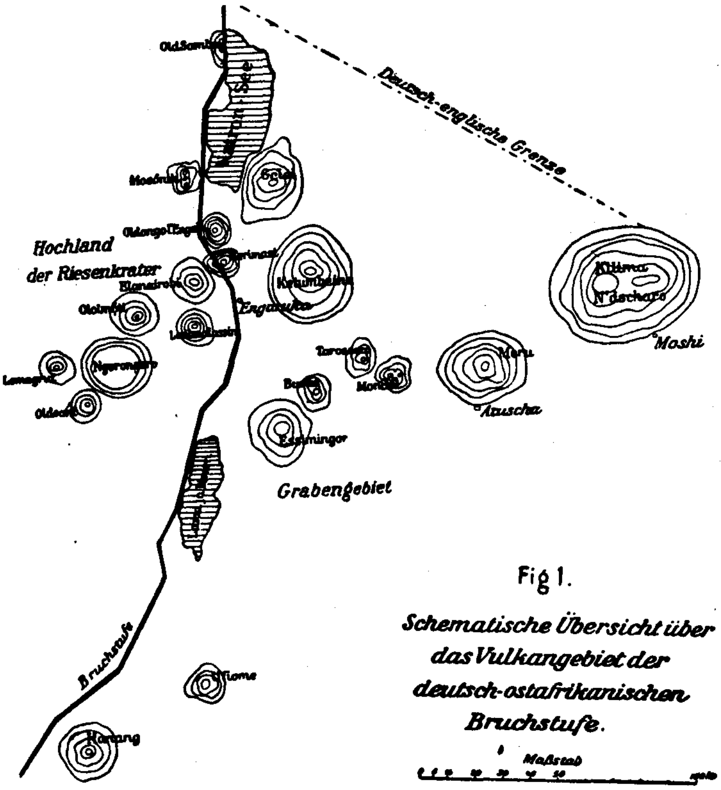

FIG. 2. *The volcanoes in the N.E. of Tanganyika East and West of the Rift wall in its section Natron-Lawa ya Mweri or Manayara lake after H. Reck's Fig. 1 in Oldonyo Lengai, Branca Festchrift, 1914.*

Schulze (loc. cit.) mentions that a lava-stream 1-2 m. thick and 100 m. broad had flowed in a southerly direction for about 200 m. from a cone 25 m. high on the top. This must have happened between December, 1913, after Reck visited the summit and April, 1915, when Schulze climbed it. Reck (1923) records further slight activity in 1915, and put the starting of a new eruption at the end of 1916.

Hobley (1918) describes the eruption of Oldonyo Lengai in January-June, 1917, as also does Reck, who mentions the reports of Verch (Reck and Schulze, 1921) who passed near the volcano shortly afterwards. This eruption is also mentioned by Gregory (1921), Barns (1923), Jaeger (1921), and by Krenkel (1922). The main features of the 1917 eruption were the disappearance through explosions of the white needle about 150 feet high, which formerly occupied the northern edge of the crater. The thick vegetation, which in 1913, made an ascent very long and difficult, was completely destroyed. The country around was covered over a radius of about 6 miles with grey and black ashes. Some of the parasitic cones on the eastern side of the mountain showed active fumaroles. Several new streams, containing warm salt-water, appeared on the north-east side, while on the south-east side a salt-water lake 1 by 2 km. extended between Oldonyo Lengai and Kerimasi. The whole mountain was white like snow owing to the sublimations of soda. The lower part of Kerimasi, the Rift-wall and land to the west were also white with soda crusts.

Barns (1921) saw Oldonyo Lengai in eruption in February, 1921.

We possess no details of the alterations which took place in the crater during this eruption or during that of 1926 mentioned in the next section and observed by Mr. Billington of Magadi.

Whilst staying at the top we were able to see roughly the results of the transformations of the last twenty-four years and we shall give a brief account of these as well as a description of the 1940-41 eruption in so far as it is possible to do so. Several months had passed since the beginning of the eruption when our visit took place.

Before going further we wish to express our gratitude to the Civil Authorities of Kenya and Tanganyika and to Dr. L. S. B. Leakey and Dr. V. G. L. van Someren for the facilities given, to Captain A. T. A. Ritchie and Mr. Hugh Copley for their assistance and to Mr. J. P. Teare, Game Warden at Arusha, Mr. Page Jones, District Officer, Masai Reserve at Monduli, and to Mr. R. R. Buckland, Engineer-in-Charge of Irrigation at Arusha for their interest and help to the expedition. A special word of thanks is due to Miss A. F. R. Hitchins for the analysis of several rock-samples, performed in the laboratories of the Geological and Mining Department, Nairobi.

2. Preliminary Investigations of the Eruption of 1940-41.

As no one had visited the summit of Lengai since the late Professor Reck climbed the mountain in 1932, the situation at the crater before the eruption is not known. No records are available about the temperature of the fumaroles or of their behaviour prior to the eruption.

Towards the end of July, 1940, Masai living east of the volcano at Londòi, noticed some rumblings and saw during the daytime, occasional puffs of smoke originating from the northern part of the summit. No big explosions, however, occurred. These phenomena must have been somewhat stronger than the occasional weak manifestations which are a feature of the volcano, for the Masai sacrificed milk and goats near the foot of the mountain, as they are accustomed to do at the time of an eruption.

On a visit which I made to Lake Magadi in December, 1940, some data about the eruption were given to me by Mr. W. H. Billington. In clear weather, the volcano, looking as if covered with snow, is clearly visible sixty miles to the south-west.

Mr. Billington, of course, did not observe the volcano regularly; but, having seen the eruption of 1926, he noticed sooner than others that there was "something going on." At the beginning of August, he saw that the volcano continued active for about two to three weeks. This period was followed by a pause lasting several days, after which it started to erupt again.

The eruption clouds showed great variations both in height and density. Sometimes they were twice the height of the volcano itself and dark in colour. During the earlier period of the eruption there seemed to be a pause of two to two-and-a-half minutes between the explosions; later the interval became longer. Sometimes a glow was seen at night and there were electric discharges in the cauliflower-like overhanging cloud. No sounds of explosions were heard.

Mr. Billington, comparing the eruption of 1940 with that of 1926, said that the latter lasted longer. Sometimes the south-west horizon was hardly distinguishable owing to the curtains of ashes which, for several weeks, were carried by the wind for a distance of a hundred miles.

On my visit to Magadi on December 10th, 1940, I saw Lengai well and it was apparently quiescent.

Interesting facts were given to me by Mr. Page Jones, District Officer, Masai Reserve, and Mr. Howe of Monduli. While on tour, eight miles east of Engaruka, about a week after the first signs of activity of Oldonyo Lengai—which were characterised by odd puffs—shortly after 10 a.m. on July 31st, a column of dark smoke appeared suddenly from the top of the volcano. This grew quickly to a black, vertical pillar which extended for over 9,000 feet above the summit, i.e., to a height of 18,000 feet. The upper part developed later into an enormous, cumulus-like cloud. The whole phenomenon looked like a gigantic pinetree. No detonations were noticed. An hour later the appearance changed somewhat; smaller eruptions occurred, followed however, by the same pinetree-like eruptions. This type of activity continued for the rest of the day and on the return of the observers in the direction of Monduli at 5 p.m., a black cloud still hung over the white rain-clouds.

