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MINISTRY OF NATURAL RESOURCES
GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
MOUNT KENYA AREA

DEGREE SHEET 44 N.W. QUARTER
(with coloured map)

by

B. H. BAKER, B.Sc., F.G.S.
Geologist
(Commissioner of Mines and Geology)

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FOREWORD

The geological survey of the area around Mt. Kenya, a dissected volcano which forms Kenya's highest mountain, took a total of nine months field work, during which time Mr. Baker worked from camps which varied in altitude from below 5,000 ft. on the Equator to above the snow line.

While the mountain had been visited by explorers, scientists and mountaineers on many occasions since 1887 (the summit was not climbed until 1899), the geology of the mountain was known in only the sketchiest detail before the present survey. The author here presents a complete picture of the geology, and deduces from the evidence of the stratigraphic column the history of the mountain from its beginnings in late Pliocene times.

Of particular interest is an account of the glaciology of the mountain, in which is described each of the ten dwindling glaciers which still remain and the numerous moraines of these and earlier glaciers. Mr. Baker also shows that Mt. Kenya was formerly covered by an ice cap 400 sq. kms. in area, and that the present glaciers are the remnants of this ice cap. This work enables the author to detail the changes in climate which took place during the Pleistocene period, and he also discusses the correlation of climatic changes in East Africa with those occurring in Europe during the Ice Age.

Nairobi,
4th August 1966.

J. WALSH,
for Chief Geologist.

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ABSTRACT

The report describes an area of approximately 1,200 square miles bounded by the equator and latitude 0°30'S, and by longitudes 37°00'E. and 37°30'E. The area covers the greater part of Mt. Kenya (17,058 feet) and includes a small part of the Aberdare dip-slope.

Physiographically the area is dominated by the large bulk of the dome-shaped Mt. Kenya volcanic pile, which bears a system of ten small glaciers on its peaks.

The rocks exposed include small inliers of Precambrian Basement System mica gneisses, amphibolites and hornblende gneisses, which are covered by the Simbara Series basalts and agglomerates, the Nyeri Tuff and Laikipian Basalts. These volcanics are derived from the west of the present area and are of presumed Miocene-Pliocene age.

The Mt. Kenya volcanics consist of basalts, rhomb porphyries, phonolites, kenytes and trachytes which make up the main period of eruption, and the plug of the volcano is composed of nepheline syenite and phonolite in the form of a ring structure. Satellite activity from fissures resulted in the eruption of further phonolites, basalts, trachytes and mugearites, and the activity on the mountain was brought to a close by further satellite eruptions of trachytes, pyroclastics, basalts, and basaltic pumice from various vents on the slopes of the original volcano. The Mt. Kenya volcanics are believed to be mainly of Pleistocene age.

Moraines are found up to 7,000 feet below the present glaciers and have been divided into the products of an older and a younger glaciation. The retreat from the younger glaciation maximum has been sub-divided into six stages on moraine evidence. An account of the present glaciers is given.

The only economic deposits of the area are building stones and road surfacing materials. An account of the water supply position with details of bore-holes is given.

I—INTRODUCTION

1. General Information

The area described in this report is bounded by the equator and latitude 0°30′S., and longitudes 37°00′ and 37°30′E., and is approximately 1,200 square miles in extent. It covers parts of Nyeri and Kirinyaga Districts (Central Region) and parts of Embu and Meru Districts (Eastern Region), and includes the greater part of Mt. Kenya. The Mt. Kenya National Park, which is defined as that part of Mt. Kenya above the 11,000 feet contour, falls in the area and is controlled by a National Park Warden based at Nyeri. Approximately half of the remainder of the area between the 11,000 feet contour and levels between 5,000 and 7,000 feet is the Mt. Kenya Forest, which is controlled by Forest Officers situated at Nanyuki, Gathiuru, Kabaru, Hombe, Ragati and Castle Forest Stations, and at Embu Forest Station at Irangi.

Work in the area was begun when the writer was seconded to the I.G.Y. Mt. Kenya Expedition (leader: Dr. I. S. Loupekine) during December 1957 and January 1958. The official survey was carried out between December 1958 and June 1959. Mr. D. J. Jennings (Geologist) assisted the writer during the survey of the upper part of Mt. Kenya.

2. Communications

The Nairobi-Nanyuki railway line passes through the western part of the area—there are stations at Karatina, Kiganjo (Nyeri Station), Naro Moru and Nanyuki. The Nairobi-Nanyuki road follows the railway line more or less closely, there being a road leading to Nyeri starting at the Marua bridge over the Sagana river.

The road system on the flanks of Mt. Kenya is much influenced by the number of rivers and streams draining radially from the mountain. Most motor roads and tracks follow the ridges and connect with the Sagana-Embu and Sagana-Nanyuki main roads. Other roads which cross the drainage are the Karatina-Kagumo-Kerugoya road, and the Kianyaga-Kiamutugu-Kirigi roads, which provide east-west access to the upper locations of Embu District. An all-weather road connects Karatina, Ragati, Hombe, Ndathi, and Kabaru and Kiganjo, and an earth track maintained by the Forest Department links the Naro Moru track with Gathiuru, Nanyuki Forest Station and Ontulili Forest Station (the latter is north of the present area).

Motor tracks providing access to the higher parts of the Mt. Kenya Forest are few, and some have fallen into disuse and disrepair. The only motor track penetrating the whole of the forest belt is the Sirimon track, which leaves the Nanyuki-Timau road to the north of the present area, some eight miles north-east of Nanyuki, and runs up a ridge to the south of the Sirimon river and ends on the moorland at an altitude just short of 13,000 feet. Saloon cars have penetrated as far as the Forest Department Hut at 9,500 feet on this track, and four-wheel drive vehicles have reached the end of it under dry conditions. The section of the track above 9,500 feet is, however, difficult and in a poor state of repair. Two Forest Department tracks from the Nanyuki Forest Station and Nanyuki Sawmills reach up to 8,000 and 8,400 feet respectively. At the end of the latter track is a fire-watchers' tower.

The most direct access to the higher parts of the mountain is provided by the Naro Moru track, which is maintained by the National Parks. It follows the Naro Moru river and ends in a clearing at 10,000 feet. A well marked path continues up the mountain, following the Teleki valley and reaching Top Hut (15,700 ft.). This is the route followed by many mountaineering parties. The Burguret track is not now motorable above Gathiuru. This track is favoured by parties ascending the mountain with pack-animals.

The Gunia track leaves the Hombe-Kabaru link road on the south-west slopes, and reaches an altitude of 10,500 feet. It is somewhat overgrown and neglected, but is easily motorable due to the absence of the steep gradients such as are found on most other forest tracks.

Several short motor tracks reach into the forest from Ragati Forest Station, and there is a recently completed forest track linking Ragati and Chehe Forest Stations. None of these tracks reaches above 7,600 feet.

Gunia and Chehe forest tracks were at one time joined in the vicinity of Gerere at about 9,700 feet, but the uppermost two miles of the Chehe track is now overgrown.

The Kamweti track on the south side of the mountain reaches an altitude of 10,000 feet, and a link road joining this track to Castle Forest Station has recently been completed. The Irangi track on the south-east sector leads upwards from Irangi Forest Station and ends at 7,600 feet.

Although the highest levels on the mountain to which a vehicle can penetrate are reached on the Sirimon track, it is the Naro Moru track which provides the most direct access to the peaks; the distance from the end of this track to Top Hut is seven miles.

The path above the National Parks Camp is, however, in peat bog in the 2,000 feet above the forest edge and in consequence this route is not favoured by those using pack animals. The latter prefer the longer but less wet Burguret track, which leads to Two Tarn Hut by a well-marked path.

Earlier routes of access to the mountain which were in favour before the recent construction of motor tracks into the forest are the Ontulili path (Hook's 'old route') and the Chogoria path (Carr's route). The former is a pleasant, dry path through cedar forest up a ridge south of the Ontulili river. It gives access to the head of the Mackinder valley, and is a good but long route for pack animals. The Chogoria path leaves Mutindua village above Chogoria to the east of the area and follows a ridge north of the Nithi river to the Urumandi Hut (10,100 ft.) at the forest edge. It continues as a well-marked path along the north ridge of the Gorges valley to Hall Tarns and finally traverses the eastern and southern slopes of Pt. Lenana to reach Top Hut. This route was the principal one up the mountain in the 1920s, and is still used occasionally by persons with the assistance of Meru porters. Its drawback is its length, for the ascent to Top Hut requires three days.

The recognized paths and routes which have been mentioned on the upper part of the mountain are marked on the map (at end) and are suitable for pack animals. The map also shows a new route linking the Ontulili and Burguret tracks in the Alpine zone, and a convenient route from Hall Tarns to Ithanguni is shown.

3. Vegetation

The vegetation on Mt. Kenya shows strong altitude zoning, and the flora of the higher part of the mountain has been called an "Afro-Alpine" flora, which shows considerable similarities to that of the other high East African mountains (Hedberg, 1951)*. The vegetational belts (based on Hedberg, *op. cit.*) are:—

	"Nival" zone
4. The Alpine Belt	Upper Alpine zone
3. The Ericaceous Belt	Lower Alpine zone
	Hagenia-Hypericum zone
2. The Montane Forest Belt	Bamboo zone
1. Savanna and cultivated Belt.	Montane rain forest zone

The lowermost belt, which extends up to the lower edges of the Mt. Kenya Forest at altitudes between 6,000 and 7,000 feet, is the cultivated or pastoral belt. Whereas the forest was evidently much more extensive than at present, especially towards the south, destruction by fire and more recently encroachment by agriculturalists has raised the lower limit of the indigenous forest to its present position.

The second belt—the Montane rain forest—extends up to levels of 11,000 feet on the west and south sides, and 10,000 feet on the eastern and northern sides. The Montane rain forest zone reaches its maximum development on the south-east sector of the mountain. It is distinguished by the occurrence of evergreen hardwood trees and some conifers. Cedars (*Juniperus procera*) and podocarpus (*P. gracilior*, *P. milanjanus*) are important on the western slopes, and camphor trees occur in the south and south-east.

*References are quoted on page 76.

The Montane rain forest passes upwards into the bamboo zone (*Arundinaria alpina*), which is best developed on the south-east slopes. The lower margin of the bamboo zone is at approximately 8,000 feet in the south-east, 7,000 feet in the south, rising to 9,000 feet in the north-west. The bamboo zone thins markedly in the north-west, and is absent in the north. *Podocarpus* trees occur in the bamboo in the western and southern sectors, but in the south-east there are large areas consisting exclusively of bamboo. Patches of bamboo occur in sheltered places well above its normal level, for instance at 11,500 feet in the Sirimon valley, at 10,500 in the Luguso valley, and at 11,000 in the Kazita valley.

The uppermost division of the Montane forest is the *Hagenia-Hypericum* zone, characterized by *Hagenia abyssinica* and *Hypericum leucoptychodes*. The latter is a "giant" form of St. John's wort. This zone is generally narrow and well defined, covering an altitude range of only a few hundred feet on the western slopes, but being rather deeper on the east. The levels of this zone are about 10,500 to 11,000 on the west, and 9,500 to 10,000 on the east, but small patches occur higher in sheltered valleys.

The lower margin of the Ericaceous belt is generally well-defined, and is marked by the transition to giant heather (*Phillipia excelsa, Erica spp.*). On the west the ericaceous forest is thin, absent or dead, the higher parts of the belt containing only discontinuous patches of shrubby heather obviously affected by fire and regenerating by means of basal shoots. On the north and east sides, however, the belt is broader and has also notable amounts of *Protea sp.* Large areas between 10,000 and 12,000 feet on Ithanguni and the north-east slopes are covered by *Erica* and *Protea* forest, the trees reaching a height of 20 feet.

The upper margin of the Ericaceous belt is very ill-defined, and patches of "heather" persist up to 13,500 feet on sheltered slopes. There is a marked inter-digitation with the Alpine belt. On all sides of the mountain except to the north-east recurring fires have clearly affected the highly inflammable heather plants, depressing the upper limit of these plants and preventing the formation of *Erica* forests except in protected enclaves.

The Alpine belt is synonymous with "the moorland", and is open, often marshy ground characterized by the well known giant groundsel, tussock grasses, *Alchemilla* shrubs and *Helichrysum*. The divisions of the alpine belt are gradational but certain associations are characteristic of each zone. The lowermost zone is characterized by yellow-flowered *Senecio brassica* and *Lobelia keniensis* which occur with tussock grass (*Festuca pilgeri*) in damp ground. An *Alchemilletum* community occurs in drier, better drained areas. The upper alpine zone is characterized by the tree-like *Senecio keniodendron*, which reaches up to 14,700 feet. In this zone the effects of solifluction and frost heaving are added to the extreme climate in determining the flora. The zone contains species of *Carex* sedge and *Agrostis* grass, *Carduus platyphyllus, Arabis alpina, Senecio keniophytum*, apparently sterile *Lobelia telekii* and two species of *Helichrysum*.

This community persists up to approximately 15,200 feet on weathered old moraine at the base of the main peaks of Mt. Kenya. In addition mosses and lichens cover most of the weathered rock surfaces. There is, however, a sharp floral boundary at the outer edge of a group of recent moraines which occur some few hundreds of feet below the present ice margins. These moraines, which are approximately 100–300 years old, are very sparsely colonized by *Agrostis trachyphylla, Arabis alpina* and stunted *Senecio keniophytum*. Mosses and lichens occur sparingly on the practically unweathered rocks within these moraines.

4. Climate

The climate of Mt. Kenya is of interest on account of its bearing on the interpretation of the glacial deposits, and because of its extreme range from the warm lowlands to the severe alpine region with its very large diurnal temperature range.

On the moorland zone a number of meteorological observations were made by S. E. Brinkman, meteorologist of the 1957–58 I.G.Y. Mt. Kenya Expedition*, principally at localities on the western slopes, which are tabulated overleaf.

*Figures reproduced by courtesy of Dr. I. S. Loupekine, leader of the Expedition.

Locality	Period of observation	Range of daily mean temperature—°C	Range of hourly mean temperature—°C
End of Naro Moru track—10,000 ft.	12–20/12/57	+6·4 – +9·1	+2·5 – +13·9
Teleki Valley—13,700 ft.	17/12/57–19/1/58	−0·2 – +4·4	−1·6 – +6·6
Top Hut—15,700 ft. ..	20/12/57–16/1/58	−4·2 – +0·2	−4·0 – −0·2

Observations by the writer with a maximum/minimum thermometer (partly shielded) showed that minimum temperatures varied between −4°C. and +8°C. on the moorland, and 15 measurements of maximum temperature all fall in the range 14°–25°C. (58°–76°F.). It should be noted, however, that the writer's observations of maximum temperature are up to 30 per cent too high, due to insufficient shielding of the thermometers. Generally during the period January-March 1959 the minimum temperatures are below freezing above the 12,000 feet contour. The minimum temperatures were lowest, however, not at the highest altitudes but in the valley floors between 13,000–14,000 feet (−4° to −8°C.). On ridge tops the minimum temperatures were approximately 2°C. higher than in valley floors at the same altitude, and this effect is due to the cold katabatic breezes that descend the valleys at night.

The range between minimum and maximum temperatures decreases with altitude, being 11·5°C. at 10,000 feet, 7·5°C. at 13,700 feet and 4°C. at 15,700 feet.

On all sides of the moorland and alpine zones of the mountain the maximum temperatures are reached between 9·00 and 12·00 a.m. On the western slopes the temperature drops after noon due to the afternoon cloudiness, but this is less marked on eastern slopes. At levels between 10,000 and 14,000 feet the relative humidity on the western slopes varies inversely with the temperature, being at a minimum of approximately 35–45 per cent in the mid-morning, but rising to a maximum at 7.00 p.m. in the early evening, when it reaches 70–90 per cent. At Top Hut (15,700 feet) however the relative humidity minima and maxima are earlier in the day, at 7.00 a.m. and at 12.00–4.00 p.m. respectively.

Sunshine records made in the floor of the Teleki valley at 13,700 feet show the strong correspondence of sunshine duration and temperature. The mean of observations covering ten days in January 1958 show the sunshine duration maximum at between 9.00 a.m. and noon, with a minimum at 3.00 p.m., and a second minor maximum at 5.00 p.m. The mid-afternoon minimum is due to the afternoon cloudiness which is referred to below.

The weather changes in the afternoon which characterize the western slopes are the most notable features of the climatic regime of the mountain. The mornings are generally clear and sunny with little wind and rapidly rising temperature and low humidity. Generally during the morning clouds begin to form at about 8,000–10,000 feet on the lower western slopes, and these grow in height and begin to be carried eastwards up the valleys by noon, bringing high humidity and a fall in air temperature. These clouds frequently reach the peak area from the west by early afternoon, and rise vertically up the western side of the peaks with a turbulent motion, and on reaching the level of the peaks are swept westwards and dissipated in the dry easterly air stream rising over and round the mountain. It is this phenomenon which gives rise to the high level (at 14,000 feet) rainfall maximum on the western slopes (*see* Fig. 1), and which protects the west-facing glaciers from the afternoon sun.

The distribution of rainfall on the mountain is indicated on Fig. 1. This shows the south-easterly rainfall maximum of 70–90 inches which is due to orographic effect during the south-east monsoon, and the minor maximum of 40–50 inches to the west of the peaks at an elevation of 8,000–10,000 feet, which is due to the westerly reversed air flow of the western slopes. The rainfall maximum is at different levels on different sides of the mountain, the lowest being on the south-east and the highest on the west. There is a pronounced minimum which coincides with the upper alpine zone. The seasonal distribution of rainfall is virtually unknown at present since the rainfall figures for the upper slopes are recorded by long-term gauges read at infrequent and irregular intervals. Observations suggest that the rainfall is strongly seasonal and occurs mostly at changes of the monsoon in April-May and November-December as in the remainder of eastern Kenya.

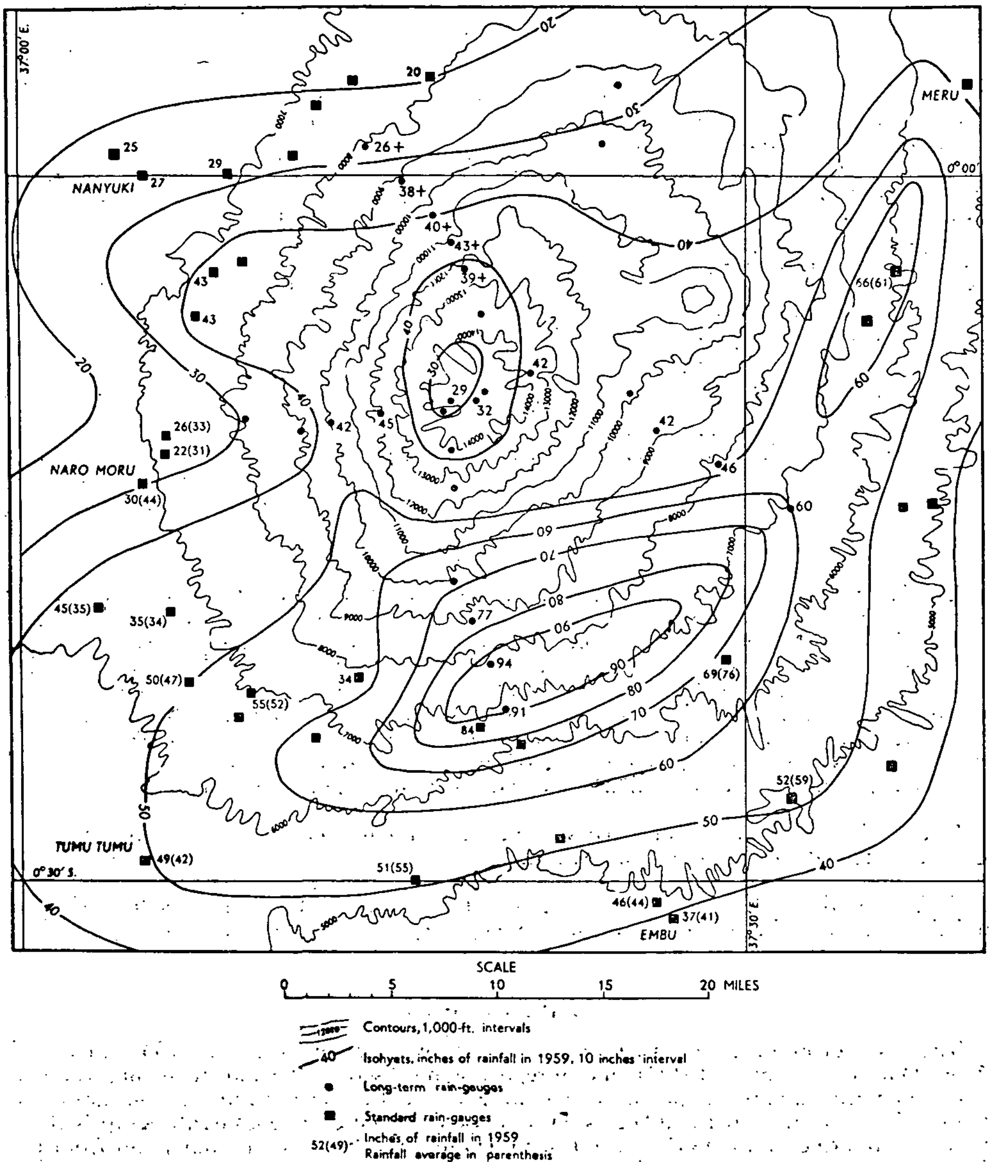

Fig. 1—Isohyet sketch map for the year 1959.

The rainfall figures for the permanent gauging stations on the lower slopes are given in the following tabulation:—

Station	1959 Rainfall-inches	Average annual rainfall-inches	Number of years over which average taken
Tumu Tumu Mission	49·14	42·13	40
Embu, D.C.'s office	37·13	41·05	51
Ragati Forest Station	55·10	52·07	26
Kirinyaga Farm, Naro Moru ..	22·28	31·42	21
Kerugoya Hospital	50·95	55·38	22
Kabaro	35·05	33·81	17
Kevote School	51·62	59·75	13
Gathiuru Forest Station	43·36	38·99	13
Kadunie Estate, Nyeri	44·64	35·46	29
Forest Farm, Naro Moru ..	25·89	33·55	11
Hombe Forest Station	50·41	46·52	11
Killard Farm, Nanyuki	28·91	33·50	11
Embu Forest Station, Irangi ..	69·97	76·52	6
Kamburaini Farm, Naro Moru	30·50	44·47	8
Castle Forest Station	84·48	—	—
Kabaru Forest Station	34·50	—	—

5. Maps

The 1:125,000 map (at end) is based on the four Survey of Kenya 1:50,000 maps covering the area—numbers SK II 121/1–2 (third edition), SK II 121/3 (seventh edition) and SK II 121/4 (sixth edition). Some of the motor tracks and paths shown in these maps in or above the forest have been amended. Due to extensive land consolidation work in the Nyeri and Embu Districts and the construction of villages during the Emergency large alterations of the road system are taking place, and the writer has endeavoured to show on the map the state of affairs at the time of the survey (December 1958 to June 1959). The positions of the villages are sketched, as are some of the new roads. The positions of forest tracks are not accurate, but are better than those indicated on the published maps.

The detailed maps of the upper parts of the mountain and the peak area are based on the excellent 1:25,000 map number D.O.S. 302.

A few additional place names have been added to the maps, and the spelling of some existing names has been modified to that employed by the local people.

6. Previous Work

The first European to see Mt. Kenya was Ludwig Krapf, who saw it on December 3rd 1849 (Dutton 1929, pp. 161–173), but on reporting his discovery he and Rebmann, who had discovered Kilimanjaro the previous year, were attacked by several European geographers, who maintained that what had been seen was not snow but calcareous earth. Krapf's claim was not confirmed until 1883, when Joseph Thomson (1887) saw the mountain from the Laikipia plateau, and described it as the eroded remnant of an old volcano, the peak being "... the column of lava which closed the volcanic life of the mountain ..."

The first ascent to the upper part of the mountain was made in 1887 by Count Teleki (von Höhnel, 1894, pp. 371–377), who reached an altitude of approximately 13,800 feet in the Teleki valley. He described the head of the Teleki valley as a crater, and brought back specimens which were subsequently identified as andesite and phonolite (Rosiwal, 1891, pp. 446–498).

A further attempt to climb the mountain was made by Capt. Dundas and C. W. Hobley in 1891. They attempted the ascent from the south but were turned back while still in the forest by the difficulty of the country (Gedge 1892, pp. 527–528). Hobley noted only two rock exposures—one of volcanic ash and the other of basalt.

The most comprehensive piece of work to be done on Mt. Kenya to date was carried out by J. W. Gregory, during his remarkable expedition in 1893 (Gregory 1896). Gregory climbed up as far as the Lewis Glacier, and reached a height of approximately 16,000 feet. (Gregory's height determinations were up to 2,000 feet too high). Gregory recognized the evidences of former glaciation on the moorland zone, described the glacial geology, and discussed the causes of the former greater extension of the glaciers (Gregory, 1894 (C)). His sketch maps show that in 1893 the Lewis Glacier reached to levels several hundred feet lower than the present day, and that the glaciers had previously descended to below 10,000 feet. He concluded that the former glaciation was due to the mountain having been built up and uplifted to the height necessary for an ice dome to form, and that this uplift resulted in the alteration of the climate of the surrounding areas, giving rise to enlarged lakes in the rift valleys and a greater extension of the alpine flora and fauna. Gregory (1900, pp. 205–222) also made observations on the volcanic geology, described the nepheline-syenite of the peak, and proposed the new name kenyte for a variety of glassy phonolite. He omitted to mention the nepheline phenocrysts that are ubiquitous in the kenytes of the upper part of the mountain (Campbell Smith, 1931). He described the sections exposed on the west face of Mt. Höhnel, and gave the general succession as:— phonolites, kenytes, then basalts: a succession confirmed by later work. Gregory summarized his work on Mt. Kenya in his book "Rift Valleys and Geology of East Africa" (1921, pp. 144–153). Many of the topographical features of the mountain were named by Gregory (1894(D), pp. 408–424), including the principal glaciers and valleys.

The summit of Mt. Kenya was climbed for the first time by H. J. Mackinder and two Alpine guides on September 13th 1899 (Mackinder, 1900, pp. 453–486). Mackinder carried out a circuit of the peak and named some of the glaciers and valleys on the northern sector of the mountain. He proved that the nepheline-syenite discovered by Gregory on the peaks extended to the summit of the mountain.

The upper part of the mountain was not visited again till 1908 when H. McGregor Ross and D. E. Hutchins carried out a circuit of the mountain on the lower moorland to study and evaluate the forest. Reference is made to the glaciation in the Hausburg valley, and photographs of the Cesar and Tyndall glaciers were taken, showing them to be substantially longer than they are at the present day (McGregor Ross, 1909, 1911).

Orde Brown (1918) ascended from the south-east, and reached a height of approximately 12,500 feet.

In the period between 1914 and 1927 much exploration was done by settlers and missionaries living in the vicinity of the mountain, but little scientific work was accomplished. The principal figures involved in these explorations were J. W. Arthur, (1921, 1923), A. R. Barlow, E. Carr, who built two huts on the mountain, and E. A. T. Dutton and J. Melhuish (in 1926). In Dutton's book (1929) is a detailed account of Dutton's and Melhuish's journey and attempt on the peaks, together with appendices on the discovery of the mountain; Shipton's 1929 ascent; the geology (by J. W. Gregory); the flora (by M. Jex-Blake); the forests (by S. H. Wimbush); glossary of place names, and a map (scale 1:21,120) of the upper moorland.

E. Nilsson examined the moraines of the Gorges valley in 1927 and returned in 1932 to prepare a map of this area (Nilsson 1935, p. 10). He described the moraines and concluded that the large terminal moraine near the Nithi waterfall marked the maximum extension of the glaciers (Nilsson, 1931, pp. 19–23). He reported patches of older, eroded moraine below the terminal moraine between the Nithi waterfall and the Urumandi hut. These he interpreted as having been laid down by an earlier glaciation. The complex of moraines behind the terminal moraine of the Gorges valley he interpreted as due to two re-advances of diminishing extent soon after the beginning of the retreat of the glaciers from the maximum. He mentions four small moraine ridges above Lake Michaelson and the moraine oop which surrounds Harris Tarn, into which tarn the Kolbe glacier descended. The Kolbe glacier has since disappeared. Nilsson (1931, pp. 39–41, 90–91) noted the similarity of the moraine sequence on Kilimanjaro, Mt. Kenya, Mt. Elgon and Ruwenzori and suggested that the course of recession from the maximum was similar on all these mountains, and that they were due to widespread climatic changes. He correlated the various moraine groups on different mountains and suggested that the expansions of the glaciers and of the lakes were contemporaneous, but produced no concrete evidence in support of these correlations.

During 1929 and 1930 the main peaks were ascended several times by E. E. Shipton, H. W. Tilman, P. Wyn Harris, G. A. Sommerfelt and R. E. G. Russell (Shipton, 1943; Tilman, 1937).

The first glaciological work to be carried out on the mountain was that by C. Troll and K. Wien in 1934 (1949). A photogrammetric survey of the Lewis Glacier was made, and the rate of flow measured.

During the period 1930–1936 R. Hook was active on the mountain, exploring the northern and eastern slopes. Hook and H. Slade stocked some of the streams and lakes with trout during this period, and improved the existing maps.

P. C. Spink (1945, 1949) visited Mt. Kenya in 1944, and noted that the glaciers were retreating.

In 1947 F. E. Zeuner (1948) made a brief journey on the north-west slopes of Mt. Kenya and described frost soil structures.

An article summarizing the geology of Mt. Kenya was written by W. Pulfrey (Mines & Geological Dept.) for the Royal National Parks in 1950, but it was not published.

In December and January 1957–1958 the writer was seconded to the I.G.Y. Mt. Kenya Expedition, leader Dr. I. S. Loupekine, to carry out a reconnaissance on the glacial geology, and a report on this work is in preparation. Other members of this expedition carried out studies in glaciology, vegetation, meteorology and hydrology.

II—PHYSIOGRAPHY

The commanding topographic feature of the area is Mt. Kenya, which is a large (partly denuded) central volcano of Vesuvian type, the summit of which is at 17,058 feet. All but the south-western corner of the area is formed of its volcanics. The volcanic pile is approximately 75 miles wide at the base, and is about 12,500 feet thick. Originally, however, the crater must have been at a height exceeding 20,000 feet. The volcano is now in the youthful stage of dissection—the upper part has suffered the greatest erosion, having been subjected to at least two periods of glaciation.

Geologically and physiographically distinct from Mt. Kenya is the part of the Aberdare dip-slope (Shackleton 1945, pp. 11–12) which occurs in the south-western corner of the area where the Laikipian basalts crop out. It consists of a plateau sloping south-eastwards at approximately 50 feet per mile, which is incised to depths of 400–500 feet by the Chania, Muringato and Sagana rivers. Rising above this plateau is Kailewa hill, which is an inlier of metamorphic rocks.

Mt. Kenya can be divided into two main physiographic zones:—the lower cultivated or forest-clad slopes, and the upper zone of open moorlands above 11,000 feet, a zone which coincides generally with the area of former glaciation. The contrast between the two zones is obvious when the mountain is viewed from a distance, for the lower slopes show in profile the smooth upward steepening curve characteristic of a central volcano, but above 11,000–12,000 feet the upper slopes lie well below the imaginary continuation of this line, *see* Fig. 2*a*. The changes in average slope, measured on the western sector, are indicated in the following tabulation:—

Altitude range feet	*Average slope feet per mile*
6,000– 7,000	100–150
7,000– 9,000	300
9,000–13,000	750
13,000–15,000	500–600

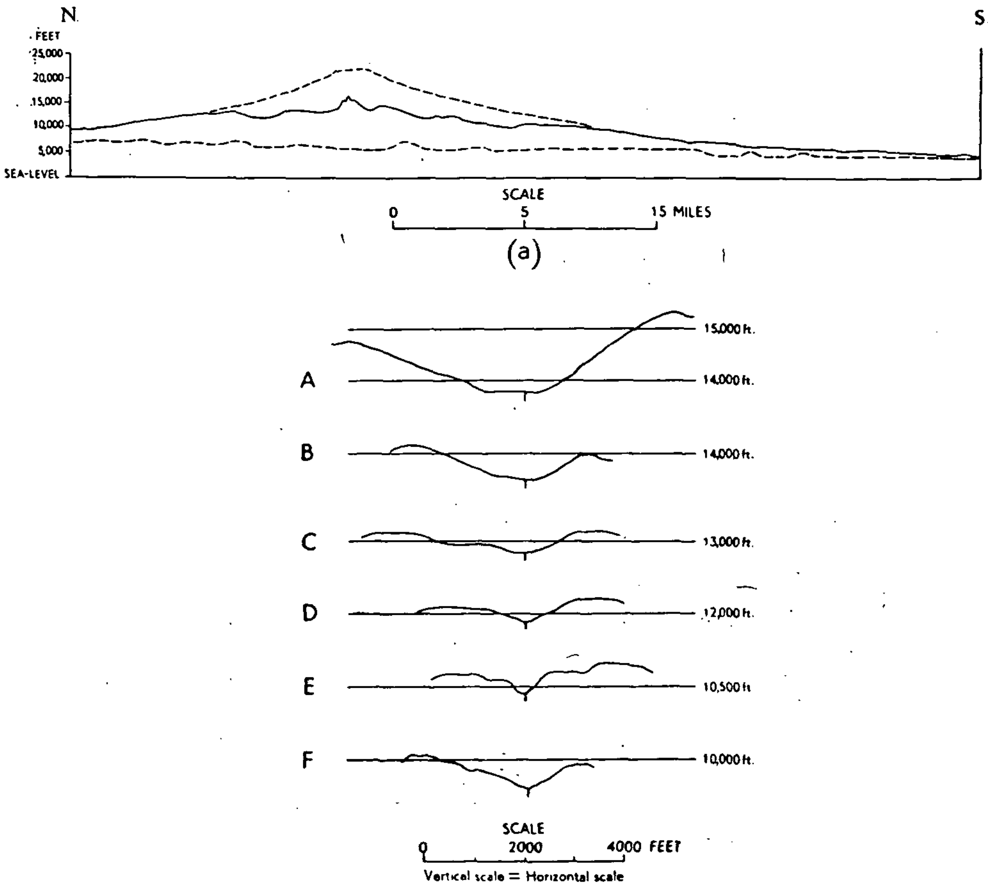

Fig. 2 (a)—Profile of Mt. Kenya showing inferred original shape and height.

(b)—Profiles of the Teleki valley at various elevations showing progressive change from glacial to fluviatile form.

1. The Lower Slopes

The lower slopes of the mountain are incised to depths of up to 600 feet by a system of radial and consequent streams. At levels between 6,000 and 7,000 feet the interfluves are broad and smooth suggesting that at these levels lowering of the original volcanic surface has been slight. At higher levels, however, the higher rainfall has resulted in a multitude of sub-parallel streams, *see* Fig. 3, which results in narrow steep-sided interfluves.

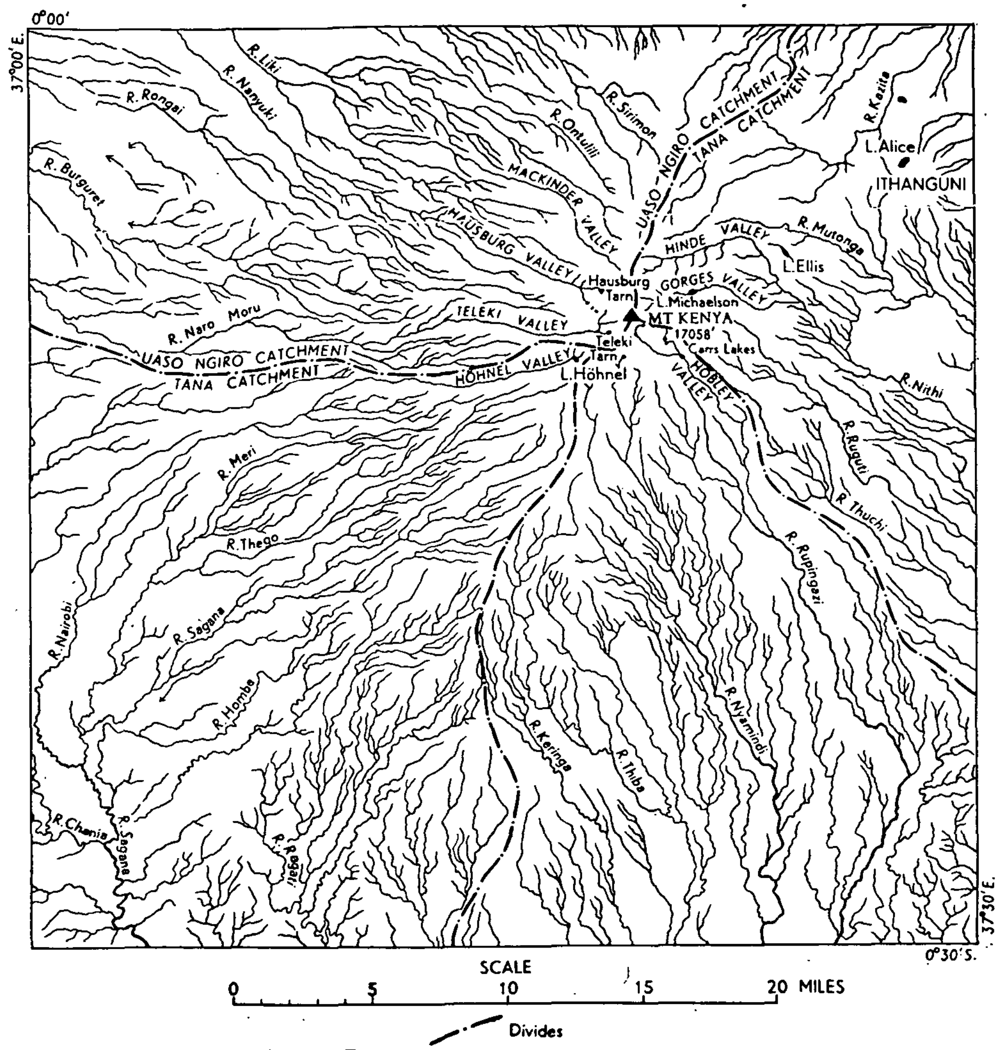

Fig. 3—Drainage pattern in the Mt. Kenya area.

Minor but significant differences of topography and drainage pattern occur on different sectors of the mountain, and these differences are reflections of the nature and age of the underlying volcanic rocks. The most marked differences are on the southern and south-eastern slopes where the contour pattern brings out the varying degree of dissection. The belt of youthful basalts between the Rumindi and Thuchi rivers contrasts with the more dissected basalts to the west and phonolites to the east. The homogeneous contours and drainage pattern on the western sector between the Ontulili and Sagana rivers, where phonolites and agglomerates predominate, is in contrast with the lesser stream density and reduced dissection apparent on the north-eastern sector, which is composed of relatively younger basalts, trachytes and pervious ashes and agglomerates.

The zone of fissile trachytes west of the Ragati valley forms an area of slightly higher ground characterized by steep-sided, often flat-topped hills such as Tumu Tumu, Kiamucheru and Niana. Some of the conical or flat-topped hills of this zone were wrongly interpreted as volcanic plugs by Shackleton (1945, p. 4, Fig. 1).

Among the relatively recent basalts forming the group on the southern slopes are those which flowed down the Rupingazi and Ragati valleys. The Ragati valley-flow can be traced from near Gerere high on the south-western slopes, down the Ragati valley past Karatina to a point near Sagana township in the area to the south. The floor of the valley is almost flat and the Ragati river is incised no more than 10–20 feet, in contrast to the much more deeply dissected and older volcanics which form the shoulders of the valley. A longer and even more obvious valley flow is that found flooring the Rupingazi valley between Thambana and a point well to the south of Embu township. Between Mwiria factory and the Njukiini Forest the almost flat floor of the valley is most conspicuous in contrast to the steeply incised neighbouring valleys. The junction of the various valley flows in tributaries of the Rupingazi in the Mbubori-Thambana area is also notable.

The whole of the north-eastern sector of the mountain, between the Nithi and the Sirimon rivers, is physiographically distinct from the remainder, being covered largely by ashes and agglomerates. The ground is gently undulating and the streams run in narrow valleys of steep V-profile. This sector is characterized by numbers of volcanic necks, cones and explosion craters. The largest of these is the volcano Ithanguni, which rises to over 12,700 feet, and is a squat flat-topped cone with a large crater-shaped depression occupied by Lake Alice. Ithanguni formerly supported a small ice-cap, which covered the summit plateau and extended down the sides of the hill, and destroyed the original crater.

Several circular stock-like bodies occur on the north-eastern slopes, notably the Giants' Billiard Table, Rutundu, the circular plateau two miles east-south-east of Runtundu, and the plateaux immediately south and north-east of Lake Ellis. The two best developed are Rutundu and the Giants' Billiard Table; they are circular and almost flat-topped, but with slight central depressions. The outer margin is an unbroken circle of cliffs rising from almost level ground. They are interpreted as the stocks of small vents which were surrounded by low crater walls or unconsolidated ash, which have since been eroded away. The stocks are composed of crudely columnar trachyte.

Other more recent small vents of pumiceous basaltic lava are found on the northern slopes and still preserve their crater form. These low vents are part of an extensive field covering much of the lower northern and north-eastern slopes, and which are part of the Nyambeni volcanic chain (Mason 1955, pp. 3–5, Fig. 2, Shackleton 1946, Fig. 9, pp. 37–38).

On the slopes of the mountain there are several crater-shaped depressions of two main types:—those not obviously connected with a volcanic vent, and some which are so connected. In the first category are the Kachimba depression one and a half miles south-east of Chehe Forest Station, the Muthere depression two miles west of Castle Forest Station, and the depression one mile east of the upper end of the Kamweti track. Those of the second type are the depressions occupied by Lake Alice (Ithanguni), Rutundu lake (Rutundu), and the depression traversed by the Ruguti river at 7,800–8,000 feet.

The depressions of the first type are characterized by their basin-like form and only slightly raised rims. The Kachima depression is 1,600 yards wide in a north-south direction and 1,400 yards wide in an east-west direction, and of an average depth of 150 feet below the surrounding country. Its floor is occupied by a swamp feeding the Ruiru river, which breaks through the southern rim of the basin. Owing to the very poor exposure in this area nothing could be discovered about the underlying structure. The depressions are, however, regarded as phreatic explosion craters caused by the contact of groundwater with the centres of still hot, thick lava flows, or possibly shallow dykes. A generally similar explanation is invoked for the depressions of the second category. The Ithanguni (Lake Alice) and Rutundu basins are both alongside trachytic necks and are formed in relatively unconsolidated volcanic ashes. Their proximity to necks which have evidently been predominantly explosive in their mode of eruption suggests that they are due to large phreatic explosions, probably as a result of the contact of groundwater with the lower still hot parts of the necks.

2. The Upper Slopes—the glaciated area

The upper slopes above the forest coincide in a general way with the area formerly affected by glaciation, and can be subdivided into the moorland zone and the alpine zone above. The two zones grade into one another at approximately the 14,000 foot contour. The main topographic differences which distinguish the upper glaciated slopes from the lower slopes are immediately clear from the maps. In the glaciated area the valleys are deeper, broader, less closely spaced, and have fewer tributaries than those below. The ridges of the lower part of the glaciated area are ice-smoothed, while higher up deep cirques are separated by serrated rock ridges. The central group of peaks is of alpine aspect—precipitous, with great cliffs of ice-worn and frost shattered rock. These peaks bear the small valley glaciers which are the remnants of the extensive ice-sheet that formerly covered the whole of the upper slopes.

(1) *The Moorland Zone*

The open, rounded valleys and ridges of the moorland zone, the ice-smoothed rock bosses, trains of erratic blocks and the well-preserved moraines, testify to the fact that the greater part of this zone was once covered by a mountain ice-sheet, of which the present glaciers are the remnants. Projecting rock pinnacles and peaks are rare and even the ridge-tops are ice-smoothed or carry lateral moraines. This zone of the mountain is reminiscent of some of the less rugged parts of the Highlands of Scotland.

The valleys of the zone have the radial consequent pattern characteristic of the whole mountain, and at the lower margin of the zone grade upwards from forms of primarily fluviatile to mainly glacial form (*see* Fig. 2*b*). The main valleys traverse the zone and head on or near the central peaks, but there are numerous smaller, shallower valleys which terminate in small incipient cirques. The valley floors are generally smooth and composed of ground-moraine; rock outcrops are in the form of ice-worn bosses, lines of cliffs, and inclined tabular bodies margined by cliffs. Much of the ridge-tops is composed of moraine or trains of large erratics; an excellent example of the latter occurs between 11,500 and 12,000 feet two and a quarter miles north of the Highland Castle, between the Nanyuki North and Liki South rivers. The southern ridges of the Mackinder and Hausburg valleys are covered by long lateral moraines over much of their lengths, and lateral moraines also curve down into the valleys, such as that between 13,000 and 14,000 feet on the north side of the Teleki valley.

The depths of the valleys increase markedly upwards in the moorland zone, but in contrast to the alpine zone the valley floors are rarely stepped and contain few lakes. Carr Lakes, Lake Michaelson and Hook Tarn are among those which occupy glacially excavated rock basins; Lake Höhnel on the other hand is a lake dammed by moraine. Some of the smaller lakes, for instance the Hall Tarns, the two small lakes on the east side of the Nyamindi East valley, and Hook Tarn, occur on ice-scoured platforms of resistant rocks which project from the valley sides.

The depth of glacial erosion in the moorland has been insufficient to yield many good examples of hanging valleys. The left bank tributary valley of the Nyamindi one and a half miles south of Hidden Tarn is, however, one such example, and there are several lesser ones on the south side of the Gorges valley.

The Gorges valley exhibits many of the glacial land-forms typical of the mountain in a particularly clear and impressive form. The terminal moraines which mark the maximum extension of the glacier down this valley occur upstream of the Nithi waterfall, at 10,700 feet. The terminal moraine loop is cut through by the Nithi river to form an extremely narrow canyon partly choked by large fallen blocks. The depth of the canyon is approximately 80 feet. Upstream of the canyon there is a complex of well-preserved lateral and terminal moraines which extend up to two and a half miles west of the warfall. The average depth of the valley in this region is 300–400 feet. From the area of the Nithi waterfall up to Vivienne Falls the valley floor has only a very gentle slope, and immediately east of Vivienne Falls it is practically flat-floored. The depth of the valley increases markedly, however, and upstream of a point one mile east of Vivienne Falls the valley sides are precipitous cliffs. At Vivienne Falls is the first of the several steps which occur in the floor of the valley. The step above the Falls is occupied by a short flat section containing a swamp; the basin above the second step is occupied by Lake Michaelson, and the ledge above the third step (at 13,700 feet) is occupied by the deposits of a lake which has since drained away. A fourth step is surmounted by a partially dried up lake basin dammed by moraine at an elevation of 14,350 feet. At the third step the Gorges valley is constricted by the Hall Tarns platform, which is a flat-topped ledge half a mile wide projecting into the valley from its northern side. This platform is composed of a resistant trachyte neck, the upper part of which is a conspicuously ice-smoothed surface containing a number of small rock-basins occupied by lakes or lake deposits. The north-western part of the platform is surmounted by an oval moraine ridge 250 feet high. The southern margin of the Hall Tarns platform is a vertical cliff 600 feet high with a steep slope covered by large erratic blocks at its base. This slopes a further 500 feet down into Lake Michaelson.

In the floor of the narrow gorge below the Hall Tarns platform is an immense fallen block of rock derived from the columnar trachyte cliffs immediately above. This block, which is approximately 150 feet high and 300 feet long, has ice-smoothed and striated surfaces on one vertical face, and exhibits good subhorizontal columnar jointing. It is a large piece of the upper part of the Hall Tarns cliff, where the ice-smoothed surface is horizontal and the columnar jointing vertical, which has fallen off since the retreat of the glacier from this part of the valley.

Ithanguni mountain is a satellite volcano which supported a small ice-cap separate from the main system to the west. It is a squat, flat-topped satellite vent margined by a deep explosion crater occupied by Lake Alice on its north-west side. It supported a small ice-cap which smoothed the summit plateau, giving rise to an undulating plateau surrounded by cliffs of variable height. Shallow ice-cut valleys radiate from the plateau and the furthest extent of the ice is marked by a lobed fringe of moraines. Below the ice-eroded level the slopes are very nearly of ideal volcanic profile having only shallow canyons cut into unconsolidated ashes and agglomerates.

(2) *The Alpine Zone*

The large cirques at the heads of the major valleys, their inter-connecting ridges, the central group of peaks and the out-lying peaks of Tereri and Sendeyo constitute the alpine zone. The main water-shed on this uppermost part of the mountain is on the ridge linking Sendeyo-Simba Col—Pt. Lenana—Tilman Peak, Grigg Peak and Höhnel Peak and coincides with the Uaso Ngiro-Tana River watershed. The central group of peaks lies entirely in the Uaso Ngiro drainage area. The Mackinder, Hausburg and Teleki valleys have their heads on the main peaks, while the remaining valleys on the eastern side—the Hobley and the Hinde—have their heads on the Lenana-Sendeyo ridge. The floors of the cirques at the heads of these valleys are at elevations between 13,700 and 14,100 feet, and many of the inter-connecting ridges are some 1,200 feet higher, but locally the rise to the highest peaks is much greater; the rise from Shipton's cave in the Mackinder valley, and from Mackinder's Camp in the Teleki valley to the summit (Batian) is 3,350 feet.

As is commonplace in alpine terrain the most conspicuous peaks (horns) occur at the intersections of the ridges bounding three or more cirques. Examples are Tereri, Sendeyo, Pt. Lenana, and the Coryndon, Delamere and Macmillan group. Numerous rock pinnacles (*gendarmes* in mountaineering terminology) occur on the higher ridges, and are well developed on the ridge between Sendeyo and Simba Col, and some others have been named, such as the Tooth, Thomson Flake and Pt. Thomson.

The main peaks of Mt. Kenya (Batian, Nelion, etc.) are in a separate category from the remainder, for their characteristic form and extra height is due largely to the peculiarities of the nepheline-syenite of which they are composed. The summit massif (*see* Fig. 10 at end) is composed of Batian (the summit, 17,058 ft.), Nelion (17,022 ft.) and Point Piggott (over 16,100 ft.), and is in the form of a reversed letter E, which faces south-westwards. The principal ridge is that connecting Pt. Piggot-Firmin Col-Petit Gendarme-Grand Gendarme-Batian-Gate of the Mists-Nelion-Mackinder's Gendarme-Pt. John and Midget Peak. A steep buttress descends from Batian to the south-west, and another descends northwards from the Petit Gendarme and carries Points Dutton and Peter. The north face is a precipitous cliff cut by narrow gullies and stone-chutes, and lies between the Krapf and Northey glaciers.

A subsidiary group of small peaks occurs in the head of the Hausburg valley to the west of the main massif, and comprises Arthur's Seat and the Eastern and Western Terminals. These peaks together with the main massif are all composed of the phonolites and syenites which form the sub-circular plug of the Mt. Kenya volcano. The steep conical form of many of the minor peaks such as Pt. Dutton, Midget Peak and Pt. John (*see* plates I and II), is found repeated on nearly all the ridges, and accounts for the pleasant symmetrical outlines which characterize the central peaks, particularly when seen from the west. These forms are controlled largely by the joint system within the nepheline syenite.

The most important joints are concentric planes with a very steep outward dip, such as those which form the greater part of the north-east faces of Batian and Nelion. Frequently nearly vertical intersecting joints give rise to crude columnar jointing, such as in the western face of the south ridge of Nelion, and on the north-west ridge of Batian. A subsidiary set of joints is inclined at approximately 45 degrees to form an intersecting system, but these are comparatively widely spaced and only locally exert a notable effect. Such places are on the lower south face of Batian, north-west of the Darwin glacier, on the eastern face of the south ridge of Nelion; and very conspicuously on the west face of Batian.

A basaltic dyke, which due to its more easily eroded nature forms a narrow gulley, cuts across the eastern face of the north ridge of Batian and forms the Gate of the Mists. It passes beneath the Diamond glacier and bisects the buttress between the two snow and ice *couloirs* that descend to the Darwin glacier. A further phonolite dyke forms a narrow chimney on the north face of Pt. John.

The concentric steep joints are most marked in the area between Arthur's Seat, Western Terminal and Emerald Tarn, where they show particularly well on air photographs. It is in this area that the ring structure of the central plug is best developed.

Around the foot of the main peak are a number of small lakes situated mostly in the floors of the large cirques. Among the rock-basin lakes are Oblong, Hausburg, Emerald and Nanyuki Tarns in the head of the Hausburg valley, and Gallery and the larger of the Thompson Tarns in the Hobley valley. Other small lakes dammed by moraine are Tyndall Tarn, Harris Tarn and Kami Tarn. Both the Curling Pond and the Lewis Tarn are small pro-glacial pools, the former being the only body of water to be permanently frozen over. The rich sapphire colour of many of the small lakes on the mountain is due to the presence of algae, while diatoms form a very high proportion of the sediment deposited in these lakes. Lakes Höhnel and Ellis are, however, of a brown shade due to the abundance of lacustrine vegetation and the resulting humus-stained water.