Mr. Buckland was at Engaruka camp on August 28th, when the volcano was behaving somewhat differently. Dark, heavy clouds of ashes were belched from the crater and reached several thousand feet above the summit. Kerimasi, north of Engaruka, was sometimes enveloped in smoke. The plains near Engaruka and the village itself were covered with a greyish film of fine ashes. The air was hazy and irritated the throat. The noise from the volcano was like a growl, or the sound of a lorry in the distance. The east wind was transporting most of the ashes in the direction of Elanairobi, Oolmoti and further away.

His Excellency, the Governor of Tanganyika Territory, Sir Mark Young, accompanied by Mr. Page Jones, flew over the mountain on November 20th, 1940. The crater showed on its northern side a funnel-like hole, hundreds of feet deep, with smoke escaping from its deepest part.

The importance of the above observations made by those persons who from close quarters witnessed the activity of the volcano at different dates proved to be of real value afterwards. The writer, accompanied by Mr. G. Babault and his son, examined the surroundings and the volcano itself on a tour which lasted from the 11th to the 18th of January, 1941.

3. Observations in the Neighbourhood of Oldonyo Lengai.

Leaving Engaruka camp on January 12th, we motored through thorny bush, at first going in a north-easterly direction towards Kitumbene, then after ten miles of very rough going, in a northerly direction towards Gelei. Passing a few hills of volcanic origin we turned west and arrived at a Masai *manyata* called Londoi.

The volcano, as it was approached at 12 o'clock, was clear of cloud and there was no sign of activity (Plate 31, Fig. 3). According to some Masai herdsmen, there had been slight activity the day before when a small cloud had escaped from the crater. The dry grass around Londoi had been burnt in patches; but the fires had been caused by herdsmen and not by volcanic action. That fires had occurred recently was also shown by the green-coloured, lower parts of the flanks of the mountain. This green coloration merged into a more yellow and grey tint on the higher parts.

While at Engaruka the ashes had not been thicker than 1 or 2 mm., at Londoi, four miles east of the volcano, the Masai said that they had reached ankle-depth. Compared with those of Engaruka, which were very fine, the ejecta at Londoi contained more coarse sand.

Travelling west, it was clear that there, also, no grass-burning had been caused by the volcanic outburst. Where the grass looked dead, its appearance could be attributed in part to the seasonal drought and, probably also, in part to the high percentage of alkaline salts in the fallen ashes.

Whilst crossing the numerous, dry river-beds and radial ravines (Plate 33, Fig. 6) which contained sand and ashes thrown out by the volcano and washed down by the rains, a slight smell of chlorine was noticed. The sands were often covered with a thin crust of soda (? carbonate) which gave to the flanks and especially to the higher parts of the volcano, its white appearance.

By comparing the photograph taken after the 1921 eruption and after the 1940-41 eruption (Plate 32, Figs. 4 and 5), it can be seen that no great changes apart from those at the summit have taken place in the outer aspect of the volcano during the last twenty years. Though the season was at its driest and no rain had fallen to dissolve the crusts, the impression is gained that the 1940-41 eruption was not so violent as that of 1921, since the whitish deposits are less well developed.

The small volcanic cones east and south of Oldonyo Lengai were not active, as they were in 1917.

In certain places on the south side at the foot of the volcano, where the ashes had remained undisturbed, samples examined showed some interesting features. On the top of the old, fine, grey-brown, weathered ashes from previous eruptions there was a layer, one-and-a-half inches thick, of fairly coarse sand consisting of particles 0.1 inch in diameter and this was covered by a grey-blue layer, two-and-a-half inches deep, of fine ashes with a particle size of 0.004 inch. These proportions remained the same when the western side was reached; but the first, earliest layer, as one approached nearer to the foot of the volcano became thicker and contained larger material, lapilli and small scoriae mixed with coarse sand and ashes. The ashes emitted later were very fine and showed no difference from those of the same period from other sites, except in that, as the distance from the volcano increased, the ashes naturally became still finer. This constant feature together with the observations referred to in Section 2 give the strong impression that the eruption of Oldonyo Lengai of 1940-41 was composed of three different phases, as have been observed with several eruptions of volcanoes in the Netherlands East Indies and elsewhere.

On Lengai, the first or preliminary phase was characterised by occasional small explosions indicated externally by odd puffs of smoke belching from the crater. These small eruptions threw up old material from the funnel. Apart from some small showers of ashes little could be seen from a distance. This period apparently lasted from about the 24th to the 30th of July, 1940.

The second or gas-phase, with discharges sometimes assuming the form of a huge column, was characterised by explosions which threw up boulders and bombs together with sand and ashes and released great quantities of gas. The heaviest material was dropped around the actual vent which was widened and swept clear of accumulated material. During this phase of volcanic activity the climax of the eruption was reached and the coarser deposits mentioned accumulated, their aspect depending on the strength of the explosions, the distance covered by the ejecta and the direction of the wind. This period, according to the observations of Messrs. Page Jones and Howe, probably started on July 31st, and although we do not know how long it lasted, it may well have carried on for one or two weeks. It is not improbable that the change from one to another phase of activity, after two weeks of heavy eruption, was taken at Magadi, sixty miles away, for a complete cessation of activity.

The third or ash-phase did not throw up material to so great a height as did the second phase and the ejecta consisted in the main of large quantities of fine ashes. This formed the final stage which persisted, on a reduced scale, until the time of my visit to the volcano in January, 1941.

These three phases, first clearly observed by Perret (1924) during the 1906 eruption of Vesuvius and later described from other volcanoes by Neumann van Padang (1931), Richard (1935), have their origin in the differences in composition of the underlying magma. The first phase, is characterised mainly by the ejection of already crystallised magma with material and debris that has collected in the upper parts of the crater. In its second phase, the eruption liberates a physically-different magma in which great quantities of gas are accumulated, whilst in the third, the lower, normal magma occurs.

The more one proceeded to the west, the more obvious it became that most of the finer material had been blown WNW, W and SW by the wind. For many miles the escarpment nearby and the hills north and east of Elanairobi were still white with deposits covering the ashes. Sixty miles away, at Oldeani, which I passed a few days later, according to the District Officer, a blue film of ashes with a salty taste covered the ground on about 18th of August, 1940. At Ngorongoro camp it had reached about a quarter of an inch in thickness. Several people, where heavy falls of ashes had occurred, spoke of the blighting of their crops or the withering of young maize and vegetables. The damage, however, was not very severe and disappeared with the first showers of rain.

Nearer to the volcano, especially on the western side, the grazing was completely ruined by the alkaline ashes and the Masai cattle were badly affected. The waterholes were spoiled and large areas of grass having been rendered useless, the district had to be abandoned by its inhabitants. It was also free from game for several months.

I was told by Mr. Page Jones that the situation was very bad at Engamat, south of Elanairobi and that the Masai cattle had to be moved elsewhere. On one of the forced treks an old woman got lost and probably died.

Gelei cattle, east of Lengai, showed patches of discolouration in the coat and on a visit to Ol Balbal and Oldoway, where I could still collect ashes from beneath sheltering rocks, an old Masai showed me some of his cattle which had lost their hair through the action of the alkaline ashes. Falls of ashes were reported from as far away as the Loliondo track on the Serengeti plains, a distance of sixty miles.

4. The Summit of Oldonyo Lengai.

The last camp was established at the foot of a few small craters on the south-west side. In order to minimise the final struggle, a camp higher up on the flanks of the mountain would have been advisable; but we were unable to persuade our Engaruka porters to go any higher with their loads. They believe that evil spirits inhabit the volcano.