The base of the main peaks is incompletely fringed by comparatively recent moraine-loops, which occur at distances of a few hundred feet below the present glaciers. These moraines are well-preserved and commonly comprise a closely spaced double loop approximately 10–30 feet thick (*see* plate II, Fig. 1).

3. Erosion Surfaces

Although the only erosion surface that can be inferred in the present area is limited to parts of the Sagana valley, brief consideration of the erosion history of the neighbouring areas is desirable in that it permits estimations of the ages of the various volcanic groups to be made in the absence of evidence from fossils.

The metamorphic floor beneath the Simbara Series is exposed at intervals in the Sagana and Nairobi valleys. In the Sagana valley one and a quarter miles west of Tumu Tumu hill the volcanic/Basement System junction is at 5,150 feet, and it occurs also in the Nairobi and Sagana valleys at the latitude of Kiganjo at 5,550 feet. The northernmost exposure of the junction is in the Thego river one mile south-east of Ngondi, at 5,650 feet. The Basement System inliers at Marua and Kailewa rise well above the level of this junction. The exposures of the sub-volcanic floor mentioned above are co-planar with the conspicuous bevel which occurs on the belt of metamorphic hills west of the Sagana valley in the area to the south (Fairburn, 1966), and can be traced as far as the latitude of Sagana township. It can be traced further south, across the Maragua gap, and finally merges with the surface defined by the base of the Yatta phonolite. The sub-volcanic surface in this part of Kenya has been shown to approximate to the sub-Miocene erosion surface (Pulfrey, 1960; Fairburn, *op. cit.*).

The sub-volcanic surface beneath the older phonolites of Mt. Kenya is exposed between Meru and Embu, and south-east of Embu (Schoeman, 1951; Bear 1952), and occurs at elevations usually between 3,000 and 4,000 feet. Bear (1952, pp. 4–5) describes the phonolites of the Munyori and Kavukumo areas resting on a peneplain at 3,800 feet, and recognizes residuals of this plain south of the Tana river. In the Embu-Meru area, however, the sub-phonolite floor is seen to be irregular, and the phonolites rest on an inclined surface which slopes much more steeply than any of the erosion surfaces known in central Kenya. Furthermore the whole of the exposed sub-phonolite floor is lower than the elevation of the sub-Miocene erosion surface in this area, for the latter is at elevations between 4,000 and 4,500 feet along the eastern and south-eastern margins of the Mt. Kenya volcanic field. The writer therefore disagrees with the statements of Bear and Schoeman (*op. cit.*), that the Mt. Kenya phonolites rest on the sub-Miocene peneplain. It is more likely that the phonolites rest on an undulating surface lowered in many places well below the level of this plain, and, in places such as the sector east of Chuka, lowered even below the projected level of the end-Tertiary (mid-Pliocene) erosion surface. On this evidence therefore the age of the Mt. Kenya phonolites of the south-eastern sector of the mountain is no older than Upper Pliocene.

Shackleton (1945, p. 5) showed that the basalts erupted from vents low on the northern slopes of Mt. Kenya flowed through valleys in the Loldaika hills and spread out on the end-Tertiary erosion surface south of the Uaso Ngiro river. For this reason he believed them to be of Lower Pleistocene age. A similar situation is presented by the basaltic field on the lower southern slopes of the mountain. These basalts extend into the area to the south as far as latitude 0° 45′ S., and can be seen to rest on a well-marked erosion surface locally. The furthest tongue of these basalts descended the Thiba valley south-east of Embu, however, where it lies considerably below the erosion surface. The erosion surface, which lies at elevations between 3,600 and 4,000 feet in the Fort Hall-Embu area (cf. Fairburn, 1966), is believed to be part of the end-Tertiary (mid-Pliocene) bevel. Both the basalts of the northern and southern slopes of Mt. Kenya are known to be among the youngest volcanic rocks of the area, and since they appear to rest on, or locally below the end-Tertiary bevel, they must be considered as wholly Pleistocene in age.

The evidence summarized above suggests that the vulcanicity of Mt. Kenya began shortly before the maturation of the end-Tertiary (mid-Pliocene) erosion surface, and continued for a considerable time after it had begun to be incised by a new erosion cycle. For these reasons the Mt. Kenya volcanics are considered to be Plio-Pleistocene in age. Since they are largely if not wholly Pleistocene they have been tentatively classified as such in various tabulations.

III.—SUMMARY OF GEOLOGY

The geology of the area can be summarized in the following tabulation:—

					Maximum observed thickness, feet.
Recent	Superficial deposits—soils, laterites, ashes, younger moraines, glaci-fluvial deposits, older moraines.				
Pleistocene	Mount Kenya Volcanic Series		basaltic pumice cones		200–300
			Thiba Basalts		>500
		parasitic vents	Ithanguni and other trachytic volcanics and necks	c.	1,200
			agglomerates		>600
		fissure eruptions	riebeckite trachytes		80
			olivine basalts		700
			mugearites, olivine trachytes		800
		Main eruptive episode	nepheline syenite and phonolite of the plug		—
			kenytes, phonolites and pyroclastics ..		>1,800
			phonolites and trachytes		>1,600
			rhomb porphyries		1,100
			phonolites		0–400
			unexposed volcanics	c.	9,500
			lower basalts	c.	150
Pliocene	Laikipian Basalts—olivine basalts, basanites, olivine nephelinites			c.	400
	Nyeri Tuff—trachytic tuffs and agglomerates ..				100
Miocene (?)	Simbara Series—basalts and agglomerates ..				>250
Pre-Cambrian	Basement System—micaceous and graphitic gneisses, amphibolites, quartzo-felspathic gneisses, and pegmatites				—

IV.—DETAILS OF GEOLOGY

1. Basement System

Metamorphic gneisses and schists of the Basement System outcrop at the southern, eastern and northern margins of the Mt. Kenya volcanic field, and occur as inliers in the south-west part of the Mt. Kenya area (*see* sketch-map of the Mt. Kenya suite, at end). Blocks of metamorphic rocks are common high on Mt. Kenya in the trachytic agglomerates west of Ithanguni, and it is clear that Basement System rocks form the foundation of the volcanics in the area.

Basement System inliers beneath the Simbara Series basalts and agglomerates occur in the Sagana, Nairobi and Thego valleys, and project above the volcanics at Marua and Kailewa. Further inliers occur at the southern boundary of the area in the Miseri river and in the area immediately west of Kabonge village. Exposures in the latter area are of hornblende-biotite gneisses with numerous patches, irregular veins and stringers of pegmatite and aplite. In more leucocratic zones felspar *augen* are developed.

The scattered exposures in the Nairobi and Thego rivers are mostly of coarse streaky biotite gneisses, with occasional thin quartzo-felspathic granulites. In the Thego river two miles east of Kiganjo there is a series of muscovite-biotite-graphite schists totalling 75 feet in thickness exposed in the river bank. A few thin bands are moderately rich in graphite, but the flakes are very fine and the graphite content too low to warrant economic consideration. There are no exposures on the upper part of the Kailewa inlier, but sandy soil and the presence of loose pieces of quartz, pegmatite and coarse biotite gneiss point to the constitution of the hill. There are exposures in the small valley one and a half miles south-west of Hiriga village. They are of massive quartzo-felspathic granulites with scattered iron oxide grains.

Highly weathered muscovite-biotite gneiss is being dug in a quarry immediately north-west of the Marua building stone quarries, and is being used as the basis of the cement-stabilized foundation of the new Karatina-Nyeri road. The gneisses are overlain unconformably by the uppermost member of the Nyeri Tuff.

In a ditch beside the new road at a point half a mile north-west of Kaiyaba village gritty quartzose soils outcrop beneath a two foot layer of dark grey swampy clays. This occurrence is suggestive of a Basement inlier in the vicinity.

The Basement System inliers of the south-western part of the area appear to represent the exposed parts of a sub-volcanic ridge extending from the Ithanga and Kakuzi hills in the area to the south, through the Fort Hall-Sagana region into the Marua-Kailewa-Ngondi area.

2. Simbara Series

The Simbara Series (Shackleton 1945, p. 2) and its equivalent to the north, the Samburu Series (Shackleton 1946, pp. 29–31) are the oldest of the volcanic rocks over a wide area east of the Rift Valley. Representatives of the Series outcrop in the sides of the main valleys in the south-western corner of the area, where they rest on Basement System rocks and are overlain by the Nyeri Tuff. The maximum thickness of the Series in the present area is developed in the Sagana valley below Kathangeini quarry west of Tumu Tumu, the thickness here being 250 feet. The Series thins towards the north, and in the Ngondi-Kiganjo-Chieni Forest area the overlying Nyeri Tuff rests directly on the Basement System.

The best sections in the Simbara Series are found in the vicinity of the Sagana Falls Power station, where nearly 100 feet of the Series is exposed at the falls. The following account is based partly on an unpublished report by A. Huddleston. The succession at the Falls and in the immediate neighbourhood is as follows:—

	feet
soft grey tuffs (Nyeri Tuff)	*c.* 80–100
lenticular boulder beds	0–15
columnar olivine basalt (Sagana Falls basalt) ..	40
brown basaltic tuffs	3–5
basaltic conglomerate	2–4
basaltic agglomerate	*c.* 30

The Sagana Falls basalt forms the lip of the waterfall, and can be traced as a feature which locally forms columnar cliffs as far down the Sagana valley as the confluence with the Karuarua Kamu stream, and it outcrops in the river upstream of the Falls as far as the

Marua bridge, and at the Sagana-Chania confluence. It does not appear, however, in the Chania river at the same level. It forms the upper member of the Simbara Series in the Sagana valley, and the lenticular boulder beds above are regarded as marking the unconformity between the Series and the overlying Nyeri Tuff.

Occupying the floor of the Sagana valley downstream of the falls, and in the Muringato and Chania valleys, are scattered exposures of basaltic agglomerates containing olivine basalt, porphyritic basalt and olivine-nephelinite fragments. The agglomerates contain both vesicular and porphyritic olivine-bearing picrite-basalt such as specimen 44/1258* from the foot of the Sagana Falls. The picrite-basalt contains notable amounts of zeolites in vesicles.

In the Muringato and Nairobi valleys one and a quarter miles south-west and three quarters of a mile north of Kirichu village the agglomerates are rich in fragments of porphyritic augite basalt and basalts with clusters of felspar phenocrysts. Among the Muringato exposures are some with fissile basalt fragments, and blocks of this type up to three feet in diameter occur in the railway cuttings north of Kirichu village.

3. The Nyeri Tuff

The Nyeri Tuff (Shackleton 1945, p. 3) forms an easily recognizable bed and can be seen in numerous quarries where it is worked as a building stone. The tuff occurs between the underlying Simbara Series and the overlying Lakipian Basalts, but oversteps the Simbara Series and rests directly on the Basement System in the Kiganjo-Chieni-Ngondi area.

The best exposures of the Nyeri Tuff are in the Nairobi river north-east of Kiganjo, where there are two large quarries on the eastern side of the valley. In the northerly quarry, on Doig's Farm, a quarry face nearly 200 yards long exposes the following section:—

	feet
basaltic rubble (Laikipian Basalts)	4
grey basaltic tuff	1–3
weathered tuff and lateritic soil	1–2
brownish grey weathered trachyte tuff	4–5
pale grey trachyte tuff (building stone)	24
medium to dark grey gritty tuff (base not exposed)	6

A similar succession is exposed in the southern quarry, but in the Nairobi river below this quarry there are cliffs of finely agglomeratic brownish grey tuffs up to 30 feet high. The base of the river exposure is some 100 feet below the top of the tuff exposed in the nearby quarry. Biotite gneisses are exposed in the river some 400 yards downstream from this point, and the estimated thickness of the tuffs in this area is approximately 100 feet. Scattered exposures in the valley side a quarter of a mile east of Kiganjo show that the lower part of the tuff is agglomeratic, with fragments of pumiceous trachyte up to three inches in diameter. Scattered trachyte agglomerate exposures occur on the path descending into the Nairobi valley one and a half miles south-east of Kiganjo.

A small disused quarry in the side of the Thego valley three-quarters of a mile south-east of Ngondi exposes pale grey tuff with lensoid pumice fragments, and scattered small tuff exposures are found alternating with exposures of Basement System rocks downstream in the Thego river as far as its confluence with the Sagana. Small disused quarries expose the tuff in the Chieni Forest one mile east of Kirichu village and immediately south-east of Gatunganga trading centre.

The best of the numerous exposures in the vicinity of Marua village is at the large Kahiga stone quarry three quarters of a mile north of Marua village, and at the quarry by the main Nyeri road immediately north-west of the village. The sections in the quarries are:—

	I *feet*	*II* *feet*
spheroidally weathering Laikipian Basalt	—	20
soft yellow-brown pumice tuffs with felspar fragments	8	12
soft weathered trachyte tuff	6	10
grey trachyte tuff (building stone)	14	6
brown-grey agglomeratic tuff	5	not exposed

I—Kahiga quarry
II—Quarry three-quarters of a mile north-west of Marua

*Numbers 44/1258 etc. refer to specimens in the regional collections of the Geological Survey, Nairobi.

In the Karatina-Nyeri road cutting east of Marua village the upper parts of the Nyeri tuff are exposed. The section due east of the village is:—

	feet
grey fine-grained tuff	12
well-bedded, yellow-brown tuffs	12
grey fine-agglomeratic tuff	20
	(base not exposed)

At the next road cutting to the south the overlying Laikipian Basalts cross the road at the bend, their base being approximately 50 feet above the yellow-brown tuffs of the previous locality. Beneath the basalts dark brown pumice tuffs with numerous small felspar crystals are exposed. A futher road cutting one mile south-east of Marua village exposes grey trachyte tuffs at road level overlain by yellow-brown tuffs grading upwards into deep red-brown soil. Near this locality spheroidally weathering Laikipian Basalt is exposed in a small quarry—the base of the basalt appears to be about 25 feet above the top of the grey tuffs.

Scattered exposures in the sides of the Sagana valley between Marua and the southern boundary of the area show that the Nyeri Tuff rests on the Sagana Falls basalt, which is the upper member of the Simbara Series in this area, and that the average thickness is approximately 100 feet. The last good exposure of the tuffs is seen in the Kathangeini quarry, near the southern margin of the area, where 30 feet of homogeneous medium to dark grey trachyte tuff with felspar and small pumice fragments occurs, and is overlain by 15 feet of soft, weathered yellowish brown tuffs of similar lithology.

Summarizing, the Nyeri Tuff of the present area is generally approximately 100 feet thick and rests with unconformity on the Simbara Series. The lower half of the formation is poorly exposed but seems to be finely agglomeratic. The upper half consists of a fine-grained homogeneous grey tuff much used as building stone, and which is between 12 and 25 feet thick. This is followed by friable yellow-brown pumice tuffs which are often brown near the top and show feeble bedding. The upper boundary is a mature soil overlain by Laikipian Basalts.

Two specimens of the tuffs were collected from the Kahiga quarry near Marua, specimen 44/1248B of the upper grey tuff (building stone), and 44/1249 from the lower, darker slightly agglomeratic tuff. Specimen 44/1248B is pale grey with numerous sub-angular pumice fragments up to one inch long, and scattered fresh felspar fragments up to one millimetre long in a fine-grained matrix of clay grade with minute claystone lenticles. All the lenticles and pumice fragments show a strong parallel alignment which is sub-horizontal in attitude in the exposures. Specimen 44/1249 is generally similar, but is darker on account of the much greater proportion of pumice fragments.

In thin section the slices show the presence of alkali-felspars up to one millimetre in size, in a cryptocrystalline clay matrix. There are small oval cavities lined with spherulitic growths, and rare green aegirine grains occur also. Some of the small clear grains may be quartz. These rocks are distinct from the similar trachytic tuffs which contain flattened glassy lenses and shards and which have been called welded tuffs. Nevertheless their bedded character and the presence of a parallel fabric suggest that they are the results of hot ash flows comparable to *nuées ardentes.*

The Nyeri Tuff dips to the south-east with remarkable regularity, its slope being approximately 50 feet per mile. It passes into the area to the south, where it has been correlated with the upper member of the Upper Athi Series (Fairburn, 1965). Shackleton tentatively correlates the Nyeri Tuff and the Kinangop and Suguroi tuffs, which are of similar lithology and geological setting (Shackleton 1945, p. 6). If these correlations can be sustained the Nyeri Tuff and its equivalents to the south and in the Rift Valley provide a most valuable marker horizon.

4. The Laikipian Basalts

The Laikipian Basalts were first described by Gregory (1921, pp. 136–143) and re-defined by Shackleton (1945, pp. 3–4). Shackleton (op. cit. pp. 3–5) showed that in the Amboni valley north of Nyeri the phonolitic agglomerates of the Mt. Kenya Volcanic Suite rest on Laikipian Basalts in one place, and in another directly on Simbara Series. He assumed, however, that the bulk of the Laikipian Basalts overlie the Mt. Kenya agglomerates along their junction north of Nyeri. Evidence from the present area suggests that the Laikipian Basalts wholly underlie the Mt. Kenya Volcanic Suite. It follows that the basalts erupted from vents on the northern slopes of Mt. Kenya (Shackleton 1946, p. 39) and the basalts erupted on the southern slopes of the mountain (the Thiba Basalts of the present report), both of which Shackleton included in his Upper Laikipian Basalts (cf. Shackleton 1945, table facing p. 6), are in fact much younger than the Lakipian Basalts of the type area in southern Laikipia and on the Aberdare dip-slope, and should be given the status of separate formations. The term Upper Laikipian Basalts should therefore be allowed to lapse.

It is proposed that the term Laikipian Basalts be restricted to the basalts of the Aberdare dip-slope, which rest on the Nyeri Tuff and underlie the outer formations of the Mt. Kenya Volcanic Suite. The basalts erupted from vents on the northern slopes of the mountain, which are younger than the Laikipian Basalts, are outside the present area, but the similar basalts on the southern slopes are named the Thiba Basalts.

The Laikipian Basalts occur in the south-west corner of the present area, where they form the upper part of the dissected and inclined Aberdare dip-slope. Exposures of these basalts are poor and scattered on account of the deep soils that have developed on them, but can be found in most of the steep streams tributary to the main rivers. The Laikipian Basalts reach their maximum development near the southern margin of the area, where they are approximately 300 feet thick. They thin markedly northwards, and in the area of Ngondi and the Sagana-Nairobi confluence they are no more than 50–100 feet thick. It should be noted that the northern margin of the Lakipian Basalts in this area is largely conjectural.

The Laikipian Basalts are compact dark grey rocks frequently exhibiting hackly fracture. In hand specimen small zeolite filled vesicles are often seen, and in some specimens minute olivines can be made out. They frequently show a well-marked columnar jointing, such as that well exposed in the main road cutting one mile north-east of Sagana Power Station, and in stream sections the columnar flows often give rise to small waterfalls. In weathered exposures a tendency to spheroidal weathering is apparent, and in more deeply weathered exposures the unaltered basalt remains as scattered rounded blocks in deep red-brown soil, as in the road cutting three-quarters of a mile north-west of Marua village.

Petrographically the basalts are of alkaline and ultra-mafic tendency—they range from olivine alkali-basalts through basanites to olivine-nephelinites, the basanites being the most numerous. The undersaturated alkali mesostasis which characterizes them all was not specifically determined, but the characteristic late vesicle fillings are always of turbid zeolites. Olivine as slightly altered microphenocrysts is present in all the rocks. The most felspathic rock, specimen 44/1288, was collected in the Karuarua Kamu stream north-west of Tumu Tumu. Specimens 44/1315 from the stream one third of a mile south-east of the Sagana Falls, and 44/1314 from the road cutting one mile north-east of the Falls, are basanites characterized by well-formed olivine microphenocrysts in a matrix of abundant purplish augite prisms and granules, scattered small plagioclase laths and a clear alkali mesostasis. Scattered iron ore occurs also.

Occurring higher in the succession, possibly forming the uppermost flow over much of the area, are olivine-nephelinites represented by specimens 44/1312 and 1313 from road-side exposures one mile north-west and three-quarters of a mile west-north-west of Marua village. Similar rocks were collected high in the succession in the area to the south from a point one mile south of Muthinga village (44/1316), one and a half miles south-west of Tumu Tumu (44/1317), and two miles south-east of Tumu Tumu (44/1318). At the latter locality is the only good exposure showing the Tumu Tumu trachyte, which is part of the Mt. Kenya Volcanic Suite, overlying the Laikipian Basalts.

5. The Mount Kenya Suite

The Mount Kenya Suite (Shackleton 1945, p. 4; 1946, p. 35) includes all the volcanic rocks erupted from Mt. Kenya and from sattelite volcanoes on its flanks, excepting only those that appear to belong to a separate and petrographically dissimilar volcanic episode, namely the Thiba Basalts and the basaltic pumice cones of the northern slopes.

The Mt. Kenya Suite covers an area of approximately 2,700 square miles, an area which is roughly circular in plan and with an average diameter of 65 miles (*see* Fig. 11 at end). Since the original outline of the volcanic pile can be re-constructed due to the relatively small amount of erosion which has affected the lower slopes, the volume of the volcanic pile before erosion can be estimated, and is approximately 2,300 cubic miles. The volume of the pile at the present day is approximately 1,500 cubic miles, some 35 per cent having been removed by erosion.

The age of the first volcanics of the suite is not known with any accuracy, but can be estimated in a general way from the erosional history of the area to be sometime in the upper Pliocene. The relatively young Thiba Basalts which overlie the Mt. Kenya Suite on the southern flanks of the mountain are much younger than the maturation of the mid-Pliocene peneplain, and are probably comparable in age with basalts of the northern slopes, which Shackleton (1946, p. 38) found to be overlain by soils containing Kenya Fauresmith and Levallois artefacts.

It should be remembered when considering the following description of the Mt. Kenya Suite that the volcanic succession was originally some 16,500 feet thick at its maximum near the centre, that some 5,000 feet of the upper part of the pile has been removed by erosion, and that only 2,000 feet of the succession is exposed in the alpine zone at the present day.

The remaining 9,500 feet of volcanics which form the basis of the mountain at the present time are unexposed and their nature is largely uknown.

The sub-divisions adopted in the succeeding description of the Mt. Kenya Suite are based largely on evidence obtained on the upper slopes of the mountain, which could be studied in much greater detail than the lower slopes due to better exposures. The difficulties in arriving at a satisfactory succession on a volcano are considerable, for such phenomena as the simultaneous eruption of volcanics from separate vents, the tendency for lavas to flow down relatively narrow valleys, first down one sector and later perhaps down another, introduces a degree of complication not normally found in sedimentary sequences. The limits of the formations described below are drawn at unconformities where these are observed or inferred, or alternatively at changes of lithology where these seem to be of more than local significance.

The Mt. Kenya Suite is divided into two parts—the volcanics of the main eruptive episode, and the volcanics of the sattelite vents. The former are mainly the volcanics erupted from the main vent that is now blocked by nepheline syenite, and the latter are the volcanics erupted from sattelite vents and from fissures on the side of the main crater. The two periods of vulcanicity are separated by the consolidation of the syenite and phonolite of the central plug.

A tabulation summarizing the succession and thicknesses of the components of the Mt. Kenya Suite is given below:—

			Maximum observed thickness—feet
parasitic vents		basalt pumice cones	200–300
parasitic vents		Thiba Basalts	>500
parasitic vents		trachytic plugs	*c.* 400
parasitic vents		Ithanguni trachytes and tuffs	*c.* 1,200
parasitic vents		Mugi agglomerate	>600
parasitic fissure eruptions		riebeckite trachytes	80
parasitic fissure eruptions		olivine basalts	700
parasitic fissure eruptions		mugearites	800
main volcanic episode		consolidation of phonolite and nepheline syenite of the main vent.	
main volcanic episode		porphyritic phonolites, kenytes and agglomerates	>1,800
main volcanic episode	parasitic vents	tuffs and agglomerates	1,600
main volcanic episode	parasitic vents	fissile phonolites and alkali trachytes	>1,600
main volcanic episode	parasitic vents	porphyritic phonolites	0–400
main volcanic episode	parasitic vents	rhomb porphyries	>1,100
main volcanic episode		unexposed volcanics	*c.* 9,500
main volcanic episode		lower basalts	*c.* 150

older volcanics or Basement System.

(1) The Main Eruptive Episode

(a) *The lower basalts*

Occurring between the northern margin of the exposed Laikipian Basalts and the southern margin of the phonolites and agglomerates in the area around Ngondi and the Royal Lodge on the Sagana river, are scattered exposures of basalts which appear to overlie the Laikipian Basalts and underlie the phonolites of the higher ground to the north. The only exposures of these rocks to be seen are in small roadside quarries and diggings along the Kiganjo-Ngondi-Tagwa hill road, and in the Thego river near the Thego Fishing Camp. An inlier of similar basalt was seen at the ford over the Nairobi river six miles north of Ngondi, and further exposures are seen at intervals in the Muthera river south of Niana hill, and in the Kamwoya river one and three-quarter miles west-south-west of Hombe Forest Station. Good exposures can be seen on the rising ground immediately east of the Kiganjo-Naro Moru road two to two and a half miles north of Kiganjo.

These basalts are dark to medium greenish grey in colour and with a tendency to hackly fracture. They contain no macroscopically visible phenocrysts and tend to weather easily to a gravel. They frequently exhibit a tendency to polygonal jointing and crude horizontal partings, and the flow exposed in the Thego river shows good columnar jointing. Their field appearance differs from that of the Laikipian Basalts in the occurrence of horizontal partings, the presence of a greenish shade and the gravelly weathering.

Two specimens were collected in the Ngondi area, specimen 44/1245 from the side of the main Nanyuki road two and a half miles north of Kiganjo, and 44/1244 from the Ushekwa river crossing two-thirds of a mile north-east of Thego Fishing Camp. Specimen 44/1245 contains numerous iddingsitized olivine microphenocrysts in a matrix of basic plagioclase, abundant augite granules and sparse iron ore. There are numerous patches containing slightly turbid zeolite. Specimen 44/1244 is slightly different in that olivine is much less abundant and the plagioclase is intermediate in composition. Both rocks are varieties of olivine alkali-basalts.

Specimens 44/1280 from the Muthera river south-east of Niana hill, and specimen 44/1252 from one mile south-east of Ngondi differ from those described above in having fissile structure and matrices with trachytic texture. Under the microscope both rocks are seen to contain oligoclase-andesine laths and fine aegirine-augite granules, a little fine iron ore and a suggestion of an alkali mesostasis. The rocks are alkali-andesites.

(b) *Rhomb porphyries and the Polish Man's Tarn vent*

Among the older volcanics exposed on the upper western part of the mountain are rhomb porphyries and subordinate phonolites on the north-western sector between the Teleki and Liki North valleys. They were erupted from a centre immediately south-west of Polish Man's Tarn, and are overlain by the porphyritic phonolites and kenytes erupted from the main vent, and by the trachytes and fissile phonolites erupted from a satellite vent. They rest on the porphyritic phonolites from the main vent in the area of Shipton's Cave.

The best exposures occur along the ridge between the Hausburg and Nanyuki North valleys, between the 13,000 and 14,300 foot levels, and in the Burguret valley in the Campi ya Farasi area.

The typical rhomb porphyry is a medium grey, compact lava, characterized by the presence of numerous rhombic felspar phenocrysts and by the absence of macroscopically visible nepheline. In most examples the phenocrysts are approximately one and a half centimetres long, but in some flows near the top of the succession exposed in the inliers in the Liki North valleys the felspars reach lengths of four centimetres. The rhomb porphyries are closely similar in field appearance, weathering and mineralogy to the porphyritic phonolites which overlie them, the only difference being the absence of nepheline phenocrysts.

Traversing towards the Polish Man's Tarn centre the rhomb porphyries show lateral changes at a distance of one mile from the centre. The lavas become steadily more vesicular, the matrix becomes glassy and is in shades of red and brown, and the rock weathers to fine gravel. The proportion of pyroclastics increases from a minor to a major amount and forms relatively thin beds with scoriaceous and de-vitrified lavas in the vicinity of the vent.

Under the microscope the phenocrysts of the rhomb porphyries are anorthclase which has been resorbed to a greater or lesser extent by the matrix, especially in an example of a glassy lava, specimen 44/1211 from one and three-quarter miles north-west of Polish Man's Tarn. In the latter rock and in specimen 44/1210 from four and a quarter miles north-west of the Tarn there are small partly altered olivine microphenocrysts.

The matrices of the five rocks sliced are variable, one has a fine saccaroidal texture of alkali felspar with interstitial pyroxene granules and iron ore, another (44/996B) collected from near the western margin of the vent has spherulitic texture, and the remainder have very fine-grained pilotaxitic matrices. All contain interstitial zeolite, and in some the zeolite occurs as turbid vesicle fillings. Small sparse nepheline phenocrysts were observed in some of the lavas outcropping in the floor of the Mackinder valley near Shipton's Cave, and nepheline was suspected in some others from the presence of small weathering pits. In composition the rhomb porphyries are clearly closely allied to the porphyritic phonolites of the super-incumbent formation. Their mineralogy is more clearly displayed in the better crystallized examples from the neck at Polish Man's Tarn, and from the neighbouring dykes.

The neck from which the rhomb porphyries were erupted is exposed immediately south-west of Polish Man's Tarn, and is represented by an inconspicuous sub-circular rock boss approximately 500 yards across composed of porphyritic microsyenite. A rock collected from near the centre of the neck (specimen 44/1208) is strongly porphyritic, the rhombic felspars reach four centimetres in length, and are set in a medium grained (0·2 to 1·0 mm.) matrix in which sparse anhedral reddish nepheline patches can be made out. The central part of the neck is homogeneous and closely jointed but there is a fine-grained marginal facies of slightly fissile green-grey rhomb porphyry with sparse felspar phenocrysts. Numerous north-west trending rhomb porphyry dykes cut the neck and the adjacent volcanics, especially around its northern margin. In thin section the porphyritic microsyenite (specimen 44/1208) is seen to contain anorthoclase phenocrysts up to four centimetres long set in a plexus of tabular alkali felspars with interstitial zoned aegirine-augite, brown alkali hornblende often with an aegirine skin, and minor amounts of anhedral nepheline. The nepheline is partly altered to analcite at grain margins. This rock is comparable to the nepheline syenite of the peak but differs from it in the occurrence of large rhombic anorthoclase phenocrysts and in the smaller proportion of nepheline. The presence of nepheline suggests that the rhomb porphyries are undersaturated and that in most examples zeolites proxy for nepheline.

The rhomb porphyries reach a maximum observed thickness of 1,000 feet in the Mackinder valley and their base is not seen. They form the lowest exposed volcanics on the western slopes but may not be the oldest lavas exposed on the upper part of the mountain, for they are likely to represent a phase of parasitic vulcanicity concurrent with the eruptions of the main centre. They are overlain by the porphyritic phonolites and agglomerates derived from the main centre and are probably underlain by these volcanics also (*see* p. 21).

(*c*) *The phonolite-kenyte sequence*

The porphyritic phonolites, kenytes and agglomerates which are described below form the bulk of the Mt. Kenya Suite. They outcrop extensively on the western and eastern slopes and occur beneath the later formations on the other sides. They were erupted from the main vent of the volcano and their symmetrical disposition about this vent proves that it was dominant throughout the later life of the volcano, and probably throughout its whole life. In the latest agglomerates of this sequence to be erupted the fragments are all of porphyritic phonolite, kenyte and fissile phonolite. This suggests that no large bodies of volcanics of other types lie hidden, and that the bulk of the unexposed volcanics are of phonolitic composition.

The phonolite and kenyte lavas, and the nepheline syenite that froze in the main vent, are chemically alike; the differences lie in texture and grain size. The kenytes are confined to the immediate vicinity of the central peak and are the glassy varieties of porphyritic phonolite. Every gradation between kenyte and phonolite is observed high up on the mountain, and on the lower slopes kenytes are absent except as blocks in agglomerate.

(i) *Porphyritic phonolites and agglomerates*

The porphyritic phonolites and agglomerates are the lateral equivalents of the kenytes, and form the greater part of the western and eastern slopes. They and the kenytes were erupted from the main vent over a lengthy period which embraced the eruptions of the two parasitic centres which produced the fissile phonolites, alkali trachytes, tuffs and agglomerates of the upper Teleki valley and the lake Höhnel area, and the rhomb porphyries of the Polish Man's Tarn vent. The evidence suggests that the phonolite main vent activity was concurrent with that of the parasitic vents of the western slopes, for there is apparently no significant break in the deposition of the porphyritic phonolites on the other sectors. The generalized succession on the western slopes is as follows; the phonolites considered here are indicated in italics:—

5. *porphyritic phonolites and agglomerates.*
4. alkali trachytes, fissile phonolites and pyroclastics.
3. *porphyritic phonolites (some with large rhombic felspar phenocrysts).*
2. rhomb porphyries—nepheline syenite neck, dykes.
1. *porphyritic phonolites (base not exposed).*

The porphyritic phonolites and agglomerates of the upper part of the mountain are exposed in the floors of some of the valleys of the northern and western slopes, and form the greater part of the south-east sector of the mountain. At a distance of two to three miles from the margin of the plug of the main vents they grade into kenytes. Agglomerates occur at all levels but are not conspicuous on the lower slopes of the moorland zone except at the base of the upper phonolite succession (5 of the table above), where they form notable beds resting on the fissile phonolites and alkali trachytes on the western and southern slopes.

The phonolites weather into rounded blocks and boulders, and outcrop in columnar cliffs. Like the kenytes extreme weathering and frost action in the alpine zone quickly reduces the blocks to a fine gravel which is an important constituent of the glacio-fluvial and lake deposits such as those in the Liki North valley. They are generally less resistant to weathering and glacial erosion than the other lava types with which they are inter-bedded, for the phonolites do not usually form the ridge-tops.

The upper phonolites and agglomerates form the whole of the basis of the forest zone and lower slopes on the western side of the peaks, but outcrops in the forest are extremely rare, and are little better on the lower slopes. In the forest belt the streams are generally choked with the gravels and boulders deposited during the over-loading of the streams at the time of the glacial maximum, and on the ridges only very rare large rounded blocks are seen projecting from the deep soil. Scattered phonolite exposures occur in the Embu district in the south-eastern corner of the area, and along the southern and eastern margins of this area agglomerates are the dominant exposed rocks.

Phonolitic agglomerates are common on the lower western slopes, west of Gathiuru Forest Station, and also in the Embu district in the extreme south-eastern corner of the area. On the western slopes they form the uppermost bed over wide areas, and are greenish brown compact rocks with boulders and fragments of porphyritic phonolite, fissile phonolite and kenyte set in a very fine brown tuff base. Higher on the mountain agglomerates are numerous as intercalations in the phonolite succession, but rarely form notably thick beds. At the base of the upper phonolites, however, at the 11,000–12,000 level on the interfluves between the Teleki, Burguret and Hausburg valleys inclined tabular agglomerates form bold crags such as the Highland Castle, where the agglomerates are at least 300 feet thick and contain blocks up to 30 feet in diameter, the average being 2–3 feet. Similar thick agglomerates occur near the base of the upper phonolites at the 13,000 foot level in all three branches of the Nyamindi valley.

In the hand specimen and under the microscope the phonolites are seen to be a remarkably homogeneous group. They are invariably porphyritic, carrying felspar and nepheline phenocrysts in greenish grey to grey compact fine-grained matrices. The felspars are generally tabular, well-formed and vary from 0·5 to four centimetres in length, the majority being in the one to two centimetre range. A few rocks with narrow lath-like flow-aligned felspars were seen. The nepheline phenocrysts range from 0·25 to two centimetres in size and are invariably smaller than the felspars in the same rock. They are generally sub-hedral to idiomorphic, waxy green, yellowish or porcellaneous buff in colour, and are sometimes not easy to distinguish from the matrix at first sight. There is considerable variation in the abundance of phenocrysts, the proportion varying from five to 40 per cent of the whole rock by volume—the felspars are usually as numerous as the nephelines, but not invariably so. The matrices are compact, often with a slight tendency to a hackly fracture—they are never fissile. They vary from grey-green to medium and dark grey, and are often finely mottled. Most of the specimens contain small ellipsoidal vesicles filled by zeolite and many contain larger partly lined vesicles. In only a few rocks are ferro-magnesian microphenocrysts visible with a hand lens.

Under the microscope the felspar phenocrysts can usually be identified as anorthoclase, and in many cases the crystals have suffered resorption by the groundmass leading to rounded and embayed outlines. The nepheline phenocrysts are frequently still more corroded, often losing their form as a result, and they are often partially replaced by zeolites along cracks. Olivine microphenocrysts occur in about half the slides examined, and are sometimes altered to iddingsite, or more rarely to serpentinous or chloritic masses. Apatite and aegirine-augite microphenocrysts are found in one third of the slides, often forming clusters with olivine and iron ore grains.

The ground-mass in these rocks is often very fine grained and indeterminate, being coloured in shades of brown and grey. In some of the finer lavas seriate alkali felspar laths are distinguishable. In the coarser examples, however, the matrix can be seen to be pilotaxitic—composed of a random mesh of tiny felspar laths, probably anorthoclase, with mossy patches of green aegirine, brown alkali hornblende and fine iron ore dust. In the majority of slides small elliptical pools of zeolites are found, and these often form the lining of the larger vesicles also. In one slide minute nepheline idiomorphs could be made out, and another, specimen 44/1045 taken from the Ontulili river at 8,700 feet, contains pools of pale blue sodalite.

Campbell Smith (1931, pp. 241–242) described one of Gregory's specimens collected from north-east of the Amboni river, seven miles north-north-east of Nyeri, a specimen which Gregory labelled Kapitian phonolite (Gregory 1921, p. 142), and which was described as such by Campbell Smith. The phonolite is certainly a part of the phonolitic series of Mt. Kenya, which is extensive north of the Amboni river, and Campbell Smith's description fits the general account of the Mt. Kenya phonolites very closely. Campbell Smith (*op. cit.*, p. 239) remarked on the very close resemblance of this rock (and some of the other Kapitian phonolites) to "Kenyte" specimens collected by Gregory higher up the mountain. Certainly the similarity between the porphyritic phonolites of Mt. Kenya and the Kapiti phonolite is very close (cf. Schoeman 1948, p. 36). A chemical analysis of the phonolite described by Campbell Smith (1931, p. 240) is quoted below:—

	per cent		*Norm*
SiO_2	52·10	or	27·80
Al_2O_3	22·29	ab	25·68
Fe_2O_3	1·73	an	8·34
FeO	4·10	ne	25·56
MgO	1·17	ac	—
CaO	2·42	di	—
Na_2O	8·60	ol	6·31
K_2O	4·66	mt	2·55
H_2O+	0·75	il	0·61
H_2O-	1·00	ap	1·34
TiO_2	0·30		
P_2O_5	0·46	W. H. Herdsman, anal.	
MnO	0·23		
Total	99·81		

The analysis indicates that the phonolite is more basic than the kenytes and nepheline syenite of the main peak (cf. p. 27) since it contains less silica, more normative anorthite and olivine. It is at the basic end of the phonolite series, of which kenyte and fissile phonolite are the intermediate and acid members.

(ii) *Kenytes*

Kenytes were first named by Gregory (1900, p. 209, 211–214) who examined the south-western slopes of the alpine zone of Mt. Kenya and distinguished three main lava-types—phonolites, kenytes and basalts. Kenyte was defined later by Gregory (1921, p. 147) as "igneous rock which consists of anorthoclase and aegirine, which typically contains glass and olivine and is the lava or dyke representative of olivine-bearing nepheline syenite".

Gregory's kenyte specimens were collected on the ridges between Mt. Höhnel (Castle Hill) and Top Hut, and from the southern side of the plug of the main peak (Gregory 1900, pp. 208–209), and were re-described by Campbell Smith (1931, pp. 242–243), who observed that Gregory had overlooked the nepheline phenocrysts in these rocks. From the accounts of the type rock and Gregory's later account (1921, pp. 146–147) it is clear that the type specimen (Gregory's number 499) is a somewhat altered example of intrusive porphyritic phonolite which forms part of the plug. Clearly Gregory regarded all the glassy or cryptocrystalline phonolites, most of them with partially devitrified matrices, as kenytes. Campbell Smith recognized the close mineralogical similarity between the kenytes and phonolites of Kapiti type (*op. cit.*, p. 243, 245), and the writer has confirmed that the kenytes are in fact textural varieties of normal phonolites allied to the Kapiti type. Gregory would probably have recognized the similarity between the "normal" (Kapiti type) phonolite of Mt. Kenya and his kenytes if he had seen the extensive occurrences of the former on the lower slopes of the mountain. Unfortunately he regarded the Mt. Kenya phonolites of the lower western slopes as representing the Kapiti phonolite (1921, p. 142), a phonolite which does not belong to the Mt. Kenya Suite. Shackleton (1945, p. 16) and Schoeman (1951, pp. 46–48), reporting on adjacent areas covering the outer western and eastern tracts of the Mt. Kenya volcanics, described the porphyritic phonolites common in these areas as kenytes. They evidently overlooked the necessity for kenytes to have glassy or devitrified glassy matrices.

The intrusive porphyritic phonolite which forms part of the Mt. Kenya plug, from which Gregory (1900, pp. 208–209) collected his type specimen of kenyte, is in a different category from the kenyte lavas described above. Although these intrusive rocks are superficially similar to the true kenytes in that they have a dense black base, this base is not glassy (cf. Campbell Smith 1931, p. 243) but micro-granular. Furthermore these intrusive rocks have been extensively brecciated and invaded by microsyenite which has resulted in a variable degree of alteration. In the writer's opinion these intrusive phonolites should be excluded from the kenytes on the grounds of their non-glassy matrix and different geological setting. They are described on p. 50.

The kenytes are the glassy or cryptocrystalline locally devitrified varieties of porphyritic phonolite. They characteristically contain numerous tabular felspar phenocrysts one to one and half centimetres long, and discoloured brownish, yellow-brown, greenish brown, or blue-grey nepheline phenocrysts up to three-quarters of a centimetre long. The matrix is rarely glassy and black, it is more often flow-banded with glassy and devitrified bands, and still more often homogeneous, "stony" and in shades of yellow-brown, brown, reddish brown, brick-red, liver and reddish grey. There is every gradation from these colours to the uniform grey to greenish grey micro-crystalline matrix of the phonolites of the lower slopes. There is therefore no precise dividing line between the kenytes and the porphyritic phonolites.

The kenytes are confined to the Alpine zone of the mountain, and the most extensive exposures are found in the heads of the Hobley and Gorges valleys, and on the high ridges above 14,000 feet on the eastern and southern slopes, where their exposed thickness is greater than 1,300 feet. Near to the main vent the kenyte flows are thin, approximately ten to 20 feet thick, and the succession contains more agglomerate than lava. The proportion of lava increases markedly away from the vent, till at a distance of two to three miles the lavas are thicker and form the greater part of the succession; tuffs are rare.

Among the thicker kenytes there is a tendency to columnar jointing and these flows form low cliffs. The kenyte terrain is characterized by ribbed valley sides and an abundance of fine scree composed mostly of material ranging from two to ten millimetres in size. In the zone of diurnal freezing the kenytes show a marked tendency to disintegrate into a gravel of small flakes, which weather further to a fine gravel—large blocks are relatively scarce. Reddish brown screes and miniature "stone glaciers" composed of material of pea grade are diagnostic of the kenyte outcrops of the alpine zone.

In hand-specimens the kenytes show an extraordinary variety of colours. In the head of the Hobley valley, on the ridge above Hidden Tarn and on the Sommerfelt Peak-Castle Hill ridge they are predominantly reddish brown to brick red in colour, with tabular felspar phenocrysts up to one and a half inches long and smaller nepheline phenocrysts usually very similar to the matrix in colour. Rarely a scoriaceous lava is yellowish in colour, and thicker flows tend to be reddish grey. The agglomerates, which are not plentiful on these ridges, are composed of similar rocks, but black glassy kenytes tend to be much more common in the pyroclastics than as flows. On the upper parts of the Coryndon, Delamere and Macmillan Peaks, stratigraphically above the dominantly red kenytes of the Hobley valley, are further kenytes with notable intercalations of agglomerate. These kenytes vary from slate-grey, khaki and putty coloured types to pale streaky yellow and brown-grey types. In the paler varieties, which are sometimes so altered and weathered as to have an earthy consistency, the nepheline phenocrysts are yellowish, and can hardly be distinguished in the matrix. On the upper part of the Delamere Peak the numerous rock pinnacles and spires are mainly of kenyte agglomerate and flow-breccia, with thin yellow-brown tuffs with glassy kenyte bombs. The more resistant cliffs such as form the buttress overlooking Hanging Tarn are of grey phonolite. At the 13,000 feet level between the Gorges and Hobley valleys the transition from glassy or devitrified flows to holocrystalline "normal" grey phonolites becomes obvious. The phonolites are thicker, there is less pyroclastic material, but several thin, one to two feet thick black glassy kenytes do occur. Similarly reddish grey "intermediate" phonolites are common around the un-named lake near the head of the Nyamindi East.

Further excellent sections in the kenyte-agglomerate sequence occur on the twin peaks Tereri and Sendeyo. The thin-bedded agglomerates and kenytes which build these peaks are highly irregular and lensoid in form. The flows are reddish brown, locally scoriaceous and full of cognate breccia fragments or of lithic debris rafted down from above. Here also there are occasional resistant flows of grey phonolite which give the ridges their stepped outline.

The ridge at the head of the Hinde valley, between the Hat and Simba Col is composed of kenytes, mostly reddish brown types with a few really glassy flows, and the ridge between Sendeyo and Simba Col is formed of kenyte agglomerates and red scoriaceous kenytes with some "normal" phonolites exhibiting variations in the number and size of the felspar phenocrysts.

Twenty-nine specimens of kenyte were collected, and in these the felspar phenocrysts varied from half to two centimetres in length, with the majority between one and two centimetres. Most of the felspars showed a stout tabular habit, in only two specimens are there thin lath-like felspars. In the devitrified glassy specimens of earthy appearance the felspars are frequently of the same colour as the matrix. The nepheline phenocrysts are invariably smaller than the felspars and less numerous; they range from two millimetres to one centimetre in size, the majority being about five millimetres long. In most rocks the nephelines are idiomorphic, but in some they occur as rounded blebs, often of a brown porcellaneous appearance. In the yellow-brown and red-brown kenytes the nephelines are often yellow, due to extensive replacement by zeolites, and zeolites occur as small ovoid vesicle fillings also. The matrices of six specimens are of black glass with perlitic cracks, a few others are flow laminated with alternations of black glass and reddish grey devitrified glass. The remainder are in shades of brown, brick red, reddish grey and reddish brown. Two specimens, both reddish brown, are of flow breccia full of small cognate kenyte fragments, and tend to a scoriaceous texture. Five other specimens have small angular vesicles, often partly zeolite filled, but large vesicles are found in only one specimen, and were observed to be very rare in the field.

Under the microscope the felspar phenocrysts are seen to be anorthoclase which exhibits cross-hatch twinning and lamellar twinning and sometimes both. The anorthoclases are subidiomorphic and have suffered varying degrees of corrosion and embayment by the groundmass. In one example, specimen 44/969 from the summit of Pt. Lenana, the felspars are full of tiny glass blebs, and an extreme example of corrosion, in which the originally tabular crystals reach a lensoid embayed form, is shown in specimen 44/1241 from the northern shore of Galley Tarn. This specimen also contains a faintly flow laminated red-brown glass matrix, such as is typical of these rocks, in which are tiny lensoid flow-aligned analcite filled vesicles, a few trapezohedral analcite grains, and analcite filling the narrow perlitic cracks traversing the glass matrix.

The nepheline phenocrysts are usually clear and only slightly resorbed by the matrix. They are, however, sometimes partially or even completely replaced by zeolites in the more altered examples. An example of zoned nephelines with pools of zeolite is seen in specimen 44/1073 from 14,700 feet on the north-west face of Tereri. This rock is unusual in containing small aegirine-augite microphenocrysts.

One third of the rocks sliced contain tiny colourless to yellow-green idiomorphic olivine microphenocrysts, but these are frequently converted to iddingsite in the more altered kenytes. Well formed apatite microphenocrysts occur in only a few specimens. One specimen (44/1003) from the foot of the north face of Pt. Thomson contains a few augite microphenocrysts.

The matrices of the kenytes are glassy, devitrified or cryptocrystalline. In the black glassy varieties the matrix is brown, red-brown or reddish grey in thin section, and usually exhibits flow lamination. In all the slides zeolites occur: in the unaltered glassy varieties as discrete clear pools, in the devitrified rocks as a more irregular and extensive mesostasis, and in extreme of hydrothermal alteration, as in specimen 44/1178, 1179 and 1181 from the col between Delamere and Macmillan Peaks, the matrix is partially devitrified and full of ramifying patches of finely granular zeolites, which in extreme cases make up to 20 per cent of the rock by volume. In a few rocks the small vesicles are zoned, the marginal parts being isotropic analcite, the intermediate zone flamboyant thomsonite or scolecite, and the centre calcite.

Some detailed mineralogical work has been carried out on the felspar phenocrysts of the kenytes by Rosiwal (1891, pp. 292–3) and Mountain (1925, pp. 35–36), and is quoted by Campbell Smith (1931, p. 244). The provenance of Rosiwal's specimen is uncertain but in view of their close similarity to the crystals described by Mountain from the kenyte tuffs and agglomerates on the west face of Castle Hill (Mt. Höhnel), both sets of specimens were probably derived from the kenyte succession. The details are:—

	Rosiwal (1891, pp. 492–3)	*Mountain* (1925, pp. 35–6)
specific gravity	2·598	2·602
extinction agle—		
on (001)	2°, 3·2°–3·8°, 2·2°–2·5°	2·9°
on (010)	10°, 5·6°–8·3°, 8°	7·8°
2V	—	51°
refractive indices α	—	1·526
β	—	1·530
γ	—	1·532
Composition—		
Or: Ab: An	27: 63·5: 9·5	27: 63: 10

The data indicate that the crystals are anorthoclase, the low optic axial angle being diagnostic, and the composition shows the anorthoclase to be sodic, near the analbite end of the anorthoclase field.

An analysis of a kenyte from the summit of Castle Hill (Mt. Höhnel) is given below, together with analyses of the intrusive phonolite and nepheline syenite from the Mt. Kenya plug, for comparison purposes.

	I *per cent*	*II* *per cent*	*III* *per cent*
SiO_2	53·80	53·98	51·64
Al_2O_3	18·46	19·43	19·12
Fe_2O_3	6·22	4·39	3·03
FeO	0·40	2·05	4·20
MgO	1·05	1·07	1·29
CaO	2·53	2·04	2·94
Na_2O	7·09	8·81	9·46
K_2O	5·46	5·27	4·37
H_2O+	3·54	1·66	1·63
H_2O-	0·85	0·13	0·39
TiO_2	0·31	0·57	1·58
P_2O_5	0·53	0·30	0·33
MnO	0·33	0·26	0·19
Totals	100·57	99·96	100·26*

*Includes 0·09 per cent Cl.

Norms

	I	*II*	*III*
or	32·80	31·14	27·6
ab	32·49	26·46	35·6
an	1·95	—	7·7
ne	15·05	23·71	16·2
ac	—	3·70	—
di	5·40	6·64	1·8
ol	—	0·14	1·6
mt	1·62	4·64	4·3
il	0·61	1·06	1·9
ap	1·34	0·67	1·0
hm	5·12	—	1·8

I—Kenyte, lava flow from the summit of Castle Hill (Mt. Höhnel). G. T. Prior, anal: (Prior 1903, p. 247).

II—Porphyritic phonolite (intrusive rock forming part of the central plug of the main vent of Mt. Kenya), probably collected from the rock rib immediately west of Top Hut. G. T. Prior, anal: (*op. cit.*).

III—Nepheline syenite, from north-west of the snout of the Lewis glacier (probably at the base of Midget Peak). F. Raoult, anal: (Lacroix, 1923, p. 258).

The chemical similarity between the kenyte and the plug rocks is notable, and the analysed example of the Mt. Kenya porphyritic phonolite (p. 24) is also very similar. The analyses therefore confirm the field evidence that these lavas are consanguineous. The fissile (Kenya type) phonolites and the alkali trachytes such as occur in the Lake Höhnel succession are at the acid end, and the porphyritic phonolite-kenyte-intrusive phonolite-nepheline syenite are at the basic end of the phonolitic rock-series which forms the main eruptive episode of the mountain.

(*d*) *Alkali trachytes, phonolites, tuffs and agglomerates*

The volcanics to be described occur on the south-western quadrant of the upper part of the mountain, in the Nyamindi West, Höhnel and Teleki valleys, the best sections being in the cliffs above Lake Höhnel. They consist of a variety of rock types characterized by their anomalous position and attitude in relation to the porphyritic phonolites and agglomerates which occur above and below them stratigraphically. The base of these lavas is seen only in the head of the Burguret valley east of Kampi ya Farasi, where horizontal fissile alkali trachyte flows rest, apparently unconformably, on west-dipping rhomb porphyries. The upper margin is well exposed at numerous localities on the slopes of the Castle Hill—Sommerfelt Peak massif south of the main peaks.

The trachyte-tuff-agglomerate volcanics are therefore interbedded in the sequence of porphyritic phonolites and rhomb porphyries which make up the main structure of the mountain, and the dips measured in these volcanics, which are radial outwards about a point some two and a half miles west of Batian, suggest that they were erupted from a satellite vent and not the main centre.