On the morning of January 17th, we crossed a large ravine (Fig. 7) cutting through an old adventive crater half-filled with debris. Some interesting incrustations were seen; deposits of nearly pure sodium carbonate in holes, probably brought there by water containing the salt in strong solution and a jelly of yellowish, colloidal sodium silicate, which dried out as brown crusts, from some cracks on the side of the ravine. The few dead tree-trunks which we passed were all that remained of some forest which was destroyed in the great eruption of 1917.

To ascend the volcano, one has to proceed as far as possible to the west in order to avoid the numerous, radial erosion gullies and to leave on one's right the brownish, overhanging rocks at a height of approximately 5,000 feet. The fairly steep western slope was covered by the well-known white incrustations and had it not been for the black foot-prints it would have resembled snow. On the towering slope of the cone near the top, the surface had to be broken with an ice-axe step by step to avoid slipping. The view extended wider and wider as the numerous "barrancos" in the west with their complicated erosion labyrinths (Fig. 12) sank deeper and deeper. Lake Natron, in the north, showed blue, green and red-coloured patches. These colours are also observed at times on Lake

Magadi and are due, I was told, to algae which appear as the result of variations in the soda content of the water.

Whilst taking a short rest on a small ridge, which had to be dug in the hardened ashes, suddenly from what seemed to be a lower level on the north side, a brown puff of smoke appeared, proof that the top was not far off.

After four-and-a-half hours' climbing, at 12-15 p.m., we arrived at a spot west of the old crater and a few minutes later the summit itself was reached. It is situated on a hill of ejecta running roughly ENE to WSW, between the old SSE and the young NNW crater. This ridge, which in 1913 did not exceed a few feet, according to Reck's (1924) photographs taken at the time and Schulze's (Reck and Schulze, 1921) profiles of 1917, became higher after the 1917, 1921, 1926 and 1940-41 eruptions through the accumulation of material ejected by the actual working crater. It forms the highest point on Oldonyo Lengai and has increased the height of 2,878 m. given by the maps, by at least 20 m.*

The old crater to the south (Fig. 14) showed a flat bottom measuring approximately 1,200 feet from ENE to WSW and approximately 600 from north to south. The south rim, approximately 90 feet high, at its highest part shows ripple marks due to aeolian action. This crater, of which no working has been recorded, had nearly the same aspect when Reck visited the volcano in 1913. It is slowly filling with material from the northern crater, as well as with mud from the hill, 300 feet high, separating the two craters. This hill showed on its south side several gulches left behind by small mud-streams. These were covered with white crusts which were found to consist of ashes underneath (Figs. 15 and 16).

The south crater, especially its south and south-west parts, was marked with impact-holes (Fig. 14) caused by boulders and bombs thrown up to a great height by the explosions from the northern crater. Most of the bombs were entirely buried forming small craters some with a diameter of over 7 feet (Fig. 17). Some of the boulders must have weighed about half a ton (Fig. 18). The big ejecta, the majority of which were thrown out during the second or gas-phase, were covered by ashes from the third and formed a large bomb-field. The large amount of decomposed material, destroyed by the action of gas and the weather after it had been thrown out, was characteristic of this field.

In the south-east part of the slope separating the two craters there was another fairly large bomb-field (Fig. 13) with thousands of bombs and fragments of boulders. In contrast to those of the first-mentioned field, the ejecta were not buried,

*The anaeroid barometer taken with me did not function, hence all heights given in the paper are approximate only.

belonged to a later period and contained much fresher material. I shall return later to the origin of these two fields.

After climbing the middle ridge, one had a good view to the north of the working crater which was about 800 feet wide (Fig. 19). In a northerly direction there was first a fairly steep slope of about 65° consisting of tuffs from the new crater. This was followed by a 90° wall, built up partly of ejecta from the old south crater and partly of those from the north crater. The second slope was followed by a third small slope of 25° and this, in turn, by a fourth which had an angle of between 15° and 20° and led to the actual working crater. This fourth terrace was demarcated on the east, south and west by a large crack and its surface was broken by a series of smaller cracks running east to west showing that it consisted of loose material.

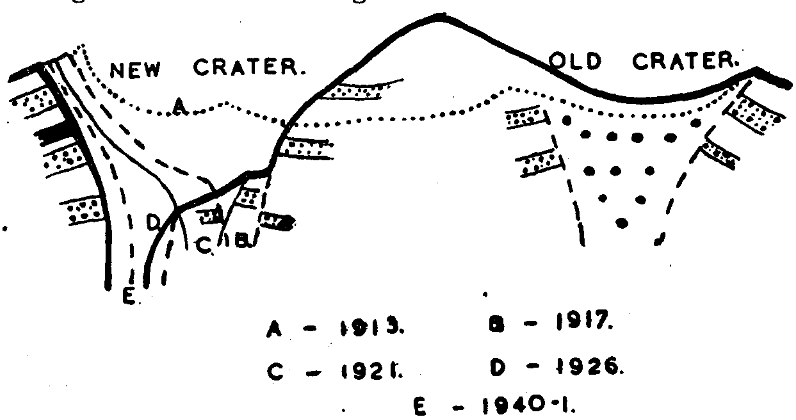

FIG. 20.

The terraces with different angles of slope show clearly how, since 1917, the eruption points or vents have proceeded successively in a north to north-westerly direction (Fig. 20). The fourth and last slope is due to the filling up of the former 1917 and 1921 craters by the accumulation of debris.

The northern edge of the wall of the crater reached approximately 300 feet above the bottom of the last terrace. The large crack, to which reference has been made, was visible on the east and west of the wall. It climbed up in a northerly direction and at two places joined the upper rim. This crack showed that subsidence of the crater after the ejection of huge quantities of material had occurred, the deepening of the eruption vent having undermined the foundations of the crater. Some white vapours were escaping from the crack on the east side.

The northern wall of the crater was formed principally of tuffs; but in one part at about two-thirds of its height the remains of an old lava-stream were seen. On the west side the rim consisted of rough, grey stalactitic material, probably soda crusts.

No living vegetation was seen although on the inner, north slope of the middle ridge there were patches of dried grass where the slope was so steep that the loose 1940-41 deposits could not stay. The heat from the crater was not, therefore, great enough to burn this grass even during the strongest eruption period. The so-called "fire columns" seen at night were probably due to the reflection in the eruption cloud of lava glowing at the bottom of the vent.

The active crater was a funnel-shaped vent, about 300 feet deep and 100 feet wide, with a pit at the bottom in an eccentric position. Fumes escaped slowly with a noise like that of a strong wind in trees.

Some interesting facts concerning the two bomb-fields were obtained. The west and north slopes of the volcano, in contrast to the south, south-west and south-east showed practically no heavy ejecta. It was also clear that the course followed by the bombs, south, south-west and south-east was independent of the main drift of the ashes which had been pushed in a westerly direction by the prevailing wind.

The position of the pit to the north of the bottom of the vent, instead of at its centre, explained the situation of the bomb-fields as well as the distribution of the larger ejecta. The eccentric explosion pit being close under the northern wall, the explosion products, owing to the resistance offered to the expanding gases, had been directed in a southerly direction. Reference to Figs. 8 and 19 will show that the north wall is nearly vertical for about 600 feet in contrast to the opposite wall which ends approximately 300 feet lower. The ejecta could only pass the south rim at a projection angle of between 70° and 90°. With an angle approaching 90° they would fall back into the crater; but if forming a parabola with an angle of, for example, 70° or 80° and if endowed with sufficient initial velocity, the projectiles could cover a horizontal distance of 2,000 feet from the explosion pit to produce the SSW field. It has already been made clear that this field was probably formed when the volcanic activity was at its climax during the second phase of the eruption.