The best exposures are in the Höhnel valley and on Shipton Peak (*see* Fig. 4(*a*)). At 13,150 feet in the floor of the Höhnel valley are small outcrops of finely mottled green grey fissile trachyte and similar outcrops are seen on the valley side to the north at 13,800 feet. There are no exposures at the level of Lake Höhnel, the lake outflow channel being cut in moraine, but a good section is obtained in a shallow gully north of the lake. Here there are 450 feet of crudely bedded agglomerate consisting of reddish brown trachyte fragments, which continue up to the level of the top of the conspicuous phonolite cliff which overlooks Lake Höhnel to the east, where they are overlain by brown tuffs.

The cliff overlooking Lake Höhnel is formed of 200 feet of fissile pale green-grey phonolite, which is either a lensing flow or has been locally eroded previous to the deposition of the overlying tuffs. The section from the floor of the valley to the summit of Castle Hill is as follows:—

		Feet
11.	porphyritic phonolites, kenytes and agglomerates (of the overlying volcanics)	950
10.	agglomeratic tuff	150
9.	green grey fissile trachyte	10
8.	olive-grey coarse tuffs	50
7.	red-brown fine grained fissile trachyte	40
6.	brown tuffs with scattered volcanic bombs	8
5.	yellow-brown thin bedded tuffaceous silts	8
4.	yellow-brown tuff resting on eroded surface	6
3.	fissile green-grey phonolite (forms cliffs)	0–200
2.	red-brown trachytic agglomerate with thin porphyritic trachytes	*c.* 550
1.	mottled green-grey fissile trachytes	*c.* 600

Dips measured in the thin-bedded tuffaceous silts (No. 5 above) averaged 11 degrees to the south, and the porphyritic phonolites and agglomerates which form the upper part of the succession dip even more steeply south-westward, for they rest unconformably on the trachyte-agglomerate sequence, and rest directly on the fissile green-grey phonolite to the east and south-east of Lake Höhnel Fig. 4(*a*). Gregory (1900, p. 218) traversed the western face of Castle Hill (Mount Höhnel in Gregory's account), and gave a succession essentially similar to that above.

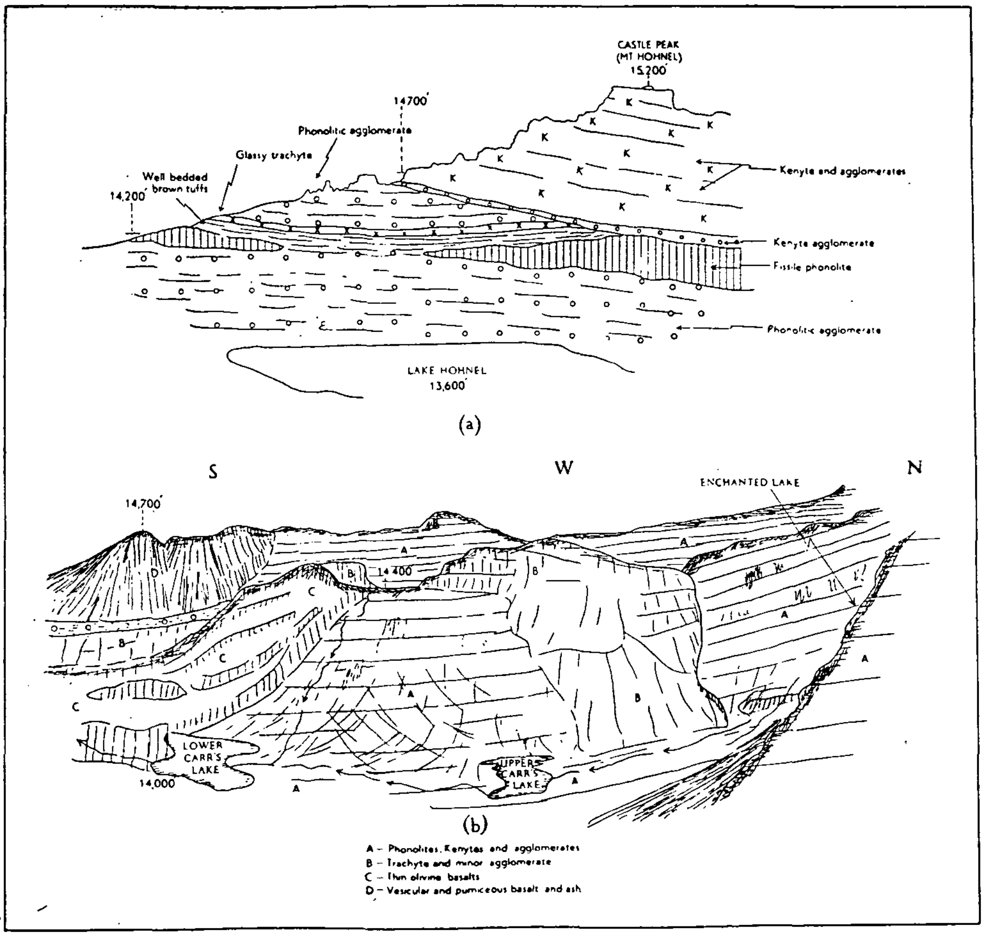

Fig. 4 (a)—Sketch illustrating the structure of the western ridge of Castle Peak (Mt. Hohnel).
(b)—Sketch of the western side of the Carr's Lakes branch of the Hobley valley.

Fissile greenish grey trachytes and phonolites similar to the first and third members of the Höhnel valley succession outcrop on the north side of the Teleki valley and in its floor between 13,200 and 13,500 feet, and also on the low cliffs immediately north of Naro Moru tarn. Shipton Peak is, however, composed of the equivalents of the porphyritic trachytes (the second member of the tabulation). Whereas these rocks are mainly agglomerates composed of reddish brown lavas crowded with small tabular felspars in the Lake Höhnel area, their equivalents on Shipton Peak are grey or brown, highly fissile and fractured, and crypto-crystalline to glassy in texture. In a few rocks nepheline was observed in hand-specimen, but the majority appear to be alkali-trachytes. They are easily distinguished from the porphyritic phonolites and agglomerates which overlie the Shipton Peak sequence by the scarcity of nepheline, the smaller and more crowded felspars, and their close fracture. The tuffs and agglomerates of the upper part of the Lake Höhnel succession do not outcrop on Shipton Peak or in the Teleki Tarn cirque due to erosion previous to the eruption of the super-incumbent phonolites.

Exposure on the north side of the Teleki valley is extremely poor due to the presence of ground moraine and solifluction deposits, but 400 feet above Mackinder's Camp flinty green, brown and grey lavas are exposed with a southward dip, and these are similar to those exposed above Naro Moru Tarn.

The continuation of the outcrop of the trachyte-tuff-agglomerate sequence is found on the north ridge of the Teleki valley between 13,700 and 14,200 feet. Here pale greenish grey to greenish buff fissile trachytes outcrop on the north side of the ridge as lines of cliffs—the lavas having a gentle southward dip. The same lavas form the cliffs at the head of the subsidiary valley west of Two Tarn Col, and pass beneath the lateral moraine capping the south ridge of the Hausburg valley. Resting on the sub-horizontal or gently southward dipping fissile trachytes west of Two Tarn Col are trachytic agglomerates which outcrop as scattered pinnacles and ridges rising from a steep scree-slope. The agglomerates are composed of brown, grey and reddish brown fissile flinty trachyte fragments in a brown unsorted matrix and have north-eastward dips of between 25 and 35 degrees. A little higher in the succession the agglomerates begin to contain an increasing proportion of coarsely porphyritic phonolites of the type on Castle Hill, and linear ridges of such agglomerates outcrop above and below the Burguret path between the 14,400 and 14,700 levels. The upper part of the agglomerate forms a resistant north-easterly dipping plate approximately 100 feet thick which outcrops on the crest of the ridge between a quarter and a half mile west of Two Tarn Hut. The eastern end of the ridge is overlain by moraine containing some very large perched blocks of syenite. The agglomerate, which is composed of large porphyritic phonolite blocks, can be traced down-dip to a contact with the margin of the syenite plug in a gully 300 yards west of Nanyuki Tarn. Seven hundred yards west-south-west of Hut Tarn a porphyritic phonolite outlier rests on the east-dipping agglomerates with unconformity.

In the Nyamindi and Nyamindi West valleys the trachytes and a phonolite are exposed beneath the porphyritic phonolites (*see* Fig. 5*b*) and are textural varieties of green-grey fissile alkali-trachyte; no agglomerates or porphyritic lavas are exposed here, and it is assumed that the Nyamindi West sequence is mainly in the fissile lower member of the Lake Höhnel succession, with the fissile phonolite forming the uppermost flow.

Sixteen rocks were collected from the area of Lake Höhnel trachytes and phonolites between the Hausburg and Nyamindi valleys. Of these 14 are trachytes or alkali-trachytes and two are fissile phonolites of a kind more common in the associated formation described below.

The trachytes are green-grey fissile lavas varying from flow-banded cryptocrystalline or locally glassy types common on Shipton Peak to platy well crystallized varieties with a satiny sheen imparted by the minute felspars of the matrix. A few of the lavas have felspar phenocrysts up to five milimetres in length, but the majority contain felspar microphenocrysts averaging one milimetre in size. In some rocks the microphenocrysts are anorthoclase, in others the alkali felspars are doubtful anorthoclase, and soda-sanidine was suspected in two slices. The matrix is of trachytoid texture, the felspar laths being anothoclase or albite-oligoclase. Green aegirine-augite as very small intersertal granules occurs in all the rocks, and occasionally forms mossy patches. Minor amounts of brown strongly pleochroic alkali-hornblende are seen in some thin sections, and interstitial zeolites occur in more than half

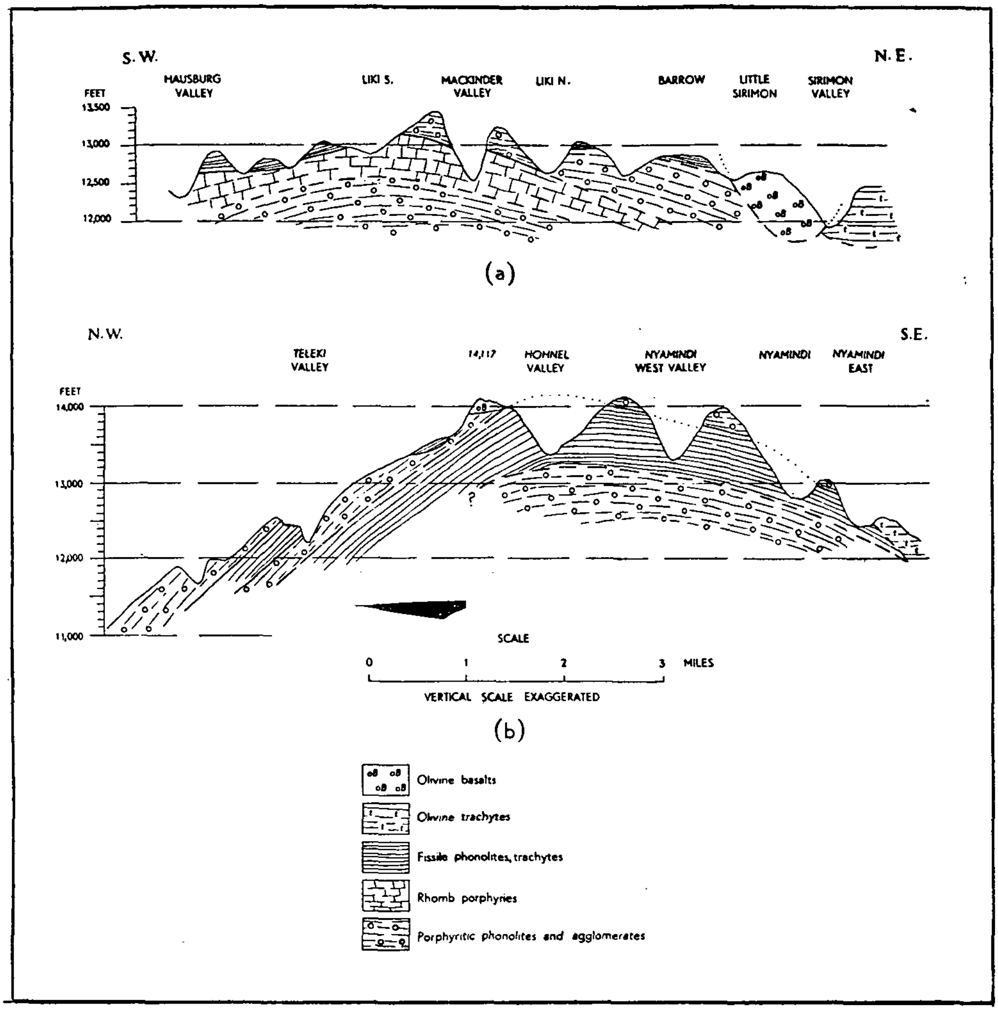

Fig. 5 (a)—Mt. Kenya; diagrammatic section on the north-western sector.
(b)—Mt. Kenya; diagrammatic section on the south-western sector.

the slides; in some rocks, particularly the very fine grained varieties, pools of zeolite occur in the matrix. Specimen 44/987A from two miles west of Lake Höhnel contains olivine microphenocrysts.

Two specimens representative of the trachytes are 44/991 from the north side of the Teleki valley one and a half miles north-west of Lake Höhnel, and 44/1191 from the Nyamindi West river at 13,400 feet.

One fissile phonolite, specimen 44/981A, was collected in the floor of the Nyamindi West valley at 13,570 feet, and although similar to the trachytes in hand specimen, differs somewhat in thin section. It contains sparse soda-sanidine microphenocrysts set in a felted mass of fine alkali felspar laths. Fibrous aggregates of green aegirine and kataphorite are the only coloured minerals, and numerous clear nepheline cubes outlined by aegirine are seen. This phonolite is closely comparable to the fissile phonolites of the north-western sector of the mountain, which are described on p. 33 and is probably the same flow as that forming the cliff overlooking Lake Höhnel. A specimen from this cliff (number 3 of tabulation on page 29) was collected by Gregory (1900, p. 215) and was described by Campbell Smith

(1931, p. 230) as a fissile phonolite of the Kenya type containing microphenocrysts of nepheline in a matrix of orthoclase or soda-orthoclase laths, aegirine, cossyrite and kataphorite. Campbell Smith (*op. cit.*, p. 235) also gives an analysis (Analysis I, below) of this rock made by Prior. A similar rock was collected from 14,300 feet on the west flank of the mountain and described by Lacroix as a phonolitic trachyte (cf. *op. cit.*, p. 233). It consists of minute aegirine and cossyrite grains set in a groundmass of felspar laths, nepheline and scattered yellow olivines. An analysis of this rock (analysis II, below) was made by F. Raoult.

	I	*II*
SiO_2	58·37	59·28
Al_2O_3	16·65	17·20
Fe_2O_3	4·09	5·33
FeO	3·03	2·37
MgO	0·37	0·36
CaO	1·66	1·84
Na_2O	7·28	7·37
K_2O	5·46	4·84
H_2O+	1·40	0·98
H_2O-	0·96	0·51
TiO_2	0·21	0·22
P_2O_5	0·08	—
MnO	0·43	—
Cl	—	—
Totals	99·99	100·30

Norms

	I	*II*
or	32·25	28·5
ab	40·87	51·35
an	—	—
wo	—	2·8
ne	7·67	5·4
hl	—	—
ac	6·01	0·8
di	7·28	1·9
hy	—	—
ol	—	—
mt	3·02	7·0
il	0·46	0·5
hm	—	0·2
ap	—	—

I. Phonolite (Kenya type). Flow from the foot of the west face of Mt. Höhnel (Castle Hill). G. T. Prior, anal: (Campbell Smith 1931, p. 235).

II. Phonolitic trachyte. From 4,500 metres (14,300 feet), west flank of Mt. Kenya (probably on the north ridge of the Teleki valley). F. Raoult, anal: (Campbell Smith 1931, p. 235).

The red-brown trachytes and agglomerates outcropping below the Lake Höhnel cliffs and on the col between the Teleki and Höhnel valleys (number 2 of the tabulation on p. 29) are almost certainly represented in Gregory's collection, described by Campbell Smith (1931, pp. 247–248) as reddish brown rocks with abundant phenocrysts of potash-oligoclase averaging 0·5 centimetres in length, but no visible nepheline. Small pyroxene-microphenocrysts occur together with altered olivine and magnetite in glassy or cryptocrystalline matrices. Campbell Smith refers to these rocks as transitional between "kenytes" and trachybasalts (*op. cit.*, p. 247).

Trachytes and trachytic agglomerates occur on the western slopes of the mountain between the Hausburg and Höhnel valleys, and are the equivalents of the Lake Höhnel succession on the lower slopes. The trachytes occur on interfluves and form a thin sequence interbedded with porphyritic phonolites and agglomerates derived from the main vent. Their occurrence at the same stratigraphic level as the Lake Höhnel succession indicates that they are the attenuated representatives of this succession. The trachyte flows dip westward at approximately the same angle as the phonolites on which they rest.

The trachytes are of the same type as occur in the lower part of the Lake Höhnel succession. They are fissile green-grey rocks devoid of phenocrysts and characterized by a platy fracture in the well crystallized types and by an angular flinty fracture in the microcrystalline types. In two of the six rocks collected, specimens 44/988 and 44/1022 from the trachyte ridge two miles west of Lake Höhnel, the matrix has the "mossy" green aegirine and patchily distributed interstitial kataphorite which characterizes the matrices of the fissile phonolites which occur on the north-western sector of the mountain.

On the interfluves between the Thego and Höhnel valleys, and between the Burguret and Hausburg valleys, beds of trachytic agglomerate occur in place of trachyte flows. Slight unconformity between the most southerly of the trachyte agglomerates and the underlying porphyritic phonolites is noticeable. This agglomerate, which reaches a maximum thickness of 200 feet, has mostly phonolite and kenyte blocks towards the base, but in the upper part trachyte blocks become dominant.

The trachytes and agglomerates of the western slopes average 100 feet in thickness, with a maximum observed development of 200 feet. This is in contrast with the maximum observed thickness of the Lake Höhnel succession of 1,600 feet.

Petrographically the lavas described above vary from fissile phonolites with only small amounts of nepheline and abundant sodic amphiboles to less alkaline varieties closer to the pantelleritic trachytes with zeolites in place of nepheline. Variations in colour are essentially due to variations of groundmass crystallinity. The fissile phonolites are concentrated in the upper part of the succession, beneath the pyroclastics where these occur, and are obviously related to the succeeding fissile phonolites which are described below.

(*e*) *Fissile phonolites*

Fissile phonolites are found in three separate areas on the northern, north-western and southern slopes, at elevations between 10,000 and 14,000 feet. In the sector between the Nyamindi West and Thego valleys the fissile phonolites are separated from the trachytes of the Lake Höhnel succession below by approximately 400 feet of porphyritic phonolites and agglomerates. In the other sectors they rest on rhomb porphyries or porphyritic phonolites with unconformity, the outward dip of the fissile phonolites being greater than that of the underlying volcanics.

The type area of the fissile phonolites is on the "Barrow" ridge—the interfluve between the Sirimon and Liki North valleys (*see* Fig. 5(*a*)). At the base of the cliffs in the heads of the Ontulili and Liki North valleys, and on the col between the two valleys at 13,400 feet, the base of the fissile phonolites is seen to consist of flow laminated very fine-grained grey-brown and red-brown phonolites with small felspar and nepheline phenocrysts. The lowest flow due south of the Barrow is a porphyritic phonolite glass, but this and the cryptocrystalline phonolites above pass north-westwards and south-eastwards into agglomerates which occur on the col west of Hook Tarn and below the fissile phonolites which form the sloping plateau between the Ontulili and Liki North valleys. The maximum development of glassy and fine-grained fissile phonolites is 200 feet and is found on the col south-west of the Barrow. The base of the fissile phonolites is exposed on the east side of the Sirimon valley a quarter of a mile south-east of Hook Tarn, where fissile reddish brown and grey phonolites containing a thin porphyritic glass are overlain by fissile green-grey phonolite of the normal type.

The fissile phonolites are approximately 200 feet thick on the Barrow ridge. In the head of the Little Sirimon valley the basal member of the phonolites is a medium green cryptocrystalline phonolite, which also forms the small inlier among the basalts north-east of the Barrow. The main body of phonolites are green-grey, fissile and with very small water-clear nepheline phenocrysts visible in the uppermost flows.

Thin flows of green cryptocrystalline phonolite occur also at the base of the series between the Mackinder and Hausburg valleys, where seven thin flows were counted with a total observed thickness of 400 feet. Phonolitic agglomerate occurs locally at the base of the flows and between them, but is never thickly developed. In other respects these phonolites are identical to those of the Barrow.

In the sector between the Nyamindi West and Thego valleys the fissile phonolites cap the ridges and overlie porphyritic phonolites and agglomerates. As on the north-western sector of the mountain some of the phonolites contain small felspar phenocrysts, but the majority are green-grey, very fine-grained and with a fissile or flinty fracture. The maximum development of phonolites on the southern sector is approximately 450 feet.

There is little variation in the petrology of the fissile phonolites. Abundant clear nepheline microphenocrysts were recognized in nine of the 12 specimens collected. In several specimens prismatic aegirine-augite microphenocrysts were found, and in two rocks from the southern sector, specimens 44/985 and 44/1195, small anorthoclase phenocrysts occur also. The matrix of the fissile phonolites is diagnostic. It is trachytic in texture and consists of alkali felspar laths with green aegirine and brown kataphorite distributed as spongy interstitial patches. Zeolite occurs as a localized mesostasis in most of the thin sections.

The disposition of formations on the southern sector of the mountain shows the fissile phonolites separated from the Lake Höhnel trachytes below by some 400 feet of porphyritic phonolites, but on the north-western sector the fissile phonolites occur at approximately the same stratigraphical level as the Lake Höhnel trachytes. The disposition and dip of the Lake Höhnel trachytes suggest that their eruptive centre was some miles west of the main peak, while the fissile phonolites seem to have been erupted from the peak area, probably from fissures, for no fissile phonolite is found among the rocks of the plug of the main vent.

(*f*) *Mugearites, alkali trachytes and olivine trachytes*

The trachytic rocks to be described are a somewhat variable suite which ranges from alkali trachyte of pantelleritic affinities through olivine alkali trachyte to oligoclase basalt (mugearite). The alkali tendency is notable throughout, and is expressed by the continuous presence of zeolites. These volcanics occur in three main areas—(i) as a substantial series on the northern slopes where they rest with strong unconformity on all but one of the volcanic groups of the main eruptive period, (ii) a series of variable trachytic flows erupted evidently from a neck at Hall Tarns, and (iii) the extensive olivine and alkali trachytes of the southern slopes, which form a thin but far reaching series of flows which penetrated nearly to Sagana township to the south of the present area.

(i) *The olivine trachytes of the northern slopes*

These lavas outcrop between the Kazita East and Sirimon valleys, and reach a maximum exposed thickness of 800–900 feet between the 12,000 and 13,000 contours on the north slopes of the Sirimon valley, and are subdivided into three parts.

A distinctive olivine basalt marked as sub-division I on the geological map occurs at the base of the trachyte series along the eastern margin of the outcrop in the Kazita West valley, between 11,000 and 11,100 feet in the main Kazita valley, forming the floor of the broad valley-head of a Kazita river tributary at 12,000 feet, and at the base of the olivine trachyte outlier on the north ridge of the Hinde valley at 12,100 feet. The basalt is characterized by a well-marked small-scale hackly fracture, giving it a finely cobbled weathered surface. In colour it is dark grey, and in some specimens small olivine and augite phenocrysts can be seen. A further specimen of the lava at the base of the trachytes in the Sirimon valley—specimen 44/1056 from two and a quarter miles north of the Barrow—is an andesite with olivine granules and many small grains of aegirine-augite. This lava forms the western base of the trachytic series as far south as the ridge between the Sirimon and Kazita West valleys.

The main bulk of the lavas are olivine trachytes which outcrop almost continuously in the Kazita West river, and are found over a wide area up to the northern boundary of the map. These lavas form curious small toothed crags and linear wall-like outcrops, due to the local contortions of the flow banding and fissility. They are non-porphyritic pale brown and grey-brown fissile lavas, with a satiny sheen due to the trachytoid texture. The paler lavas frequently show red-brown iron oxide films on joints, weathered surfaces and in vesicles, and this feature distinguishes these types of lava on the southern slopes also. Many of the trachyte lavas are finely vesicular, and these are soft and earthy under the hammer.

The upper part of the trachyte series is exposed on the ridge tops on the east side of the Sirimon valley and is distinguished by the symbol II on the geological map. At approximately 300–400 feet below the tops of these ridges the trachytes become dominantly green in colour

PLATE I

Fig. 1—The north-east face of the peak of Mt. Kenya, viewed from Simba Col. The greater part of the peak is of nepheline syenite, but the dark buttress in the left centre is part of the outer ring of phonolite. The snout of the Gregory glacier is at the left margin.

Fig. 2—The Lewis glacier. Dark bare ice with crevasses and folded ice banding occurs in the foreground.

PLATE II

Fig. 1—The peak area viewed from Sendeyo in the north. The summits shown are (from left to right) Pt. Lenana, Pt. Thomson, Nelion, Batian (17,058 ft.), Pt. Piggott. The valley below is the Mackinder valley, and the glaciers visible are (from left to right) the Gregory, Krapf, Northey and Josef glaciers. The stage VI moraines below the Gregory glacier are well shown.

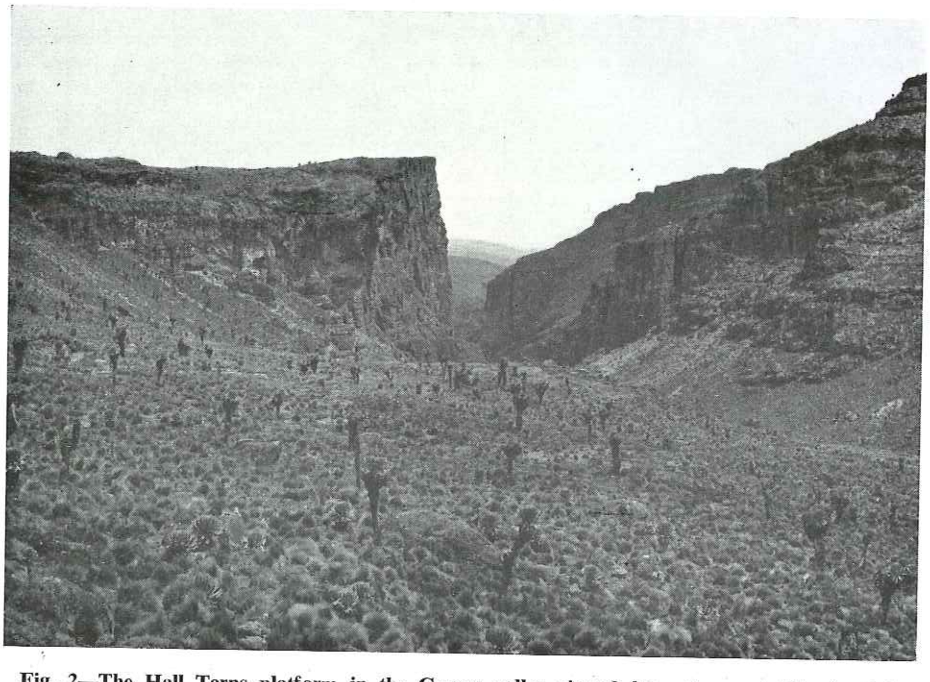

Fig. 2—The Hall Tarns platform in the Gorges valley viewed from the west. The banded cliffs of the phonolite-kenyte volcanics are contrasted to the cliffs formed by the trachyte stock which forms the Hall Tarns platform on the left.

PLATE III

Fig. 1—Pillars and pedestals of "older" moraine in the lower Gorges valley. Behind the pillars is a part of a "younger" lateral moraine of stage ID, with blocks littering its surface.

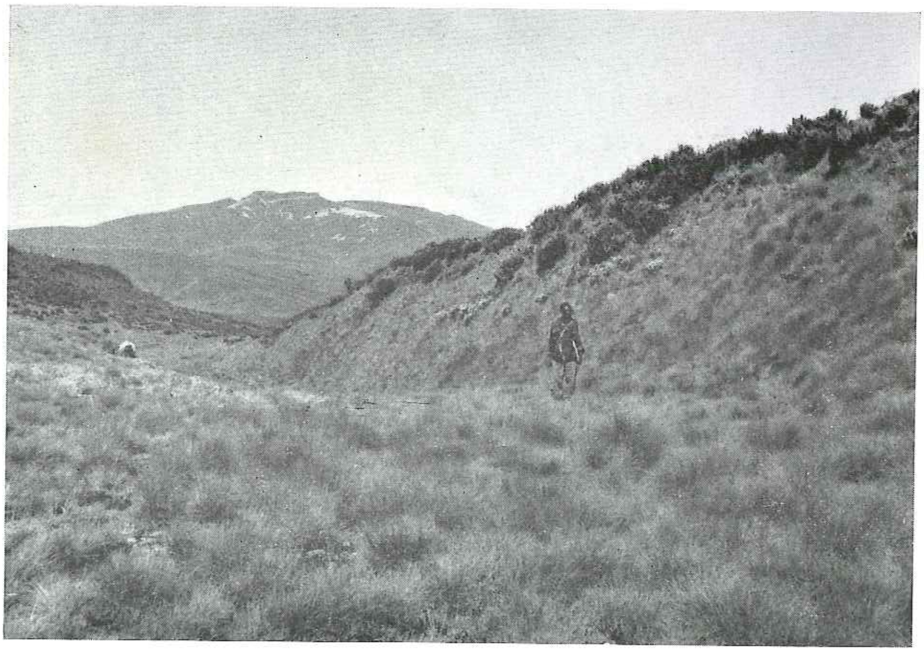

Fig. 2—Small uneroded fault scarp immediately south-west of Mugi hill. Ithanguni volcano is in the background.

PLATE IV

Fig. 1—The eastern side of Mugi hill—a kenyte-phonolite dome. The mounds at the foot of the hill are freeze and thaw structures.

Fig. 2—Partially developed stone and mud polygons due to freeze and thaw action on moraine. The alignment of the structures is due to movement of the whole mass down-slope.

and contain stout felspar phenocrysts up to 12 millimetre long in a distinctly coarser matrix. The uppermost part of the ridge is composed of tabular green trachyte flows margined by cliffs showing crude columnar jointing. The lavas are green-grey, relatively coarse grained and are crowded with small felspar phenocrysts and minute pyroxene prisms.

Under the microscope all but four of the 32 specimens sectioned proved to be olivine trachytes showing only minor variations. The majority are not porphyritic, but in some the ubiquitous yellow ferriferous olvine is microporphyritic. In addition to scattered subhedral fayalite, the remainder of the matrix exhibits microlitic texture, the Carlsbad and lamellar twinned felspar laths, which are probably anorthoclase, make up nearly all the rock and are trachytically aligned. Aegirine-augite microphenocrysts are common and are often altered largely to iron ore pseudomorphs. Aegirine granules are sparingly distributed and the matrices are usually dusted with fine iron ore. In many of the slides an alkali mesostasis was suspected. Two slides are similar to those described but are devoid of olivine, and in two others, specimens 44/1078 and 44/1062, the felspar laths were identified as oligoclase. These specimens were collected from the outlier one and a half miles south-east of the Barrow, and from the easterly of the two small inliers on the north ridge of the Kazita valley at 11,800 feet and are mugearites.

Three and a half miles west of Rutundu, on the northern slopes of the mountain, there is a conical hill rising 300–400 feet above the surrounding country. Scattered exposures on the lower slopes are of pale grey, reddish weathering olivine trachyte lavas dipping down the slopes of the hill. The summit area is composed of massive trachytes of variable appearance, some are pale grey, others neutral grey and vesicular, and yet others are bluish grey like some of the fine-grained phonolites. Erosion of the hill has been slight and there are no sections to indicate its structure. Its form and the absence of a crater suggests that the hill may be a small olivine trachyte cumulodome (Cotton 1952, pp. 156–169), built of viscous lava during or possibly after the trachyte eruptions of the northern slopes. A specimen of the most widespread lava on the western slopes (44/1063) contains numerous olivine microphenocrysts in a trachytic matrix of anorthoclase laths. The specimen is indistinguishable from some of the olivine trachytes of the Kazita river section nearby.

(ii) *The Hall Tarns stock and associated trachytic lavas*

The Hall Tarns rest on a platform projecting from the northern side of the Gorges valley, the surface of the platform being at the 14,000 foot level. This platform, which is margined on three sides by cliffs, those on the south-east side overlooking Lake Michaelson being vertical and up to 800 feet high, is the up per surface of a stock-like body of trachyte which is 1,450 yards long and 900 yards wide elongated in a north-east south-west direction. On the upper surface of the trachyte platform are a number of glacially eroded rock basins containing small lakes. The stock is surrounded by a cylindrical body of agglomerate which varies from a width of a few yards in the west to 850 yards in the east. The structure of the stock is in marked contrast to that of the adjacent volcanics, for the stock is homogeneous, unbedded and has vertical columnar jointing on a large scale, whereas the adjacent phonolites and agglomerates show the banded cliffs and terraced slopes of a bedded sequence (*see* Plate II, Fig. 2). The olivine trachytes, alkali trachytes and mugearites which occur on the northern ridge of the Gorges valley and in the area extending from Lake Ellis to Urumandi and beyond, were probably erupted from this vent. It is notable, however, that the 13,000 foot isopachyte drawn at the base of the trachytic lavas on the northern, eastern and southern slopes is an almost perfect semicircle centred on the main vent, suggesting that the bulk of these lavas may have been erupted from the main vent.

The basis of the Hall Tarns stock is massive olivine trachyte, represented by specimen 44/1096 from near the eastern margin of the mass. This rock has small olivine microphenocrysts in a basis of ill-formed anorthoclase laths, and aegirine-augite microphenocrysts. On the northern half of the stock is a curious finely pumiceous lava which is locally full of small cognate lava blocks, which give it the appearance of a flow breccia. This lava appears to form a thin irregular layer on the more massive olivine trachyte beneath, and its surface is pitted by dry scree or swamp filled hollows resembling small explosion craters. Two specimens of this lava, 44/1095 and 44/1145, show that it is an unusual trachyte consisting of lathlike to subhedral anorthoclase felspars full of iron ore dust, iron oxide pseudomorphs of a prismatic mineral, prisms of aegirine-augite and small spots of a brown pyroxene. The lava closely resembles some of the earthy and rubbly trachytes from the area east of Lake Ellis, which are described below. The tuffs and agglomerates which surround the stock are best exposed on the slopes north of Lake Michaelson, where they form small cliffs with a tendency to erode to pillars and high caves, and have been named the Temple. Locally the pillars are capped by large perched blocks. A crude horizontal stratification can be made out in this agglomerate, even in the narrow development on the western side of the stock. Close to the stock margins, however, the agglomerates dip very steeply towards the stock, emphasizing its funnel-like shape. Towards the north-eastern edge of the agglomerate outcrop a horizontal trachyte flow rests unconformably on the agglomerate.

It seems that the Hall Tarns stock and its pyroclastic surround are the upper part of a low parasitic vent, on account of the funnel-shaped section it presents. The pyroclastics are the foundations of the crater walls, which probably did not rise very high above the present level. It is possible that the present Hall Tarns platform is the slightly eroded surface of the lava lake that occupied the original crater floor at the time of final quiescence.

The trachyte lavas of the northern ridge of the Gorges valley are very similar to the olivine trachytes of the Kazita West section, for they are brown-grey to green-grey glistening fissile trachytes with the curious "knobbly" weathering forms characteristic of this type. Specimen 44/1094 taken at 12,300 feet on this ridge is a mugearite, with scattered yellow olivine microphenocrysts in a base of trachytoid oligoclase laths and fine iron ore grains. Similar lavas, but identified as olivine trachyte rather than mugearite, outcrop at the Nithi waterfall (specimen 44/1039) and at intervals upstream in the Nithi North river as far as the Hinde Valley terminal moraine. Bouldery porphyritic phonolites are exposed beneath the trachytes to the west of the olivine basalt crater, and the basalts and tuffs of the crater overlie the trachytes to the east of the river. Scattered on the trachyte outcrops are thin discontinuous layers of earthy brown trachyte rubble which is described below.

The olivine trachytes outcrop on two low plateaux of rounded outline to the south and east of Lake Ellis, both of which are partially capped by the earthy brown trachyte and are surrounded by it. These plateaux and the intervening area are of particular interest for they have been fissured and faulted very recently (Fig. 6). The belt of fissures is a mile wide and the fractures are mainly aligned north-east south-west, and cut across all the formations of the area, including the recent olivine basalt flow and its vent. The majority of the faults downthrow to the north-west, and those cutting the valley south-east of Lake Ellis have blocked the former overflow channel, forming a small pond connected to the main lake. Along the narrow channel connecting the pond and the main lake there is a well-marked terrace a few feet above water-level; this terrace is slightly up-warped and now slopes gently north-westwards. The fissures on the south-eastern end of the trachyte plateau south of the lake occur on a slight rise in the plateau and gape widely. They are clearly due to slight up-doming in their vicinity.

The faults are best displayed half a mile west of Mugi, where they form small scarps up to 20 feet high in soft easily eroded "earthy" brown trachyte rubble. Their perfect preservation suggests that they cannot be more than a few hundred years old (*see* plate III, Fig. 2).

The movements that gave rise to these structures are of volcanic rather than tectonic origin, and are likely to have been caused by near-surface intrusion. It is significant that the fissured areas lie in a zone approximately between two vents of very different characteristics, namely the Mugi vent of phonolite and kenyte breccia (*see* p. 42), and the olivine basalt vent at the southern end of the fissure zone, and affect them both. The plateaux south and east of Lake Ellis have much in common with the Rutundu and Giants Billiard Table plateaux, which are described separately (p. 43).

(iii) *Trachytes of the southern slopes*

Pale reddish brown weathering trachytes, olivine trachytes and mugearites are found on the southern slopes of the ridge east of the Nyamindi East, where they pass beneath basalts on the lower slopes, occur as scattered outliers in the upper Nyamindi West, and as a very long series of flows which extend from the upper south-western slopes, through the forest, and form the lower slopes in the Tumu Tumu-Niana area north and west of Karatina. This series of flows extends down the western side of the Ragati valley nearly as far as Sagana township in the area to the south, where they rest with unconformity on formations older than the Mount Kenya Suite (Fairburn, 1966). A further interesting occurrence of these trachytes is in the Hobley valley in the area of Carr's Lakes.

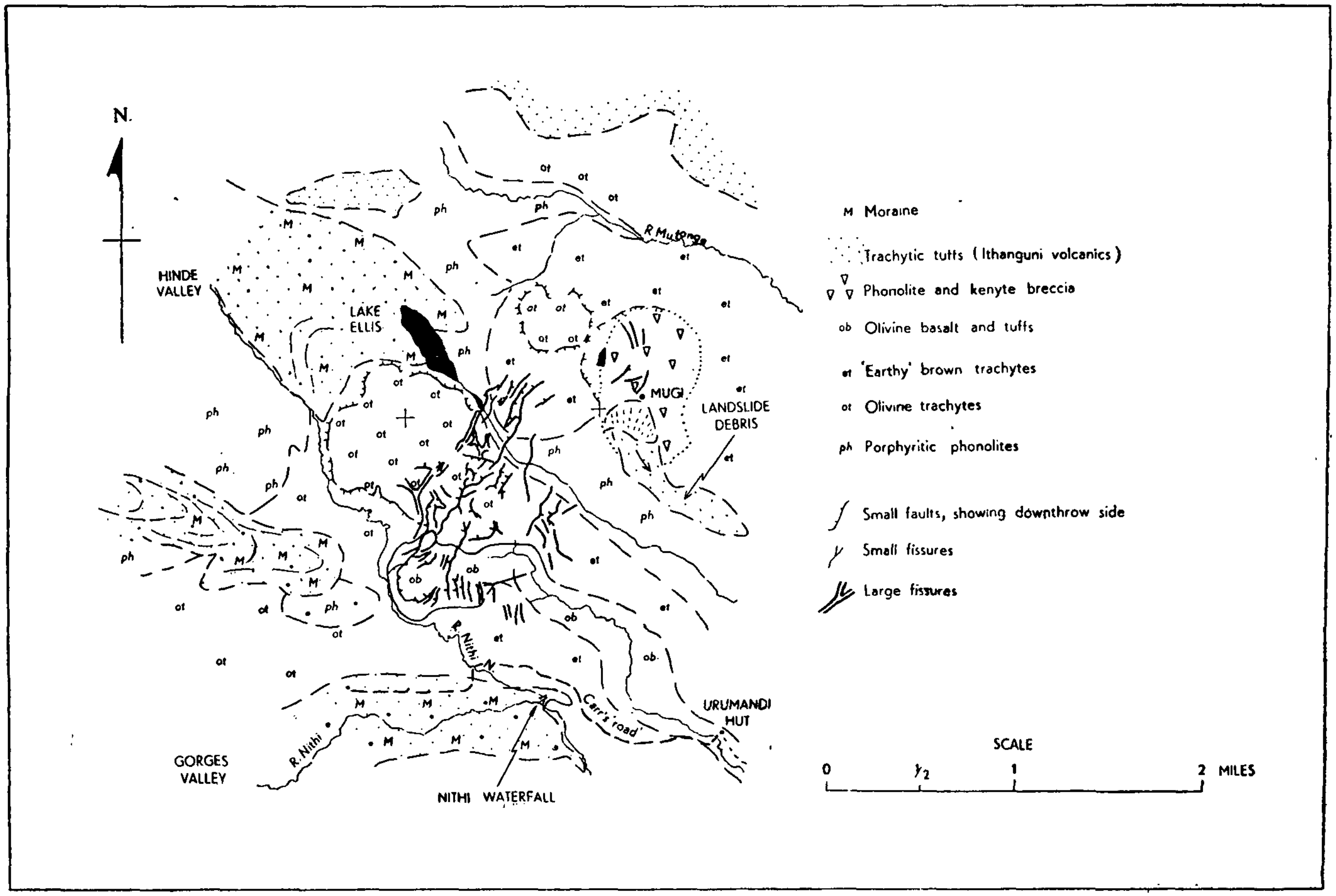

Fig. 6—Geological sketch-map of the Lake Ellis-Urumandi area.

In the Hobley valley south-east of Enchanted Lake there is an outlier of olivine trachyte up to 400 feet thick, which forms a marked plateau with cliffs on two sides (*see* Fig. 4*b*). The trachyte rests on the phonolites and kenytes with marked unconformity in or near the bottom of a major valley, for the trachytes outcrop on the southern side of the valley, west of Carr's Lakes, and can be traced down the west side of the valley downstream of the lakes, where it is overlain by a considerable thickness of kenyte agglomerate and rubbly vesicular basalt. The relationships in the Carr's Lakes area are illustrated in the following tabulation:—

West side of Hobley valley	*Floor of Hobley valley*
vesicular basalt vent	olivine basalts vesicular basalt
kenyte agglomerate olivine trachyte	? olivine trachyte (not exposed)
phonolites and agglomerates	

In the Hobley valley therefore both the olivine trachyte and the basalts above, which were evidently erupted from the much eroded vent a quarter of a mile south-west of Carr's Lake, occur in the floor of a major valley, and are overlooked by high ridges composed of older rocks.

The main cliffs of the trachyte outlier south of Enchanted Lake are composed of three members: a basal phonolitic agglomerate with angular trachyte fragments, the main bed consisting of trachyte flow-breccia, and a cap of phonolitic agglomerate containing minor amounts of trachyte and olivine basalt fragments. Near the eastern end of the outcrop trachyte lava is exposed. The rock (specimen 44/1174) is pale medium grey with a rough feel, and contains oligoclase laths, abundant olivine microphenocrysts, aegirine-augite and fine iron ore; it is a mugearite. A specimen of the trachyte at 12,400 feet on the west side of the Hobley valley (44/1104) is microporphyritic with anorthoclase and olivine microphenocrysts in a matrix of anorthoclase laths, aegirine-augite granules and a zeolite mesostasis; it is an olivine alkali trachyte.

The ridge east of the Nyamindi East valley is capped by reddish weathering pale grey glistening olivine trachytes of the usual type. Very similar lavas form upstanding outliers on the ridges bordering the Nyamindi West valley. The trachyte here forms crags with polygonal columnar jointing and an ill-defined fissility indicating high dips, particularly the northernmost outlier, which rests with marked unconformity on the older trachyte-fissile phonolite sequence, and dips markedly into the Nyamindi West. The lavas are reddish weathering silvery grey trachytes represented by specimen 44/1194A and B, from the largest and next largest of the outliers respectively, and 44/1198 from the south-western outlier. All the rocks are finely porphyritic olivine trachytes, in which the olivine is variable in amount.

The main outcrop of the trachytes on the upper south-western slopes, which extends down into the forest belt, is of largely hypothetical outline for the exposures in this region are poor. Pale weathering green-grey or grey fissile trachytes were seen at intervals on the Gunia track in the forest north of Gerere hill and in the Ragati river at 9,600 feet. Further exposures were seen near the Kamweti track between 10,300 feet and 11,000 feet, and in the inlier of fissile trachyte east of Ragati Forest Station. The continuity of the trachyte between the exposures near the upper limit of the forest and those of the Niana area is hypothetical, and is based on the occurrence of a belt of swampy valleys which seem to characterize the trachyte outcrop in the forest.

(iv) *Trachytes of the Karatina-Tumu Tumu-Niana area*

The trachyte outcrop of the lower south-western slopes coincides with a belt of discontinuous steep-sided hills of which Niana, Kiamcheru, Kianganda, Giakagena and Tumu Tumu are the main examples. The trachytes which are poorly exposed on these hills are pale brown or buff weathering fissile lavas weathering into slabby blocks. In hand specimen they are normally very fine-grained and devoid of phenocrysts, and of blue-grey colour. Only two types seen had microphenocrysts of felspar and a rough pale matrix indicative of moderate grain size. The inferred thickness of these lavas is nearly 1,000 feet on Niana, between 500 and 700 feet in the Kianganda-Giakagena area and generally less than 500 feet in the Tumu Tumu region.

They can be seen to rest on porphyritic phonolites on the slopes descending to the Muthera river north-west of Gachuero and Gateguni villages, but south of Gachuero they overlap the phonolites and rest directly on the Laikipian basalts along the western margin of the outcrop. In the area to the south (Fairburn, 1966) the trachytes overlap on to the Basement System about three miles south-east of Karatina, and continue as a capping to a low plateau which ends two miles north-west of Sagana Township. On their eastern margin the trachytes are overlain by the Ragati basalt, a member of the Thiba Basalts. Petrographically the majority of the trachytes are alkali-trachytes with anorthoclase, aegirine-augite, fine iron ore dust and often a suggestion of an alkali mesostasis. Many also contain fayalite micro-phenocrysts, and only one rock, specimen 44/1276 from the Kamuguairi river north-west of Gatondo village, is a mugearite of unusual composition, since it contains augite and biotite in addition to the olivine and oligoclase. Unfortunately this rock was not seen *in situ*, but derived from a loose block on the trachyte outcrop east of Ragati Forest Station.

The trachytes and mugearites described above closely resemble the suite represented by the Sattima Series on the Aberdare Range (Shackleton 1945, pp. 2–3) and appear similar in age and petrography to the fayalite phonolite of Nyeri hill (Shackleton 1945, p. 4; Campbell Smith 1931, pp. 249–250) and the trachyte of Longari Hill, which rises above the marginal phonolites of the Mt. Kenya Suite just outside the western boundary of the area. Shackleton (op. cit.) suggested, however, that the Nyeri and Longari Hill rocks are part of the Laikipian Basalts. In view of their composition and post-Laikipian Basalts age they are probably sattelite vents of the Mt. Kenya Suite.

(*g*) *Pantelleritic trachytes*

These rocks are found in small localized occurrences of no great thickness scattered about on the upper moorland zone of the mountain as small lava occurrences and as dykes. The largest outcrops are on the interfluve between the Mutonga and Kazita East rivers between the 11,700 and 12,100 foot contours, and north of the Ruguti North river between 10,300 and 11,600 feet. Smaller, thin plates are found on the western side of the upper Kazita West valley, on the col between the Liki North and Sirimon valleys, and on the western side of the Nyamindi West valley at 13,900 feet.

The trachytes are easily distinguished in the field for they are pale grey-buff to brownish buff rocks with a rough feel, and they weather easily to an almost white fine felspathic sand. Under the hammer they are soft and friable. Their pale colour, friability and finely mottled appearance are the main features. Some of the olivine trachytes of the Kazita West section and the paler earthy trachytes of Ithanguni superficially resemble these rocks, but are generally darker in colour.

The exposures north of the Mutonga river are of an extensive area of riebeckite trachyte showing faint flow lamination and basaltic inclusions, and in other parts the rock is full of cognate fragments of rounded shape suggestive of a flow-breccia. These rocks probably exceed 100 feet in thickness, and weather into sinuous low cliffs, groups of pillars and undulating rock mounds. They are overlain to the east by the trachytic tuffs of the Ithanguni volcanics.

Four dykes of pale sodic trachyte were found in the alpine zone of the mountain, and in three cases they outcropped in a col in a ridge, due to their easily eroded nature. One dyke traverses Simba Col and forms the eastern end of Simba Tarn, from where specimen 44/1156 was taken, and the same dyke passes close to Lower Simba Tarn on the other side of the Col (specimen 44/1139). A further dyke occurs in the col immediately north of Pt. Peter (specimen 44/1205), and another forms the col between the heads of the Hinde and Kazita West valleys (specimen 44/1172). A similar dyke was found on the eastern slopes of the Hobley valley half a mile south-south-east of Gallery Tarn.

In the hand specimen the samples from the lavas and from the dykes are indistinguishable. The majority of specimens—44/1156, 1172, 1205—mentioned above, and specimens 44/981C and 1188 from the outlier in the Nyamindi West valley, are composed of very stout tabular anorthoclase crystals in which are scattered riebeckite clusters. Specimens 44/1190 and 44/1139 contain small scattered pools of quartz. Specimens 44/1160 and 44/1144, from the outcrops north of the Mutonga river and north of the Ruguti North river respectively, contain deep brown barkevikitic hornblende and minor aegirine-augite in place of riebeckite. Both of these lavas contain rounded xenoliths of much altered olivine basalt. Specimen

44/1079 from the col between the Mutonga and the Kazita East valleys contains aegirine-augite and a patchy quartz mesostasis. In no case does the amount of quartz justify the name comendite, but it is possible that most of these rocks contain minor quartz in the groundmass, although it was only recognized in three. Characteristic of these rocks are the stumpy tabular anorthoclase crystals which often have a curious extinction resembling poorly developed Baveno twinning. In this and in their general petrography they are closely comparable to the Gibele type of soda-trachyte (Campbell Smith 1931, pp. 220–222), and to the Plateau Trachytes of the Magadi area (Baker 1958, pp. 18–22).

The restricted size and scattered nature of the outcrops of these lavas suggests that they were erupted as viscous lavas from small fissures, and their acid composition and eruption at the end of the main eruptive episode of the Mt. Kenya Suite suggests that they may be the final differentiates of the magma chamber.

(*h*) *Olivine basalts*

The main outcrop of these basalts is between the Ontulili and Sirimon valleys on the northern sector of the moorland. Other scattered occurrences of similar basalts which post-date the eruptives of the main vent are included in this formation and outcrop in the following places:—

(1) as an outlier three and a half miles north-east of the Barrow,
(2) as a series of valley-flows down the Hobley valley,
(3) on interfluves between the Teleki and Sagana valleys,
(4) in the lower Mackinder, Liki North and Ontulili valleys.

The basalts of the Sirimon region can be seen to rest with marked unconformity on the fissile phonolites and pophyritic phonolites which floor the Ontulili valley, and a similar unconformity is less well exposed in the Sirimon gorge between 10,000 and 12,000 feet. The basalts appear to occupy a deep valley eroded along the western margin of the olivine trachytes of the northern slopes (*see* Fig. 5*a*), and in two places basalts are seen as outliers overlying these trachytes. The majority of exposures of the basalts are of compact, fine-grained neutral-grey to dove-grey rocks weathering to smooth pale grey rounded blocks. Many of the exposures along the Sirimon track are, however, of a deeper grey basalt with hackly fracture, which resembles the "rubbly" basalt which occurs at the base of the olivine trachytes in the Kazita West valley. At the southern end of the basalt outcrop agglomerate with a high proportion of phonolite fragments is found beneath the basalts. The agglomerates reach a thickness of a little over 200 feet.

Specimens of the basalts south of the Sirimon river show them to contain small olivine and augite microphenocrysts in a groundmass of felted plagioclase, augite granules and ore. In one specimen an alkali mesostasis was suspected.

The basalts forming the outlier north-east of the Barrow are rather darker than the typical basalts described above; they contain olivine microphenocrysts in a normal basaltic matrix. It is possible that these basalts were derived from the pumiceous basalt cones which surrounded the basalt outcrop on two sides, but since their occurrence is similar to that of the other basaltic outlier to the west they are tentatively included with the basalts of the Sirimon valley area.