The SE field probably originated later, when the activity was decreasing and the initial velocity had become smaller. Its centre is only just over 1,000 feet in horizontal distance from the crater. It is not impossible that the explosion pit was shifted during the eruption so that the boulders and bombs took a south-easterly direction. The scattered aspect of both fields is easy to understand since, between 70° and 80° or over, many projection angles are possible and probable.

Even if one knows the projection angle, it is practically impossible in ballistics to construct the parabola of a projectile without knowing its initial velocity. It is equally impossible to determine the highest point of the trajectory. For the bomb-fields of Lengai, however, it is probable that some of the ejecta reached a height of between 2,000 feet and 4,000 feet.

While standing on the middle ridge at 2-50 p.m. on the 17th, a small eruption occurred, followed a few seconds later by the appearance of a grey cloud which went up fairly quickly to 600 feet. At 3-04 p.m., accompanied by a terrific noise as of crashing trees, a second eruption took place (Plate 33, Fig. 8). It came from a deep level, for it was ten seconds before brownish smoke was seen. The explosion level of this second explosion must have been approximately 300 feet deep as the smoke took a further ten seconds to reach the upper edge of the crater on its northern side. The edge soon became invisible. A strong smell of sulphur came over and ashes 0.1 to 0.5 mm. in diameter fell on the paper on which I was writing three minutes after the explosion occurred.

These two explosions, with another following when I was back at the camp, showed that the volcano was still active. No temperatures could be taken and no analyses of gases could be made under the circumstances. They will have to be postponed until a later date when the fumarolic stage has again been reached.

5. Petrographical Notes on the Pyroclastics of the 1940-41 Eruption.

The time spent in the neighbourhood of Oldonyo Lengai was too short to allow of the collection of enough material to enable a detailed classification of the successive rocks which took part in the building up of the volcano to be given here. The supposition that some differentiation has taken place in the composition of the rocks is confirmed, for example, by the tuffs of different colour that occur in the deep eastern valley facing Londoi: the yellowish tuffs and brecciae belong to an older series, while the grey tuffs are characteristic of a later date. Further indications of variability are found in the layers of some of the adventive craters around the volcano. For example, in a small crater south of Lengai, tuffs rich in biotite can be seen under the previously-mentioned grey and yellow tuffs and above an old steppe formation of calcite in concretionary nodules.

Furthermore some metamorphic material found in the layers of ash in the river-beds that one crosses, give evidence that the volcano in its earlier eruptions had to break through formations of older origin.

The specimens brought back are divided into four groups:

(1) Essential ejecta of the 1940-41 eruption: L6a, L7, L9 and L11.
(2) Accidental ejecta: L6b, L12 and L15.
(3) Accessory ejecta: L4, L10, L13 and L14 with two specimens of an older eruption: L16 and L17.
(4) Other secondary products formed later through outside circumstances: L1, L2, L3 and L8.

(1) *The Essential Ejecta.*

These consist of fresh lava boulders and bomb-fragments thrown up mostly during the second and third phases of the eruption.

Macroscopically the rocks are grey in colour, with a medium-grained structure, porphyritic. Nepheline in grains up to 3 mm. in size is visible to the naked eye together with occasional prisms, of which some reach 4 to 5 mm. in length, of pyroxene. This latter mineral, of black colour in the rock, varies from pale to dark-green in thin splinters. When altered the rock shows a whitish, powdery surface similar to that of L10.

Under the microscope, L9 and L11 are very similar and may be described together. The major constituents are nepheline, pyroxene and some magnetite. Pyroxene, although not the most conspicuous mineral in these lavas, forms large phenocrysts, evidently crystallised before the nepheline. The crystals are mostly idiomorphic, of large rectangular size and frequently show confused, fringed, terminal portions. The pyroxene, grass-green in colour and sometimes darker near the margin or of zonary structure, is a sodiferous augite, approaching to monoclinic aegirine. The angle of extinction is as low as 15°. In sections perpendicular to the axes the optic sign is negative.

Nepheline occurs in numerous, large rectangular and small hexagonal or square idiomorphic or hypidiomorphic sections. The mineral is uniaxial and shows a positive sign in perpendicular sections. The nepheline often contains inclusions of minute needles and crystals of aegirine-augite.

The matrix is composed mostly of idiomorphic nepheline with some augite microlithes. Grains of magnetite are scattered throughout the slide and occur as a fine dust in the matrix. In L9 some microlites of sanidine, arranged like a fan, occur in the matrix, while in L11 some of the smaller hexagonal sections of nepheline show a corona of kataphorite.

L6, a lapilli of the second phase of the eruption is much altered and contains corroded crystals and vesicular holes. The nepheline when showing zonary structure in hexagonal sections, is often dark or even opaque under crossed nicols. Non-pleochroic and colourless augite, occurs in biaxial laths, 2 mm. long, with aegirine.

The ashes of the first and second phases of the eruption are not mentioned here for obvious reasons: (*a*) they cannot give a true picture of the composition of the magma as they are not of juvenile but of composite origin, belonging as they do to a mixture of pulverised old rocks and debris thrown up by the volcanic explosions, (*b*) transported in the eruption cloud for variable distances, they were liable to rapid weathering.

L7, was taken from the fine ash-layer of the third period. It was covered with the characteristic, slightly protective white crust to which we shall return later. These ash-deposits show less important alterations as the greater part of them was formed well towards the dry season. L7 has the same constituents as L9 and L11, but seems to contain more isotropic glass.

L6a, L7, L9 and L11 are all nephelinites.

Two analyses from the essential ejecta are quoted here. They were made by Miss A. F. R. Hitchins, B.Sc., A.I.C., Chemist and Assayer of the Mining and Geological Department, Nairobi.

	L7 %	L11 %
SiO_2	39.66	42.44
TiO_2	2.01	2.15
Al_2O_3	11.49	12.20
Fe_2O_3	6.70	6.33
FeO	3.56	3.14
MnO	.33	.34
CaO	17.54	10.73
MgO	1.90	1.03
K_2O	3.52	5.19
Na_2O	7.84	14.24
P_2O_5	1.03	.60
CO_2	2.54	.50
S	.28	.—
F	.43	.28
Water below 110° C. ...	1.31	.46
Water above 110° C. ...	.30	.19
	110.44	99.82
Less O_2 equiv. to Fluorine	.18	.12
	100.26	99.70
Less O_2 equiv. to Sulphur	.12	.—
	100.14	99.70

Norms according to Niggli.

	L7 %	L11 %
si ...	85.5	94.4
al ...	14.4	15.8
fm ..	23.9	20.4
c ...	40.4	25.6
alk .	21.1	38.—
k ...	0.22	0.14
mg ..	0.46	0.16
ti ...	3	3
p ...	0.9	0.4
qz ...	—98	—157

Nephelinites have been described not only from several places in East Africa, but also from other localities in and outside Africa. Some analyses of similar rocks follow for comparison below:

Analysis No.	1.	2.	3.	4.	5.	6.
SiO_2	43.59	43.47	38.80	40.45	41.18	43.17
TiO_2	2.71	2.52	4.30	3.21	4.04	—.
Al_2O_3	15.07	12.60	14.22	17.32	12.40	15.24
Fe_2O_3	6.96	9.85	7.28	7.25	7.47	7.61
FeO	4.54	3.53	6.34	4.—	6.89	2.67
MnO	0.25	1.74	0.14	0.08	0.35	—.
CaO	10.53	11.96	12.35	11.78	11.69	10.63
MgO	3.51	4.11	5.65	4.43	5.15	5.81
K_2O	3.87	1.74	2.19	3.78	.48	4.07
Na_2O	6.03	3.25	5.—	5.99	6.59	5.68
P_2O_5	.62	1.04	.72	.71	.97	—.
CO_2				.15		
Water below ...	2.57	4.14	1.80	1.18	2.75	3.57
Water above 105			1.40			
	100.25	99.62	100.19	100.31	99.96	99.39

(Analysis No 1.—Nephelinite, SW part of the caldera-rim Mount Elgon, from Odman, 1930.)

(Analysis No. 2.—Nephelinite, Fort Ternan, Kenya, from Goldschlag, 1912.)

(Analysis No. 3.—Nephelinite "augitite," west of Ngong Bazaar, Kenya, from Smith, 1931.)

(Analysis No. 4.—Nephelinite, Etinde Volcano, Cameroons, from Wolff, *a.*)

(Analysis No. 5.—Nephelinite tephrite, Lyngemarkenfjoldes, Godhaven Disco, Greenland, from Wolff, *b.*)

(Analysis No. 6.—Theralite, Martinsdale, Crazy Mountains, Montana, from Rheinisch.)

Generally speaking, when SiO_2 decreases in a magma, Al_2O_3 and Na_2O also decrease, while Fe_2O_3+FeO, MgO and CaO increase. For the Lengai rocks we see with a low SiO_2 content a rather low MgO and an abnormally high Na_2O and K_2O content, while Al_2O_3, Fe_2O_3+FeO and CaO show about the normal percentages for igneous rocks low in silica. The rocks are undoubtedly affiliated to the alkali-rich magmas between nepheline syenite and alkaline gabbros, foyaite or theralite. With regard to some singularities in their composition (high Na_2O, low MgO, etc.), we may suspect that the magma of Oldonyo Lengai has been influenced locally by contact with older formations, which have resulted in assimilation; but, so long as we have no stratigraphic information we cannot draw further conclusions. A study of the nearby Rift-wall and more petrographic data of the constituent rocks of the surrounding volcanos will perhaps give a key to solve the problem.

The low silica content associates the Lengai lavas with the basic magmas, typical for some of the offshoots belonging to the great Atlantic volcanic chain.

(2). *Accidental Ejecta.*

L6b, which was brought up together with L6a, shows under the microscope an altogether different structure and approaches to phonolite with ophitic structure.

Macroscopically L12 is a grey, medium-grained rock showing crystals of felspar up to 5 mm. in size, together with pyroxene and agglomerates of biotite. Some isolated plates of the latter attain the very large size of over two inches.

L15 is a whitish rock of fine texture with some grey-green parts containing dark grains of indistinct, non-crystalline form.

Seen under the microscope, L12 and L15 are both holocrystalline rocks, M12 being melanocratic in contrast to L15 which is hololeucratic, or composed almost entirely of white minerals. The structure of L15 is partly granular, partly of intersertal fabric.

Pleochroic, idiomorphic pyroxene forms the major constituent of L12. Many augite crystals show a dark edge of aegirine, biaxial and negative. Some amphibole seems to be present: also nepheline and plagioclase anorthose. A feature of the augite is the inclusion of a dust of magnetite or limonite disposed in zones. Biotite is sometimes massed around some of the pyroxene or forms inter-stratified colonies in small irregular grains with highly bi-refringent, monoclinic pyroxene.

The mineral content of the rock and the fact that there is no matrix (deep origin) associate L12 with the rock family of nephelinitic gabbros.

L15, as already mentioned, consists mainly of light-coloured minerals. The lamellar felspar shows Carlsbad twinning and is sanidine, a variety of felspar orthose. The sanidin is sometimes idiomorphic or in grains with indistinct crystalline outline, often shows corrosion and contains minute inclusions. Small masses of highly-bi-refringent zircon, scaly chlorite and some greenish, lamellar serpentine occur in the slide.

L15, with its alkaline felspar, although it has not quite its appearance is a digested gneiss.

(3) *Accessory Ejecta.*

During the first and second phases of the eruption, the quantity of accessory ejecta was overwhelming. The altered rocks L4, L10, L13 and L14 belong to the western field of boulders and bombs.

L4 is a powdery product from boulders which at the time of the eruption were thrown out in a solid condition, but which weathered rapidly afterwards into a brownish powder. Under the microscope the greater part consists of intricated, light-coloured, crystalline aggregates. The aggregates appear to be partly soluble in water and form, after evaporation of the latter, fan- and feather-shaped needles of, probably, sodium sesqui-carbonate. There is about 12% of the oxide of iron Fe_3O_4 as dark-brown granules which are attracted by a magnet.

Mr. J. A. Stevens of Magadi made an exploratory analysis of L4. It contains, among other constituents, the following:—

Fe_2O_3	11.99%
CaO	6.82
MgO	0.38
Na_2CO_3	40.
Na_2SO_4	5.4
K	0.37
SiO_2	0.16

L10 is a rock which was formerly grey in colour like the ordinary ejecta, L9 and L11; but of which the nepheline has become much altered and converted to a soda-rich white powder showing, under the microscope, the same aggregates as in L4.

L13, taken from a large block, of which several were encountered, especially in the western field of ejecta, is a whitish-grey, soda-containing mud with some altered nepheline. These blocks of mud showed, after drying out, a multitude of cracks in their outer shell and fell to pieces when tapped gently with a hammer.

L14 was taken from another large bomb (Fig. 18) of salty taste and conchoidal fracture. It consists mainly of semi-transparent minerals. Under the microscope there appear to be some large, non-pleochroic, highly bi-refringent crystals of bi-axial, negative anorthoclase in addition to quartz and magnetite. Around the magnetite small collections of interstitial needles with low bi-refringency of, possibly, anorthite are constantly found. In sections the quartz reveals uniaxial structure with low bi-refringency parallel to the optic axis. It shows undulating extinction like crushed quartz sometimes does in gneiss.

The rocks L10, L13 and L14 have been analysed for K_2O and Na_2O by Miss A. F. R. Hitchins with the following results:—

	K_2O			Na_2O		
	Insoluble fraction.	Soluble fraction.	Total.	Insoluble fraction.	Soluble fraction.	Total.
L10 ...	2.20	2.72	4.97	6.53	17.79	24.32
L13 ...	4.18	1.15	5.33	12.24	12.45	24.69
L14 ...	2.75	0.41	3.16	11.39	4.67	16.06

L10 and L13 are obviously much richer in Na_20 than the normal magma L7 and L11 with 7.84% and 14.24% respectively.

This high content of Na_20 does not indicate necessarily that these are exceptional eruptive rocks or juvenile deposits of soda. The soda may have been derived from the silicate in the ordinary soda-bearing rocks. The rocks had accumulated for a long time in the crater before the last eruption took place, or forming part of the northern wall, which as we have seen was partly blown away when the eruption vent shifted northwards, were slowly decomposed by hydrothermal action. Volcanic gases like $C0_2$ could combine with the Na ions to form sodium carbonate in the upper parts of the volcano. The highly-soluble salts were washed along cracks or fumarole channels to form accumulations rich in Na (L4 ?). If the ions Cl or $S0_4$, which are common in fumarole incrustations and hot springs came into contact with this solution chlorides or sulphates, etc., would be formed. The phenomena are probably complex and more data on temperatures, pressure and analyses of gases will be necessary to solve the problem.