The basalts of the Hobley valley occur as an isolated group of outcrops between Enchanted Lake and the lake immediately to the south, and also covering the whole of the flat floor of the valley west and down-stream of Carr's Lakes. Basalts cover the olivine trachyte outcrop on the lip of a valley at the eastern end of the swamp and four flows can be made out, which descend into the valley and dam the southern end of Carr's Lake (*see* Fig. 4*b*). They are extensively ice eroded and forms small cliffs and rounded bosses of distinctive form. The contact between the basalt and the phonolite can be seen at the outlet of the lake, and is nearly vertical, confirming that the basalts flowed down a deep valley. The basalts are medium to dark grey lavas with olivine phenocrysts, and some flows have small felspar phenocrysts also. The matrices vary from fine-grained and flinty to rough textured, and they weather in pale shades of brown and grey as do the basalts of the Sirimon valley. It is notable that the Hobley valley basalts are overlain by approximately 200 feet of phonolitic and basaltic agglomerate, possibly derived from the vesicular basalt vent, the eroded remains of which are visible high on the western ridge of the valley south-west of Carr's Lake.

The basalts which outcrop on the ridge between the Sagana and Thego valleys on the south-western moorland are probably less than 100 feet thick. They are neutral grey to pale grey, very pale weathering rocks in which small felspar phenocrysts can sometimes be made out. All these basalts contain olivine in thin section, together with augite and labradorite laths. They overlie both fissile and porphyritic phonolites with unconformity.

A series of basalts approximately 300 feet thick form an outlier capping the south ridge of the Teleki valley one mile west-north-west of Lake Höhnel. The succession up the north-west side of the hill is as follows:—

rubbly basalt (forming the summit)

fissile basalt

basaltic tuff (20 feet thick)

fissile basalt

reddish brown glassy basalt (pyroxene phenocrysts)

rubbly basalt (pyroxene phenocrysts).

The basalt at the base shows columnar structure along the western and north-eastern margins of the outcrop, which are cliffs, and rests on variable thicknesses of moraine. On the southern side of the basalt outcrop the lowest rocks are basaltic agglomerates resting on the trachytes and trachytic agglomerates of the much older Lake Höhnel trachyte-phonolite succession. The unconformity beneath the basalts is strongly marked on the north-eastern side of the outlier where the basalt overlaps several older lavas. Two specimens, both from the lowermost basalt, prove to be olivine basalts, one with small pools of zeolite.

The occurrences of basalts in the lower Mackinder valley, on its northern ridge, and in the floor of the adjacent Liki North valley are tentatively included in the present basaltic formation, for these basalts also rest with strong unconformity on the underlying rhomb porphyries and phonolites. The deep section offered by the lower Mackinder valley where it enters the forest was unfortunately not visited, and the thickness of these basalts and their extent down into the forest is not known. The basalts form thin valley flows poorly exposed in the floor of the Liki north and the Mackinder valley, and cap the intervening ridge. They are fine-grained neutral to dark grey olivine basalts with olivine and augite microphenocrysts and contain minute pools of analcite. One specimen, 44/1129 from the southern slope of the Mackinder valley at 11,800 feet, is probably a trachybasalt with olivine.

A feature of all the basalts described above is their occurrence as isolated flows, often in valleys, resting with marked unconformity on the older formations. A substantial period of quiescence and erosion intervened before the eruption of these basalts.

(*i*) *Dykes and sills*

Intrusive representatives of almost all the main lava types are found on the mountain, invariably in the moorland zone. No doubt there are dykes on the lower slopes of the mountain, but none were seen due to the poor exposures. The dykes are commonest in a zone within three miles of the central peaks. There is a tendency for them to be disposed radially about the peak, but this is not well-marked, and there is no apparent tendency for closely-spaced swams of dykes to have been injected except immediately north-west of the Polish Man's Tarn nepheline syenite stock, where there are numerous dykes of rhomb porphyry cutting both the stock and the adjacent volcanics. Three trachyte dykes radial to the Ithanguni stock were seen on its southern side, and of these two were seen connected to superposed lava sheet as feeders. The occurrence of dykes of the later eruptive phases in earlier formations confirms the eruptive sequence proposed. Thus dykes of fissile phonolite, basalt and pale olivine trachyte, representative of the later eruptive phases, are found cutting the earlier volcanics.

Basalt dykes of the later basaltic eruptions are particularly numerous in the peak area, supporting the suggestion that the olivine basalts such as those of the Sirimon valley were erupted from fissures. One basalt dyke traverses the nepheline-syenite of the main peak, forming a narrow gully which traverses the north face between the Northey and Krapf glaciers, forms the Gate of the Mists Col between Batian and Nelion, and the ice-couloir beneath the Diamond glacier.

A description of these dykes would be superfluous, for they have the same composition and mineralogy as the lavas. Two dykes are, however, unusual, the microsyenite dyke at Polish Man's Tarn, and the trachyte dyke east of Lake Höhnel.

The microsyenite dyke at Polish Man's Tarn is approximately 15 feet wide and is cut by narrow rhomb porphyry dykes of similar trend. A hand specimen (44/997) from near the Tarn is grey, medium-grained and finely mottled. It carries felspar phenocrysts 12 millimetres long. Another specimen, 44/1207 taken from 300 yards to the south, is medium grey, more fine-grained, and also contains 12 millimetre felspar phenocrysts. There are narrow streaks of coarser grain size in the rock. Specimen 44/997 contains a mesh of turbid alkali felspar, probably anorthoclase, with granular aegirine-augite, mossy cossyrite and brown sodic amphiboles in intersertal clusters. No nepheline was recognized. In specimen 44/1207 the rock is microporphyritic and the groundmass consists of turbid alkali felspar laths with scattered aegirine-augite grains and iron ore. The rocks represent a microsyenite dyke associated with the nepheline syenite stock nearby. In the area of moraine immediately north of the Tarn are several other closely spaced dykes outcropping at short intervals, which are not shown on the geological map. They have the same north-westerly trend as the rest of this dyke swarm and consist of three narrow rhomb porphyry dykes, one biotite-bearing porphyritic phonolite, and another phonolite with unusually large glassy nepheline phenocrysts.

The trachyte dyke which traverses the cliffs of Lake Höhnel is notable for its very large tabular felspar phenocrysts, which reach a size of ten by five centimetres, and occur in a green-grey base. These phenocrysts are anorthoclase, and the rock contains a second generation of one centimetre long phenocrysts in a fine-grained matrix in which green pyroxene and a yellowish brown mineral of high polarization colours can be made out. There are small pools of analcite. This coarsely porphyritic alkali trachyte dyke is unlike any other rock seen on the mountain.

(2) The Satellite Vents

The volcanics to be described are separated from the Mt. Kenya Suite in time, space and in mode of eruption. The first group to be described, however, is of similar composition. It seems likely that the eruptives of the satellite vents derived from a different magma chamber from those of the Mt. Kenya Suite, and the later basalts are almost certainly connected with the Nyambani Volcanic Series, a Series built up by a chain of small basaltic vents the majority of which are to the north-east of Mt. Kenya, but which extend continuously into the present area.

(a) *Mugi*

Mugi hill is situated one mile east of Lake Ellis, and rises 400–600 feet above the surrounding country (*see* Plate IV, Fig. 1). It is half a mile wide at the base, and has smooth, steep sides sloping at angles of 40 degrees. The upper part is a circle of hillocks surrounding a shallow central depression. Erosion has had little effect on this hill, the only traces being gullies less than ten feet deep. At the western foot of the hill there is a steep sided triangular depression occupied by a swamp; the farther side of the depression is formed by a cliff of olivine trachyte. The impression gained is that Mugi covers the eastern three-quarters of a small but deep explosion crater. The whole of the southern slope of the hill is steep and rock exposures are abundant in contrast to the lack of exposure elsewhere. This triangular face represent a very large land-slip scar; the track of the slip and its debris can be clearly seen in an elongated zone extending one mile south-east of the hill.

On the western slopes of the hill up to the summit no bed-rock is exposed—the slopes are covered with rubble and blocks of phonolite and black glassy kenyte. On the side of the land-slip, however, faintly banded glassy vesicular kenytes are exposed. The area of the track of the land-slip is littered with kenyte and phonolite blocks, sometimes in linear mounds, and the track is margined by a lip or raised edge of angular blocks.

The shape and composition of the hill suggest that it is a cumulo-dome of very viscous kenyte and phonolite, the outer surface of which is largely fragmentary due to the fracturing of already solidified lava during enlargement of the dome by the internal intrusion of lava (Cotton 1952, pp. 156–169). A few poorly developed small fissures and fault scarps traverse the upper part of the hill, and are probably associated with the fissuring of the Lake Ellis area. This fissuring and the movements that caused it may have been the cause of the land-slip that removed part of the southern slope of the hill.

(b) *The trachytic necks*

On the north-eastern slopes of the mountain there are six trachytic necks of which Ithanguni is the largest and is described separately. The remaining five necks are all between the 8,000 and 11,000 foot contours, and are characterized by their form. The best developed necks are those forming the Giant's Billiard Table and Rutundu. These are sub-circular in plan and three-quarters of a mile across at the greatest width, and are surrounded by lava cliffs 300–400 feet high. The upper surface is remarkably smooth and is almost flat; on the Giant's Billiard Table there is a slight central depression, which is more marked on Rutundu and the neck to the east of Rutundu. The similarity of shape and structure between these circular plateaux and the summit plateau of Ithanguni is notable. The plateaux on the eastern margin of the area were not examined, but are so similar to the remainder in appearance that there is little doubt that they are of the same structure and composition. A further plateau three miles east of Urumandi is tentatively included with the trachyte necks. It is a circular level area at the same average elevation as the nearby slopes, but it projects above ground level at its south-eastern end, and is below the surrounding ground at its north-western end. It was not visited during the survey but is suspected to be a trachyte neck due to its form and the nature of the nearby lavas.

Both the Rutundu and Giant's Billiard Table necks are composed of massive alkali trachyte with widely spaced columnar joints. The rocks are pale greenish grey, with a rough matrix, and weather to a brown colour not unlike the earthy brown trachytes and pyroclastics which occur in association with these vents. The brown trachyte rubble which litters the ground at the foot of the western side of the Giant's Billiard Table gives no hint of structure and could be derived from pyroclastics or lava. In the Mutonga river nearby, however, sub-horizontally bedded trachytic tuffs and agglomerates are exposed close to the neck. The cliffs surrounding the lake in the explosion crater at the southern margin of the Rutundu neck are also composed of stratified trachytic pyroclastics of approximately horizontal attitude, and similar rocks outcrop at intervals in the Kazita gorge south-west of Rutundu. Only on Ithanguni was lava seen in close proximity to these trachyte necks. There is therefore little in the vicinity of the necks to show the size and nature of the volcanic superstructure, if there was such a superstructure. There are, however, two possibilities: the trachyte necks are plug-domes or *pitons* formed by the forcible extrusion of a cylinder of very viscous trachyte, such as the plug-dome of O-usu in Japan (Cotton 1952, pp. 175–178), or that the neck is residual and that it represents the prism of lava frozen in a low pyroclastic crater, such as the Hopi necks in north-eastern Arizona (Williams 1936, pp. 117–119). The Hopi necks are, however, much less wide than the Mt. Kenya trachyte necks.

Two specimens were collected from these necks, 44/1091 from the cliff at the western end of the Giant's Billiard Table, and 44/1102 from the southern cliff of Rutundu. Both are greenish grey fissile rocks with a faint mottling and sparse two millimetre felspar phenocrysts. Anorthoclase microphenocrysts are numerous in specimen 44/1102, and are seriate to the groundmass, which contains flow-aligned anorthoclase laths, mossy interstitial aegirine and scattered iron ore granules. One or two minute cubes may be of nepheline. Specimen 44/1091 is very similar but has brown patches of an alteration product, and there is an extensive analcite mesostasis. The fine lath-like nature of the groundmass felspars, and the mossy aegirine, together with either nepheline or much primary zeolite shows that these rocks are allied to the fissile phonolites rather than the trachytes. They closely resemble the Ithanguni lavas.

The brown earthy trachytes which have been referred to in the account of the olivine trachytes of the Lake Ellis area (p. 36) are found between Lake Ellis and Urumandi and reach northwards to beyond the Mutonga river. Similar rocks occur as agglomerates in the Kazita valley north-west of Ithanguni. These problematical rocks cannot be assigned to any definite origin, but the close association between them and the trachytic necks such as the Giant's Billiard Table and Rutundu suggests that they may have originated from these vents. This is supported by the similarity between weathered trachyte from these necks and the earthy trachytes.

The brown trachytes and agglomerates are very poorly exposed due to their easily eroded nature, and their field occurrence is often in the form of rubble and float. In the Nithi north river west of the basalt vent, there are exposures of brown faintly flow-banded lava overlain by loose rubble of earthy trachyte. Similarly the plateau south of Lake Ellis, which is composed of brown weathering olivine trachyte, is capped by a rubble of brown trachyte. Between this plateau and Mugi hill, and extending towards Urumandi and across to the Mutonga river, is an area of porphyritic brown earthy trachyte which contains loose blocks of phonolite in the vicinity of the Mugi vent. Over most of this area it forms a thin layer resting on the porphyritic phonolites beneath. Most of the blocky earthy trachyte of this region contains small felspar phenocrysts, and some rocks are quite coarse grained; the broken faces of the felspar of the matrix can be made out with a hand-lens. North-west of the Giant's Billiard Table the slope down to the Mutonga is littered with such rocks—the fragments are generally rounded and rarely exceed nine inches in size, and scattered about there are blocks of Basement System gneisses up to four feet in diameter, proving that much of the material here is agglomeratic. Further north the earthy trachyte rubble is overlain by laminated trachytic tuffs from Ithanguni. Exposures in the Mutonga valley north of Mugi suggest that the earthy trachyte rubble overlies yellow ashes, and below these are green-grey trachytic agglomerates, trachyte lavas, and phonolite at the base.

The occurrences of earthy trachyte in the Kazita valley north-west of Ithanguni are of undoubted agglomerate, there being exposures in the river and the surrounding slopes between the 10,600 and 10,800 foot contours. These are overlain by the fine ashes which outcrop sporadically on the adjoining ridges, and which form the ground between Ithanguni and Rutundu, and west of Rutundu.

The trachytes are brown in colour, highly porous due to microvesicles, friable and easily trimmed. No large vesicles were seen, nor any traces of types with scoriaceous structure or a glassy facies. Some of the agglomerate blocks in the Kazita valley section were of trachyte breccia cemented by microvesicular trachyte. In most of the rocks minute cleavage faces of felspar crystals are visible, and in some scattered stout phenocrysts up to half a centimetre long are present. Three specimens were collected, specimens 44/1083 and 1084 from the Chogoria path (Carr's road) two miles south-east and 400 yards west of Urumandi respectively, and 44/1101 from the Kazita valley one and a half miles west-north-west of Lake Alice. Specimen 44/1083 is medium grey-brown in colour, microvesicular and porous, with a sheen due to minute felspars. In thin section it consists of alkali felspar laths set in a matrix of spongy iron ore and pools of brown glass. Specimen 44/1084 is similar to 44/1083 in hand specimen except for the presence of small felspar phenocrysts seriate to groundmass size, and the matrix contains small aegirine-augite prisms, clumps of fine iron ore granules, and a patchy turbid zeolite mesostasis. Specimen 44/1101 contains flow-aligned felspar laths in a speckled cryptocrystalline groundmass.

These trachytes are probably the products of the explosive activity of the trachyte necks, whose lavas they most closely resemble. These explosions no doubt resulted from the vulcanian activity of the vents, and may also have produced some of the finer tuffs which are associated with the agglomerates in the Mutonga section. The activity of these vents ceased when they were occupied by quiescent trachyte in the form either of lava lakes or of viscous plug-domes.

(c) *Ithanguni—trachytic lavas and pyroclastics*

The volcanic pile of Ithanguni on the eastern slopes of the mountain is the largest of the satellite volcanoes, and it is still in an early stage of dissection; moreover, the exposure on its upper part is good due to the fact that it has suffered a short period of glaciation. Ithanguni is a squat conical mountain surmounted by a flat summit plateau approximately one mile wide, and which reaches to 12,776 feet. To the south, east and north the slopes fall off evenly at approximately 20 degrees, but to the west the mountain is linked by a rounded ridge of pyroclastics to the main mass of Mt. Kenya. One and a half miles west-south-west of the summit plateau a broad, shallow basin occurs in the pyroclastics. This basin is one and a half miles across at its widest part and has the appearance of a large explosion crater. At the foot of the north-western side of the summit plateau there is a smaller but deeper explosion crater occupied by Lake Alice. On this side of the mountain the Lake Alice crater lays bare the side of the neck, which forms cliffs up to 900 feet high overlooking the lake. Low cliffs margin the neck and the summit plateau around the remainder of its circumference. By projecting the surface of the older volcanics beneath Ithanguni the thickness of the Ithanguni volcanics can be estimated at approximately 3,000 feet. Previous to the onset of erosion these volcanics were probably only a few hundred feet thicker than at the present time.

The deepest sections exposing the Ithanguni volcanics occur on the steep slopes south-east of Lake Alice, between the southern lateral moraine and the cliff face. The upper 600 feet of the succession here contains mostly pale buff, yellow-brown and brown ashes of sand grade with thin agglomerate and a flow laminated partly glassy brown and buff pocellaneous trachyte outcropping at 12,500 feet. The lower 300 feet of the slope is partly obscured by moraine and eluvial ash but scattered outcrops of thin trachytes occur about 300 feet above lake level, and can be traced round the western side of the lake where they are seen to be intercalated in ashes and agglomerates. Similar trachyte lavas are found in the cliffs east of the lake, but are thicker here and are overlain by a minor development of reddish brown ashes.

On the northern, eastern and western sides the summit plateau is surrounded by trachytes dipping outwards. These lavas are exposed only on the glaciated pavements and hummocky rock bosses which characterize the ice-worn belt within the fringe of terminal moraines. The lavas are somewhat variable in colour due to their fine grain, and are grey and brown, frequently flow banded, and sometimes fissile. Vesicular varieties are rare but some lavas contain scoriaceous patches. These lavas on the northern and north-eastern slopes are strongly fissured at their contact with the wall of the neck, in contrast to the remainder of the neck margin, which is surrounded by a sheath of trachyte breccia.

On the southern side of the neck the trachytes can be seen to overlie a succession of pisolitic and pumiceous ashes which dip at eight degrees to the south-south-west. These pyroclastics continue up to the breccia sheath of the neck, and are cut by three dykes, two of which are feeders to superposed thin trachyte sheets 800 yards south-east of the summit. The trachyte lavas to the west thin to a thickness of a few feet and become glassy. Two hundred yards south of the summit massive trachytic agglomerates rest on these attenuated glassy trachytes, here only two to three feet thick, and these rest on laminated ashes. On the upper south-western slopes only pyroclastics are exposed, dipping at 28° to the south-west close under the summit ridge. This ridge is composed of flow banded trachyte of felsitic appearance and is exactly similar to the north-west dipping lava interbedded with ashes which outcrops on the ridge top 200 yards to the north-west.

The trachyte neck is formed of massive lava with a tendency to vertical columnar jointing. At the margins the rocks are fragmentary and pass imperceptibly into trachyte breccias and agglomerates which dip at steep angles towards the centre of the neck on its western sides. On the southern side of the neck a narrow breccia-agglomerate bed margins the neck but its attitude could not be determined. Lavas which dip beneath the neck form the summit of the plateau, and other lavas are in contact with the neck along the north-eastern margin. The trachytes forming the neck are grey to green-grey, compact, often fissile rocks in which very scattered small tabular felspar phenocrysts are seen. The upper surface of the neck, i.e. the greater part of the summit plateau, is composed of pale brownish grey to silvery grey, fissile, glistening lavas which are quite distinct from the main mass of the neck on which they appear to rest as a shallow plate. These pale trachytes are similar to the pantelleritic trachytes found as small outliers and dykes on the upper part of the main mountain (p. 39).

It is likely that the Ithanguni neck was surrounded by a low crater wall consisting mainly of pyroclastics, and that the upper surface of the neck is only slightly reduced below its original level. The upper part of the neck, which widens appreciably upwards, is the prism of lava that froze in the crater floor, and the subjacent lava breccias and agglomerates represent the inner slope of the crater. The pale trachytes which form the cap of the neck may represent a late effusion of lava on to the solidified lava floor of the crater. The crater walls, which were constructed of unconsolidated pyroclastics, have been easily removed by erosion, especially ice-action.

Petrographically the lavas and the neck rocks are virtually indistinguishable—all are alkali trachytes of slightly differing characters. The differences in colour from pale silvery grey to deep grey are due to variations in crystallinity and the form of the ferro-magnesian minerals. More than half the rocks collected are porphyritic or microporphyritic, the felspars being sparse small tabular anorthoclase or soda-orthoclase crystals. Except in the case of the glassy trachytes forming the summit ridge (specimens 44/1166 and 1167), and one specimen from the outer margin of the neck at the foot of the cliff overlooking Lake Alice (44/1162), the matrices are fine-grained, trachytic and consist essentially of lathy anorthoclase, granular or mossy aegirine-augite and, rarely, brown sodic hornblende. Two of the lava specimens contain minute olivine granules in the matrix, and olivine microphenocrysts were found in one of the dykes on the south side of the neck (specimen 44/1104), in one specimen of the pale trachyte which forms the capping of the neck (specimen 44/1165), and in one of the lavas. Two specimens of the lavas had saccharoidal matrices devoid of ferro-magnesian minerals but with an abundance of fine iron ore. In the majority of the rocks sliced analcite was observed or suspected as a mesostasis in the groundmass.

The pyroclastics derived from Ithanguni volcano are wide-spread on the north-eastern slopes, where they blanket the earlier formations, and give rise to a distinct physiographic province on the mountain. They are preserved up to eight and a half miles west of Ithanguni on the ridge flanking the Kazita West and East valleys. Exposures of these almost unconsolidated ashes and agglomerates are poor except in the lower Kazita river, which cuts a precipitous canyon, and in some of the streams draining the steeper slopes. Some of these streams, namely the right bank tributaries to the Kazita, are incised so deeply that they run in narrow inaccessible canyons up to 30 feet deep, in which the tops of the canyon walls are no more than ten feet apart.

In the area of the Kazita river immediately west of Ithanguni a thickness of at least 1,500 feet of pyroclastics can be inferred, but from this area they thin in every direction. The ashes which make the greater part of these beds dip at variable angles usually down the slope of the mountain, and these dips are depositional and reflect the slope of the floor on which the pyroclastics were deposited. The ashes and fine agglomerates are well exposed in the broad valley-head south of the Kazita West at the 12,000 level. The lowest beds are fine brown agglomerates with fragments averaging four inches in diameter. These are overlain by well bedded sandy and pisolitic ashes. The dominant colours are yellow-brown, brown, grey and olive-grey, the finer material being the darkest in colour. Well laminated brown and yellow ashes outcrop at intervals on the ridge north of the Mutonga river up to the 12,200 foot level, and locally these beds dip up to 22 degrees to the east. The pyroclastics are well exposed at intervals in the Kazita river between 10,000 and 11,000 feet, the lower part of the section exposes agglomeratic earthy brown trachyte of the type described on p. 38 but higher up these agglomerates are overlain by finely bedded ashes and agglomerates with thin yellow claystone beds.

The area between two and four and a half miles west of Rutundu contains numerous exposures of pale buff and brown pumice tuffs which form sculptured crags and cliffs and which contain caves and overhangs. The lower portions of some of the cliffs and overhangs have been extensively eaten by animals on account of the high saline content, which is evidenced by efflorescences of sodium carbonate. In one favoured locality the animals (mostly eland, zebra, duiker and possibly a few buffalo) have eaten or licked away at least three feet of pumice tuff over a frontage of 15 yards.

6. Basaltic lavas and vents

The volcanics to be described are the basalts and vents which were erupted on the flanks of Mt. Kenya after the trachyte-phonolite activity of the main vent and the satellite volcanoes had ceased. There is no doubt that the whole of the basaltic vulcanicity is Quaternary in age, for the most far reaching flows descend the Thiba valley south-east of Embu, and reached levels below the mid-Pliocene erosion surface in that area (Bear 1952, pp. 30–31*). There is little doubt that the Quaternary basalt vulcanicity of the present area was current with and of the same type as the Nyambeni vulcanicity (Mason 1955; Rix, The Kinna area, in preparation (includes summary of the Nyambeni volcanic series)), for the chain of Nyambeni-type basaltic vents extends into the present area.

(1) The Thiba Basalts

The basalts of the southern slopes have been separated from the Laikipian basalts as described by Shackleton (1945, pp. 3–4; *see* p. 18 of this report), and are named the Thiba Basalts after the main river which traverses their outcrop. The Thiba Basalts occur between the Ragati and Rupingazi valleys and generally below the 11,000 foot contour, and extend into the area to the south (Fairburn, 1966) to a little beyond latitude 0°45′S. They cover an area of approximately 500 square miles, and were erupted from a series of vents along an east-north-easterly trending line on the southern slopes of Mt. Kenya, between the 9,000 and 11,000 foot contours. Other basaltic vents occur on the slopes of the mountain, and are included in the Thiba Basalts due to their apparently similar age and composition.

*Note, however, that Bear's view of the age of the erosion surfaces, the Mt. Kenya phonolite, and the Thiba valley basalt is, in the writer's opinion, incorrect (*see* page 14 of the present report).

The age of the Thiba Basalts cannot be determined accurately without fossil evidence, but several other factors, tabulated below, enable an estimate to be made:—

(1) the basalts descend the lower Thiba valley to elevations below the mid-Pliocene erosion surface of the Tana valley (Fairburn, 1966)

(2) the vents from which these basalts were erupted are moderately well preserved, and are recognizable as craters on the air photographs.

(3) on the younger flows in the Ragati and Rupingazi valleys river incision is generally less than 20 feet,

(4) one basalt vent situated between the Rupingazi and Thuchi valley terminal moraines at 11,000 feet partly underlies this moraine, showing that the vent is a little older than the last glacial maximum, which can be tentatively put in the upper Pleistocene.

These facts suggest a Pleistocene age for the basalts, and the writer would guess that the bulk of the activity occurred in the Middle and Upper Pleistocene.

The Thiba Basalts are sub-divided into three groups for ease of description. Since the complex stratigraphy within the group has not been fully worked out these groups are based on distinctions of field appearance and petrography, but there is evidence that the groups are natural to some extent.

(a) *The basalts of north-western Embu district*

The basalts to be described cover the greater part of the Thiba Basalt outcrop, and are margined to the west and east by the younger Ragati, Nyamindi and Rupingazi basalts, and overlain in Inoi location by the microporphyritic basalts and ashes which form the youngest division of the Thiba Basalts. The basalts outcropping near the western margin of the Thiba Basalts, in the area of Gerere and Biruoini, in the Chehe Forest Station area and in Iriaini, Kiine and Mwenia locations appear to be the oldest, for this area is dissected to a greater extent than the basalt terrain to the east. The differences in degrees of dissection can only be appreciated by study of maps with 50 or 100 foot contour intervals.