The rock specimens L16 and L17 although they do not belong to the latest eruption, are mentioned here. Both specimens are grey-greenish rocks which show, in addition to phenocrysts of nepheline, numbers of dark laths of pyroxene. Microscopically some of the pyroxene, in transverse and longitudinal sections, has a grass-green to brownish colour. In thin sections the two terminal portions are often perpendicular to each other (87°). The extinctions of the plates fluctuate between 4° and 45°, indicating the presence of augite, aegirine-augite and aegirine. In addition to pyroxene there is also some hypersthene showing extinction of about 0°, and with negative optic sign. Amphibole prisms showing extinction of between 10° and 16° are numerous in L17.

The ground mass of L16 contains many grains of non-pleochroic pyroxene and is dotted with magnetite, whilst L17 shows a more glassy matrix in which are numerous dark-green crystals of aegirine-augite and hypersthene. In contrast to L9, L11, etc., nepheline is much less prominent.

Both L16 and L17 are nephelinite-augitites rich in iron. Augitites from Ngong, containing about 13% ferrous and ferric oxides have been quoted from Campbell Smith (Analysis No. 3, page 103).

(4) *Secondary Products.*

L1 was found between some layers of ashes in the western ravine at the foot of the volcano. The incrustations occurred as round cakes of yellowish and whitish colour or grey where ashes of the eruption adhered to them. They are composed of accumulations of crystalline soda, obviously deposited by infiltration of water and are entirely soluble.

L8, another grey crust, consists of ashes cemented together by soda carbonate.

L2 is a jelly-like product, already mentioned in Section 4, page ..., which was flowing out from cracks in the side of the same ravine. It was identified by Mr. Stevens as a gel of sodium silicate. Unlike L1 and L3 it has the appearance, when dry under the microscope, of non-crystalline aggregates or concretions of transparent or light-grey matter with dendritic or arborescent form.

L3, the white crust giving to Oldonyo Lengai and its surroundings their well-known white colour, is merely a white film which cannot be collected without the underlying matter to which it adheres. Mr. Stevens kindly made a preliminary analysis of these crusts collected from ashes on the top of the volcano. While $Si0_2$ with 34.60%, Al_20_3, Fe_20_3 and Fe0 with a total of 20.70% and Ca0 with 17.25% have percentages similar to those found in L7 the alkaline constituents were apportioned as follows: Na_2C0_3, 8.8%; NaF, 0.15%; NaCl, 0.69%; Na_2S0_4, 0.76%; giving a total of 10.20%.

6. Literature.

Barns, T. A., 1921. *Geographical Journal,* **58,** 401-416.

Barns, T. A., 1923. Across the Great Craterland to the Congo. London.

Fischer, 1882. Reise im Masailand, 1882/83. Mitt. d. Geogr. Ges. Hamburg. 85-87.

Goldschlag, M., 1912. Beitrage zur Kenntnis der Geol. und Petrogr. Ost Afrikas. II. Central Blatt. Min. 586.

Gregory, 1921. The Rift Valleys and Geology of East Africa. London.

Hobley, C. W., 1918. This *Journal,* **6,** 339-342.

Jaeger, 1921. Zeitschr. d. Ges. f. Erdk. zu Berlin. 277-278.

Krenkel, E., 1922. Die Bruchzonen Afrikas. Berlin.

Neumann van Padang, M., 1931. Die Beziehungen zwischen Anfang und grosster Kraftentfalt ung eines Vulk. Ausbruches. 6e. Nederl. Ind. Natuurwetensch. Congres. Sept., 1931. Bandoeng. 670-679.

Odman, O., 1930. Volcanic Rocks of Mt. Elgon in British East Africa. Geologiska Foreningens i Stockholm Forhandlingar. **52,** 485.

Perret, F. A., 1924. The Vesuvius Eruption of 1906. Study of a Volcanic Cycle. Carnegie Institute of Washington. Publ. 339.

Reck, **H.**, **1914.** Oldonyo l'Engai ein tatiger Vulkan in Gebiete der Deutsch Ostafr. Bruchstufe. Branca Festschrift.

Reck, H., und Schulze, G., 1921. Ein beitrag zur kenntnis des Baues und der jungsten Veranderungen des l'Engai Vulkans im nordlichen Deutsch-Ostafrika. *Zeitschrift f. Vulkan,* **6**, 47-72.

Reck, H., 1923. Uber den Ausbruch des Oldonyo l'Engai in Deutsch-Ostafrika im Jahre, 1917. *ibid,* 7, 55-57.

Reck, H., 1924. L'Engai Bilder. *ibid,* **8**, 172-174.

Rheinisch, R. Petrograf. Practicum II. No. 1. 93.

Richard, J. J., 1935. Enkele Aanteekeningen omtrent den Gg. Raoeng op Java. IV. Eruptieverloop. *Leidsche Geologische Mededeelingen,* **7**, 23.

Schöller, M., 1904. *Equatorialafrika,* **1**, 184, 185 and 191.

Smith, Campbell, 1931. *J. Geol. Soc.*, London, **87**, 212-258.

Thomson, J., 1885. *Durch Masailand,* **2**, 148.

Wolff, F. (*a*) *Der Vulkanismus,* **2**, 2 Teil 1 Liefer. 1104. No. 6. (*b*) *ibid*. 932. No. 8.

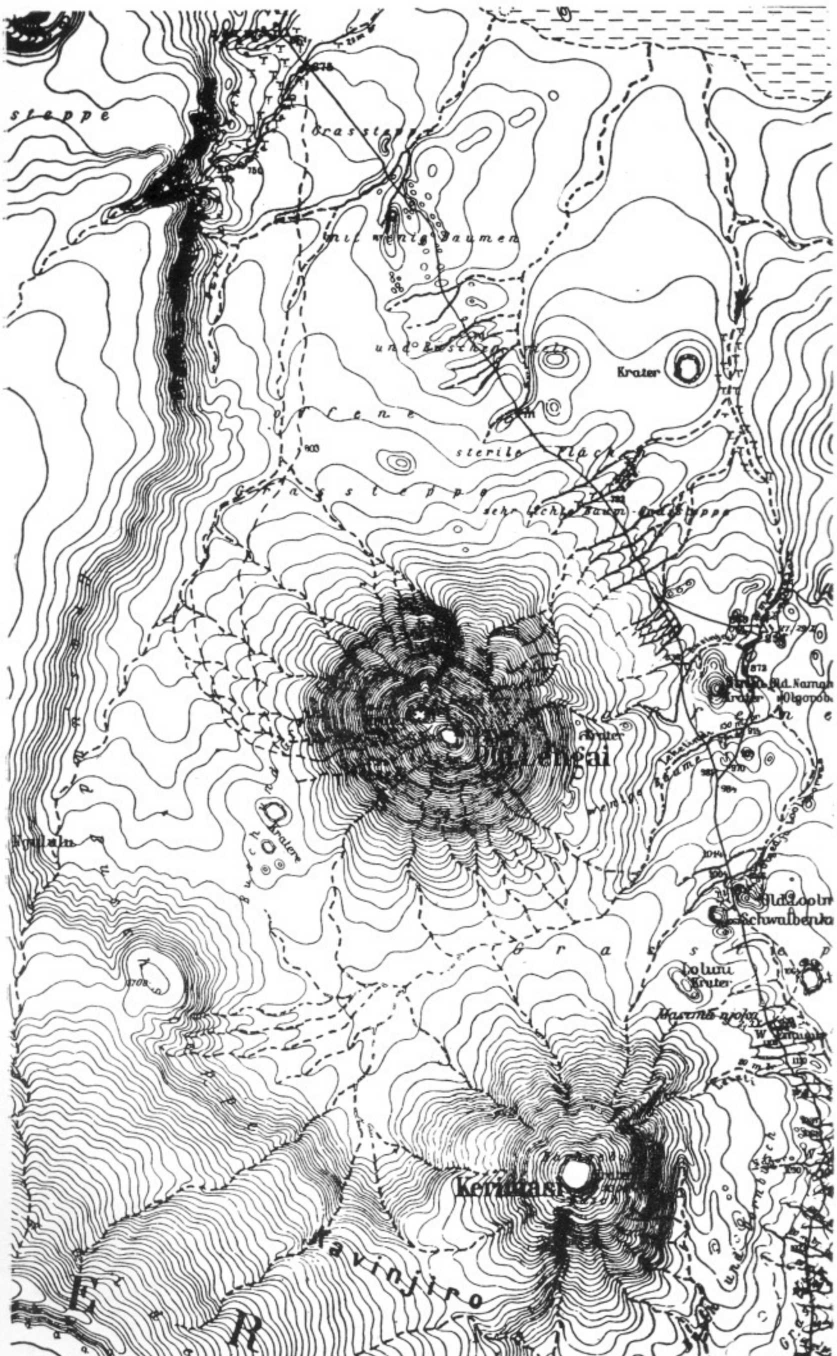

FIG. 1. *Map showing Oldonyo Lengai and Kerimasi (after C. Uhlig's map "Die Ostafrikanische Bruchstufe von 1° 40′ to 4° S. lat.")*

PLATE 31.

FIG. 3. *Oldonyo Lengai seen from the east side at Londoi.*

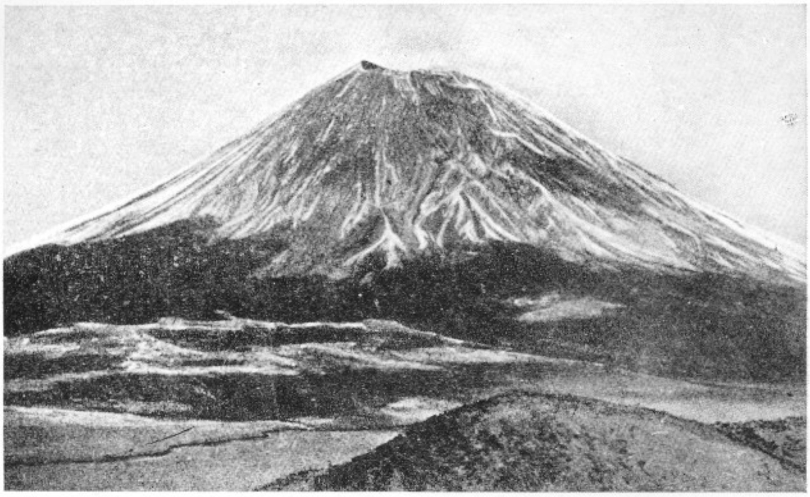

FIG. 4. *Oldonyo Lengai as seen from Kerimasi saddle after the eruption of 1921.*

Photo: BARNS.

FIG. 5. *Oldonyo Lengai seen from the valley between Kerimasi and Lengai, January, 1941.*

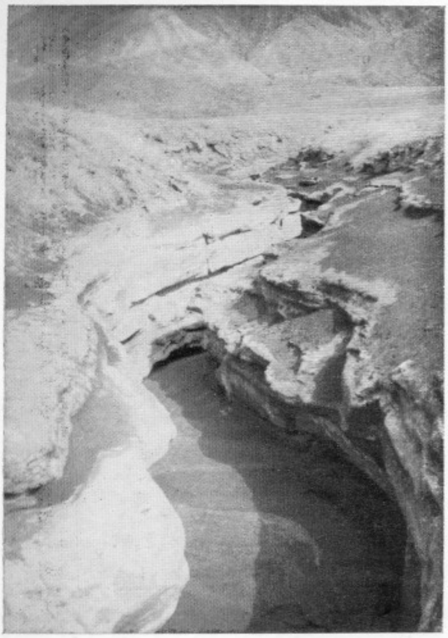

FIG. 6. *Radial ravine on the south side of the volcano.*

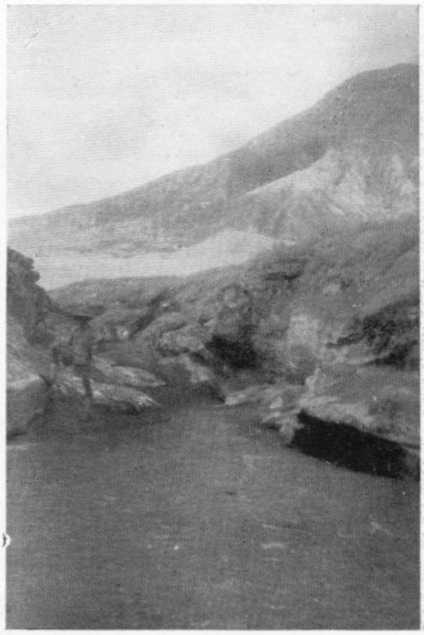

FIG. 7. *The ravine between Lengai and the south-western parasitic crater.*

FIG. 8. *The small eruption of 3-04 p.m., 17th January, 1941.*

PLATE 34.

FIG. 9. *Oldonyo Lengai from the south.*

PLATE 35.

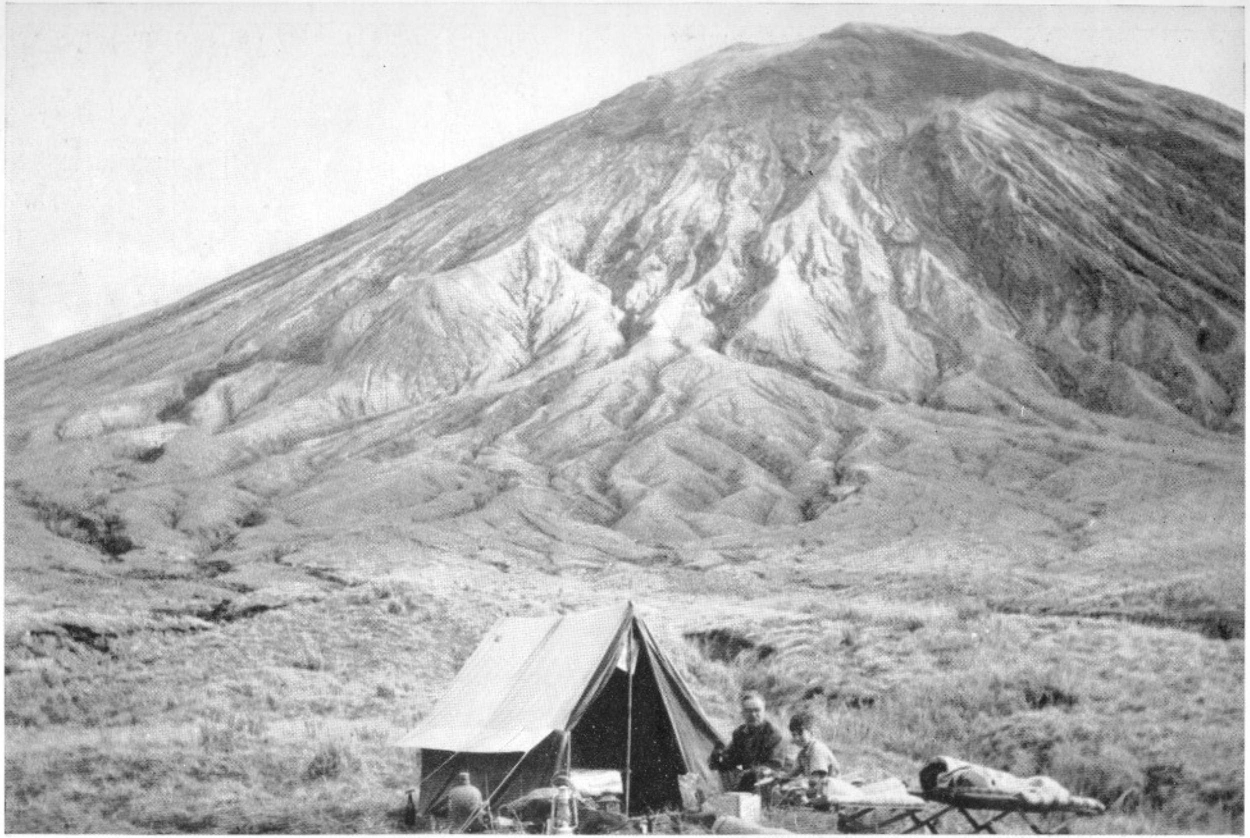

FIG. 10. *Camp on the S.W. side*

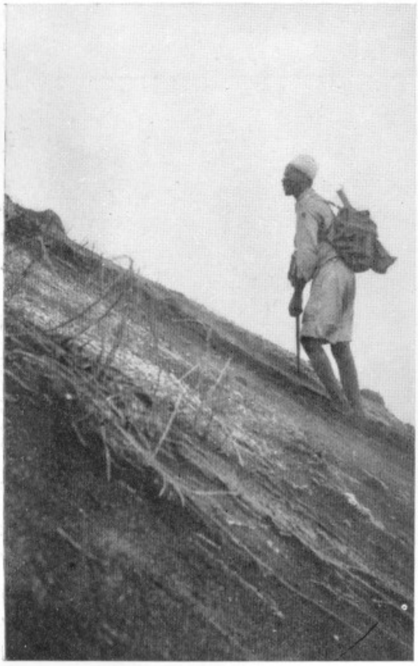

FIG. 11. *Remnants of vegetation about halfway to the top.*

FIG. 12. *Erosion on the west foot of Oldonyo Lengai.*

FIG. 13. *The eastern bomb-field.*

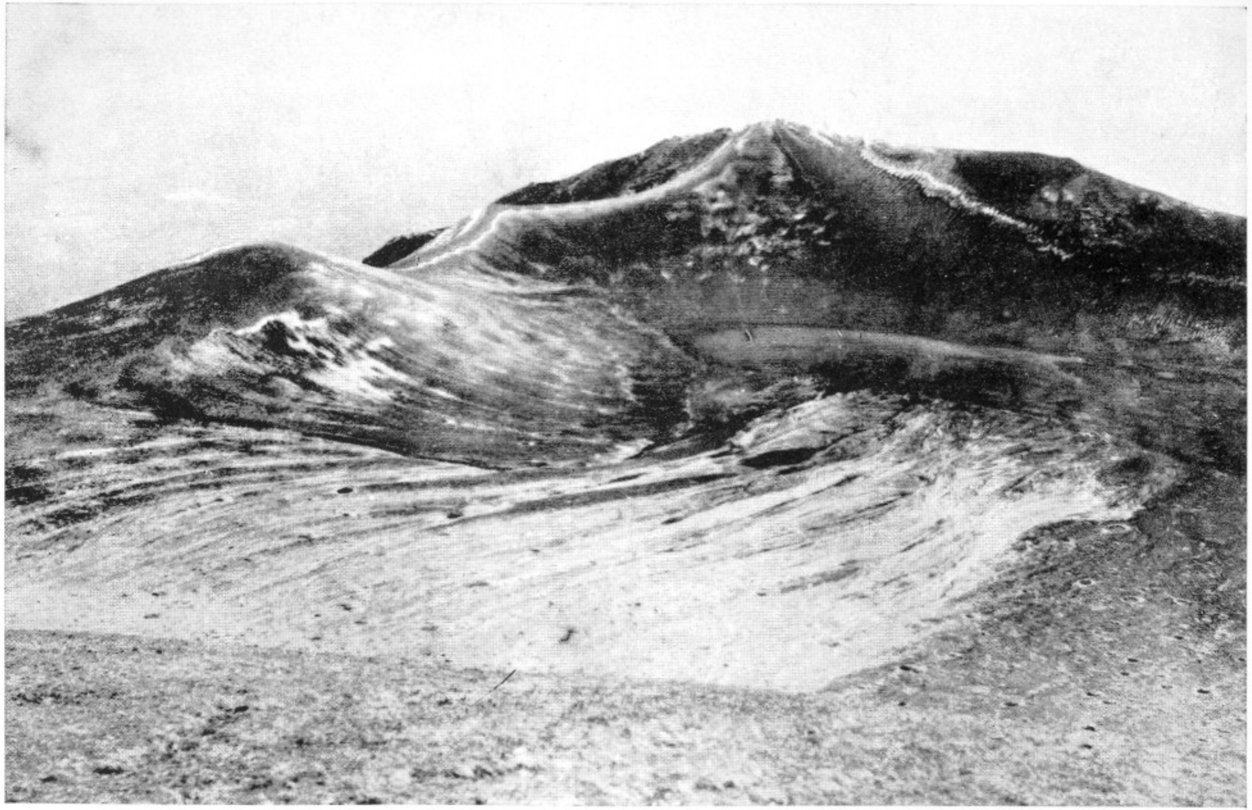

FIG. 14. *The old SSE crater with numerous impact-holes of bombs on the right.*

PLATE 38.

FIG. 15.

FIG. 16.

Marks left by mudstreams along the southern slope of the middle ridge between the two craters.

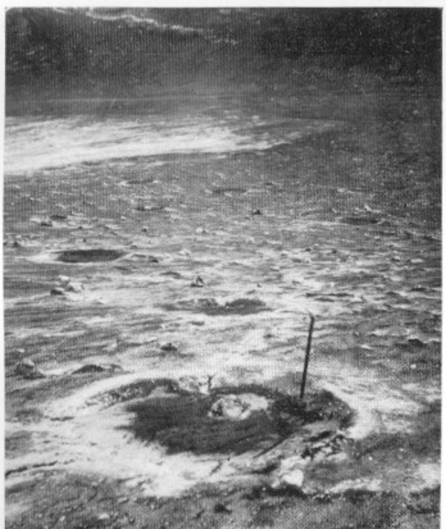

FIG. 17. *A 7-foot crater and half-buried boulder from the 1940-41 eruption.*

FIG. 18. *One of the boulders thrown out during the 1940-41 eruption.*

PLATE 39.

FIG. 19. *The active NNW crater.*