The basalts in the Biruoini-Chieni Marsh area in the forest are dark dense basalts without phenocrysts. Below the forest the basalts are mostly porphyritic, with lath-like felspar phenocrysts up to half an inch in length, and in many of these rocks minute olivine phenocrysts can be made out. Such types are common in the area between Kiangai, Kahuru, Kiaruhiu and Moragara villages, and are also found on the track above Chehe Forest Station between the 7,000 and 9,000 foot contours. Farther to the south, on the Kiangai-Karatina road, fissile dense basalts often with bluish vesicles are seen and are reminiscent of the Laikipian basalts. Forming the higher ground immediately south of Kiangai village and west of Gathambi are medium grey rough-textured porphyritic olivine basalts, and similar rocks form the more level ground east of the line Kachimba-Ruiru river-Kiamaina-Kabonge. These olivine basalts pass beneath the microporphyritic basalts of Inoi location, and similar types are only rarely seen further east except south and south-west of Ruangondu village.

To the east of the younger basalt of Inoi the greater part of Kabare location is composed of dense basalts, examples of which are well exposed at the Tetu bridge over the Keringa river north-west of Gatugura village. These lavas are either fissile or blocky and the blocky varieties often weather into spheroidal masses. The eastern limit of the dense dark basalts passes approximately along the line Kathaiya-Gatugura-Karumande-Kathandeni; east of this line the lavas are porphyritic columnar basalts characteristic of the valley floors of the Nyamindi and Rupingazi valleys.

The vents from which the basalts were erupted occur at the upper margin of the basaltic area, at Gerere (10,000 feet), the end of the Kamweti track (10,600 feet), and in the Nyamindi and its tributary valleys at 10,600 and 11,000 feet. Of these the last two are well preserved vents with deep central craters and walls breached to the south—both are one third of a mile wide. The Gerere and Kamweti track vents are slightly larger and more eroded, but are still recognizable as small vents on air photographs. The Gerere vent is surrounded by an area of scoriaceous olivine basalts, and the Kamweti vent is of vesicular brown-grey microporphyritic basalt, with basaltic tuffs, scoria and agglomerate poorly exposed on the slopes below.

Very little traversing was done in the forest on the basalt outcrop owing to the extremely poor exposure, the dense vegetation and the lack of time. The geology of the forest on the southern slopes is therefore tentative.

Two broad depressions were found on the basalt outcrop, one at Kachimba and the other near Muthere. Both are basin-shaped, 150–200 feet deep and margined by slightly raised sides. Only the Kachimba depression was visited, and this is occupied by a swamp feeding the Ruiru river. Only two basalt exposures were seen on its flanks, but from its form there is little doubt that it is a large explosion crater, probably of phreatic origin.

Petrographically the majority of the specimens collected from this division of the Thiba Basalts are microporphyritic olivine basalts. Basalts with visible felspar or olivine phenocrysts are rare, the former are found mostly in Iriaini location of eastern Nyeri, the microporphyritic basalts occupy the remainder of the area described. The essential minerals in the basalts are andesine-labradorite, ferriferous olivines, augite, and iron ores. In half the slides traces of analcite in the matrix or as discrete pools was seen. Apatite rarely occurs as an accessory mineral.

(b) The Rupingazi, Nyamindi and Ragati basalts

At the eastern and western margin of the basalts described above, and as a separate area centred on the Rupingazi valley between the 11,000 foot contour and the southern boundary of the area, are youthful pale to medium grey olivine basalts which characteristically occur as valley flows. The area occupied by these basalts is characterized by low relief and only minor incision by streams, and the margin of their outcrop in the Rupingazi valley area in the forest is based almost entirely on evidence from air photographs, and is at the edge of a broad belt in which the topography is markedly youthful compared to that of the adjacent country. In the Rupingazi valley north of Embu, however, the relationship of the basalt flows to the underlying dissected phonolites is very well displayed.

The basalts which descended from the two low, dome-like, undissected vents at 9,300 feet west of the Rupingazi flooded a wide area in the forest, and flowed down into the upper Kii and Rupingazi valleys.

The Rupingazi valley is flat-floored and steep-sided from Thambana village to the southern boundary of the area and beyond. The physiographic anomaly of a flat-floored valley occupied by a river incised only 10–20 feet into the valley floor in a countryside of dissected topography is immediately apparent, and is explained when the floor of the valley is found to be occupied by a recent lava flow. Between Thambana and Rugumu the valley floor is slightly undulating, there being low elongated mounds and ridges which are linear surface features of the lava flow. The lava in this area is largely vesicular flow-breccia—the lava was of the blocky or *aa*-type—and the linear mounds are probably pressure ridges. In the vicinity of Mwiria factory the Rupingazi river is on the eastern side of the valley and locally exposes the steep basalt-phonolite contact which slopes towards the centre of the valley.

The basalt of the lower Rupingazi is medium grey, rough textured and contains very scattered olivine and felspar phenocrysts up to one centimetre in size. It often displays good columnar jointing, as at the intake of the Embu Water Supply works at the northern margin of the Njukiini Forest.

Basalts which closely resemble those of the Rupingazi are found near the southern boundary of the area between Kathaiya and the Nyamindi river, and extend northwards as far as a line joining Gatugura, Karumande and Kathendeni. Darker, denser basalts with small olivine phenocrysts are found one mile west of Kiamutugu and flooring the lower Nyamindi valley. The latter exhibit good columnar jointing, and are valley flows similar to those of the Rupingazi valley.

The Ragati olivine basalt is a distinct flow which can be traced from the forest on the south-western slopes down the Ragati valley to a point well to the south of the present area, north of Sagana township. The Sagana-Karatina-Ragati Forest Station road is built on this basalt. The Ragati valley is broad and flat floored and, like the Rupingazi valley, is in marked contrast to the deeper, incised valleys to the east and west. Neutral grey blocky porphyritic olivine basalt is exposed along almost the whole length of the Ragati river. The Ragati basalt flowed down the western margin of the older Thiba Basalts and inundated the eastern edge of the hilly ground formed of the Mt. Kenya trachyte.

(c) Microporphyritic basalts in Inoi location

Much of Inoi location is occupied by soft microporphyritic basalts, ashes and agglomerates which are believed to have originated from a group of four low vents between one and a half and three miles north-east of Chehe Forest Station, and from the completely undissected ash cone which is Kilima Kamuruana hill.

The typical lava of this region is a brown weathering basalt with scattered one centimetre felspar phenocrysts in a matrix full of minute lath-like felspar microphenocrysts, often accompanied by small olivines. These types outcrop in the Mukengaria river on the forest boundary and up to two miles to the south, in the neighbourhood of Rutue mill, and in a broad belt east and west of Thaita village. In the southern half of the outcrop the basalts are commonly overlain by poorly consolidated brown agglomerates and ashes, which outcrop on interfluves. Similar agglomerate is seen as loose fragments on the track north-east of Chehe Forest Station, on the western slope of the Kiamariga vent, and forms the whole of the dome-like Kilima Kamuruana vent.

The outcrop of these rocks is relatively undissected in comparison with the ground to the east and west, and further evidence of the young age is provided by the unconsolidated nature of the agglomerates, the youthful appearance of the vents, and the fact that they are seen overlying the older Thiba Basalts in the Mukengaria river and in the streams north of Kerugoya. It is possible that these volcanics are of the same age as the basaltic pumice cones of the northern slopes of the mountain which are described below.

(d) Other craters and vents

Well preserved craters and vents are recognized in the forest belt on the eastern and western slopes of Mt. Kenya to be in the same state of dissection as those from which the older Thiba Basalts were erupted. These were recognized on air photographs, and are located in the Thuchi valley (three vents), in the Nithi valley near the eastern margin of the area, Kehari and Tagwa hills on the south-western slopes, and two vents among the tributaries to the Burguret river on the western slopes. Of these only Kehari hill and the Burguret vents were visited. The outlines of the other vents and the hypothetical boundaries of their lavas are inferred from air photographs.

These vents are between half and three-quarters of a mile wide at the base and rise up to 500 feet above the surrounding country. Only the uppermost vent of the Thuchi valley has a well-preserved crater—in the remainder the crater is either destroyed by erosion or, as in the case of the Nithi valley vent and Kehari and Tagwa hills, never existed.

The lower slopes of Kehari hill and the northern vent of the Burguret river system were searched for exposures without success, but in each case the foundation of porphyritic phonolites was found outcropping in the streams near the bases of the hills. In the case of the two vents examined it seems that very little, if any, lava was erupted, and it is likely that the vents are ash cones.

(2) Basaltic Pumice Cones

The south-western extremity of a large field of basaltic cones and vents which covers a wide area of the north-east of the present area, and form the Nyambeni Volcanic Series (Rix, Kinna area, report in preparation) occurs on the northern slopes of Mt. Kenya. Fifteen vents and cones occur between the Kazita river and the northern margin of the area, and are in the form of low cones, often with ill-preserved shallow craters. The vents are up to three-quarters of a mile in diameter at the base, and rise up to 300 feet above the surrounding country. Exposures are extremely scarce and the only erosion to affect them has been the cutting of shallow gulleys which usually expose surface debris consisting of rounded blocks and pebbles of highly vesicular or pumiceous basalt. The surface of the vents is littered with similar material. In no case was lava seen extending beyond the slopes of a vent.

Lava was, however, seen on the two vents nearest the Kazita river, and two specimens (44/1116 and 1117) from the northern slope of the vent four and a half miles east-north-east of the Barrow prove to be scoriaceous oligoclase basalt with much iron ore and no recognizable ferro-magnesian minerals, and fine-grained fissile olivine basalt respectively. The superficial material normally seen is of reddish brown weathering highly vesicular scoriaceous or pumiceous fine-grained basalt. No definite pyroclastic beds were seen on these vents, but much of the superficial material is of ashy consistency.

These vents appear to be composed of highly vesicular basalts which were extruded without explosive activity and which are limited to the vents themselves. They appear to belong to the latest phase of activity of the Nyambeni volcanic chain (Mason 1955, pp. 8–9).

7. The Central Plug of Mount Kenya

The plug of Mt. Kenya, which forms the highest peaks of the mountain, occupies the conduit through which passed the greater part of the volcanics which build the mountain, for the volcanics of the main eruptive episode are symmetrically disposed about this centre.

The plug is sub-circular in plan (Fig. 7) and is one and a quarter by one and a half miles in dimension. In its eroded state it forms a complex of precipitous peaks and is excellently exposed over a vertical distance of nearly 3,000 feet. Parts of the southern and eastern margins are obscured by glaciers, scree or moraine, however, and much of the central part is inaccessible even to experienced rock-climbing parties.

The structure of the plug is of a series of partial concentric cylinders and lenses about a central core of nepheline syenite, the cylinders having vertical axes. The outer ring consists of fine-grained phonolite, locally much altered and penetrated by syenite, which margins the plug on the northern and eastern sides. To the west the marginal rocks are porphyritic syenites separated from the central syenite mass by a septum of phonolite similar to and apparently continuous with the phonolite of the outer ring on the north. The central region is occupied by coarse nepheline syenite which contains zones full of phonolite xenoliths.

(1) Phonolites

Fringing the plug on its northern and eastern sides is a body of phonolite which is between 250 and 300 yards wide. At no locality was the outer margin of this phonolite exposed, but the margin can be mapped to within 20 or 30 yards except on the scree and moraine covered slopes below the Gregory and Krapf glaciers. The inner margin of this phonolite body is exposed in the area between Point Peter and Kami Tarn, and below the snouts of the Krapf and Lewis glaciers. In each of these localities the contact is vertical or nearly so, but is usually characterized by a transitional zone in which the adjacent syenite penetrates the highly fractured and altered phonolites near the contact to form an intrusion breccia.

The phonolites are distinguished from the volcanic sequence with which they are in contact by their homogeneity, the black non-vitreous matrix, by the occurrence of reddish nepheline phenocrysts and by the lack of stratification and pyroclastic beds. In these respects the phonolites of the outer ring are identical to those of the body between Oblong and Hut Tarns. The phonolites outcrop at or near the base of the main massif, being less resistant to glacial plucking due to their close jointing, and the majority of lakes in the peak area are found on their outcrop.

In several areas the phonolites contain rounded xenoliths, and this structure is very difficult to make out where the xenoliths and the host rock are very similar, as is usually the case. Areas where cognate phonolite xenoliths are common are on the south ridge of Nelion, down to the margin of the Lewis glacier (*see* Fig. 7), at the eastern margin of the plug immediately north of Thomson Flake, and at intervals along the phonolite outcrop between Hut Tarn and Oblong Tarn.

In the hand specimen the phonolites closely resemble the kenytes, and have felspar and nepheline phenocrysts in a very dark grey to black fine grained base. The matrix is never glassy, however, nor does it have the greenish shades of the better crystallized phonolite lavas. In the neighbourhood of the contact with the central syenite body the phonolites are often affected by recrystallization, and become pale brownish grey variable rocks, in which the felspar and nepheline phenocrysts can be made out with difficulty. Within 20–50 yards of the syenite contact the altered phonolites are often closely reticulated by microsyenite veins, and the phonolites become flinty, pale greenish buff in colour, and are much coarser grained than the unaltered rocks. Such recrystallized phonolites are especially common at the phonolite-syenite contact between the Krapf glacier and the trachyte dyke west of Kami Tarn.

Large quantities of phonolite xenoliths are found in the central syenite body in well-defined zones, two of which occur on the west face of Point Piggott, and evidently have the same orientation as the adjacent syenite margin. In these xenolithic zones the fragments are well rounded and form more than half of the rock by volume, and are similar to the phonolites of the main body. Similar xenolithic zones were observed on the left bank of the Northey glacier, at 15,400 feet, and the occurrence of xenolithic syenite blocks in the lateral moraines of the Darwin, Josef and Northey glaciers suggests that further xenolithic zones occur high up on the rock faces where these glaciers originate. A further complex xenolithic belt is found on the south face of Point Piggott, on the cliffs overlooking the Tyndall glacier. Blocks of phonolite up to eight feet in diameter are found here, the blocks themselves often being xenolithic, and containing fragments of phonolite of varying texture. Many of the phonolite fragments of this zone are paler than normal and show evidence of alteration.

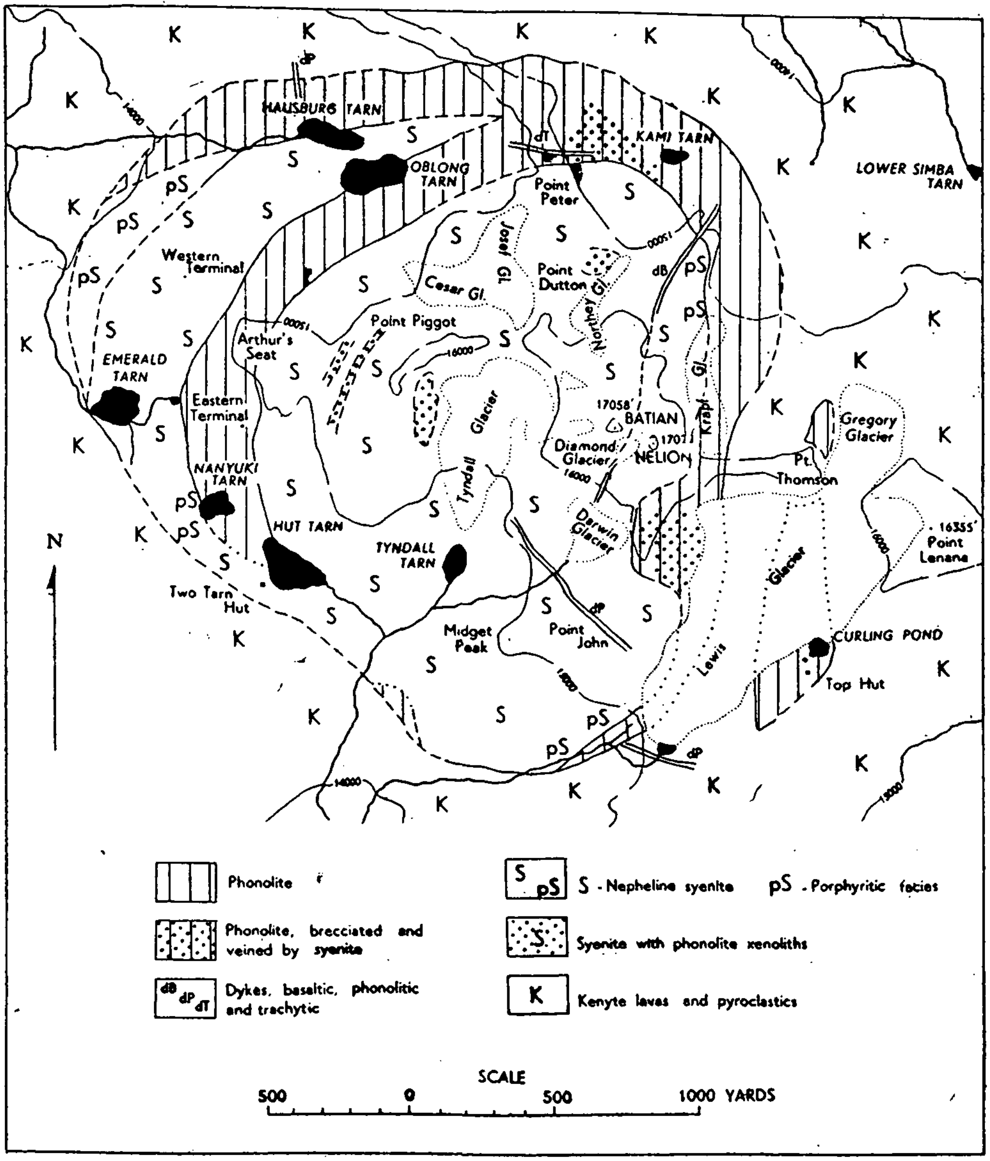

Fig. 7—Geological map of the Mount Kenya plug.

In thin section the phonolites are seen to be very much alike in composition, but to exhibit variable textures. In all the slices examined porphyritic felspars occur, but in most the felspars are rounded, with granulated borders and numerous inclusions. In most cases the felspars can be identified as anorthoclase by the occurrence of fine lamellar twinning and the moderate axial angle. The nepheline crystals are more frequently broken down to granular aggregates full of veins of zeolites, or are dispersed throughout the matrix as a zeolitic mesostasis, or as minute cubes in felspars. Characteristically the matrix is granular in texture, the felspars occurring as small stout tabular crystals often embedded in larger plates of felspar and zeolite in the form of sieve texture. Minute stout aegirine prisms are common, and a liberal dusting of iron ore granules is notable. Aegirine-augite occurs as ragged microphenocrysts in some rocks, or is pseudomorphed by masses of iron ore and alkali hornblende in the more recrystallized varieties. In several of the slices the aegirine-augite granules are yellowish and exhibit anomalous blue polarisation colours, and small plates of sieved brown biotite are not uncommon. Both cossyrite and kataphorite are extremely rare, but can be detected in association with altered sodic pyroxene in some slices. The only accessory mineral is apatite. Examples of these phonolites are specimen 44/972 from 200 yards west of Hausburg Tarn; 44/1035 and 1037 from the phonolite xenoliths in syenite at the west bank of the Tyndall glacier.

The phonolite fragments in a microsyenite base on the upper part of the south ridge of Nelion (cf. specimen 44/971A) at 16,000 feet, differ from the others in that they are very fine grained and turbid, and seem to be closely related to the phonolite outcropping at Top Hut, which is described below.

The rocky boss on which Top Hut stands is composed of homogeneous porphyritic phonolite with poor columnar jointing. The rocks are similar to the phonolites of the main plug in hand specimen, and appear to have a vertical contact against bedded kenytes at their south-western margin. Exactly similar homogeneous phonolites form the buttress below and to the north of Point Thomson, but here the phonolite is overlain by a bedded sequence of kenytes and agglomerates which form Point Thomson itself. The Lewis glacier obscures the relationship between these occurrences of plug-type phonolites and the plug itself, but it is possible that the two parts are joined beneath the Lewis glacier along the sub-glacial high indicated by the crevassed bulge of the glacier surface between the Curling Pond and Point Thomson. This body may represent a separate intrusion into the volcanics marginal to the plug in the form of a short ring dyke.

Two specimens (44/1029 and 1107) collected 100 yards south of Top Hut show corroded anorthoclase and nepheline phenocrysts in a dark turbid base with some small aegirine microphenocrysts and small pools of analcite. They are closely comparable to the phonolites included in microsyenite on the other side of the Lewis glacier on the south ridge of Nelion. An analysis of the phonolite near Top Hut is quoted on p. 27, and shows the close chemical similarity between these phonolites and the phonolitic extrusives.

(2) Nepheline Syenite

The whole of the central part of the plug is composed of massive nepheline syenite, and a lens of nepheline syenite occurs also in the north-western part of the plug. The central syenite body post-dates the phonolites adjacent to it, but the age of the western syenite body is uncertain.

The syenite consists of three main types—massive coarse-grained syenite which forms the central mass, porphyritic syenite which is a marginal facies to the main mass and which forms the greater part of the western body, and microsyenite, a chilled marginal facies of very local development, which intrudes the shattered adjacent phonolites.

The porphyritic syenites are found largely in the western marginal part of the plug, and at the contact of the syenite and phonolite near Nanyuki Tarn. They are also common but not universal at the contact of the central syenite, and were observed 100 yards north-west of Lewis Tarn, below the snout of the Krapf glacier and west of Kami Tarn. These latter occurrences are of a gradational marginal facies not more than 20 to 30 yards wide. The microsyenites are restricted to the fine vein stock-works which penetrate the phonolite in several places.

In the field the nepheline syenite is seen as a coarse grained rock composed largely of tabular felspars reaching a length of 1·5 centimetres, with interstitial finer grained mosaics of felspar and reddish nepheline. The scarce dark minerals are confined to intergranular positions. Some variations in nepheline content were observed in the field, but were of too irregular a nature to be mapped. The rocks are normally grey in colour, but vary to pale greyish brown in some outcrops. The gradation to the porphyritic facies occurs by a progressive decrease in the medium-grained component of the rock, with the result that the felspar phenocrysts become scattered in a medium to fine-grained matrix.

In thin sections the felspar phenocrysts are seen to possess a good but not perfect tabular outline, and to be rarely twinned. A few lamellar and one cross-hatch twinned felspar was seen (specimen 44/1038 from the snout of the Darwin glacier). In some slides, however, the phenocrysts appear to be sanidine on account of the low axial angle, for instance in specimen 44/1204 from the north-western shore of Oblong Tarn, and 44/1001 from 200 yards north-east of the snout of the Northey glacier. Subdhedral nepheline phenocrysts are scarce, for the nepheline normally occurs as a part of the matrix of interlocking anorthoclase crystals, in which brown kataphorite is seen as anhedral plates and skeletal slieved grains. The kataphorite is often associated with smaller granules of cossyrite, and shows a tendency to have marginal envelopes of aegirine-augite. In some slices, for instance specimen 44/1036 from immediately west of the snout of the Tyndall glacier, ferriferous olivine is present and is associated with iron ore, apatite and the other ferro-magnesian minerals in aggregates. In this slice the felspars of the matrix are mostly sanidine. Apatite prisms are common in the syenites, but iron ore is very scarce. Biotite was seen in a porphyritic syenite (specimen 44/979) from the western side of the Darwin glacier.

The porphyritic syenites are represented by specimen 44/971B, from the xenolithic syenites on the south ridge of Nelion, in which there is a cloudy fine grained interlocking felspathic matrix with scattered aggregates of aegirine granules.

The nepheline syenite of the plug is closely related to the phonolites in composition and mineralogy (*see* analysis on p. 27). The occurrence of olivine is especially indicative of the close relationship of these plug rocks and the olivine-bearing phonolites, kenytes and trachytes.

(3) Structure and Formation of the Plug

The map (Fig. 7) shows the concentric structure of the plug. Within the plug rocks, especially between Nanyuki and Emerald Tarns, the structure of the plug is indicated by concentric jointing parallel to the local syenite-phonolite contacts. Wherever these contacts and joint systems are observed they are seen to be vertical or at very steep angles outward towards the plug margin. The form of the phonolite bodies is that of incomplete cylinders with vertical axes, about a central cylindrical body of syenite.

Abundant evidence was found that the main inner syenite body is younger than the adjacent phonolite, but no definite evidence was found for the age relationship of the western syenite body to the neighbouring phonolites. In particular it is not known whether the two syenite bodies are continuous immediately west of Hut Tarn, for the critical area is covered by moraine. The most likely order of emplacement is from the outside inward i.e. the Hausburg Tarn phonolite, the western syenite, the Arthur's Seat phonolite, and finally the central syenite mass. This hypothesis does raise some problems, however, the first being that it requires two periods of syenite emplacement separated by a period of phonolite emplacement, and it requires that the two phonolite bodies in the north-west be of different ages. These requirements are unlikely in view of the fact that the phonolite is likely to have crystallized at a time when it was near to the surface, i.e. the volcanic pile was near its present height, and the syenite must have crystallized more slowly when the pile was considerably higher. These observations are difficult to reconcile with the alternating solidification of phonolite and syenite which has been proposed.

The only alternative crystallization sequence that can be postulated is that the phonolites all solidified at one time, and that magmatic withdrawal in the conduit left the Oblong Tarn-Arthur's Seat phonolite as a rigid septum in the pipe. A period of activity then may have ensued until the final quiescence of the main vent, when syenite would crystallize in all the remaining spaces within the conduit. Neither hypothesis seems wholly satisfactory, and further detailed examination of the contacts in the plug rocks is needed to solve these problems.

8. Superficial deposits

(1) Lateritic Soils and Ashes of the Lower Western Slopes

On the lower western slopes of Mt. Kenya, in the sector between Kiganjo and Nanyuki, there are considerable thicknesses of soils, laterites, ashes and solifluction deposits to depths exceeding 20 feet. These are exposed along the banks of rivers, in gullies and road cuttings, and comprise an interesting and varied series of superficial deposits, with which artifacts are often associated. The most continuous sections are found along the eroded valley sides of the principal rivers—the Nanyuki, Burguret, Naro Moru and Nairobi rivers, and similar deposits were recorded on the northern slopes by Shackleton (1946, pp. 40–44). The deposits were not studied in detail due to lack of time, but the more interesting sections were measured and some are described below.

A typical section on eroded slopes a quarter of a mile east of Hook's farm two miles south of Nanyuki is:—

	Feet
brown soil	1½
brown soil with ironstone pebbles	1½
lateritic ironstone with limestone cement	½
loose ironstone pebbles	½
yellow-brown gritty ash with calcareous concretions	3
brown-grey unstratified ash with well-rounded syenite and phonolite pebbles of 4″ diameter	>5

The superficial soil with ironstone pebbles at the base is widespread over the whole of the lower western slopes of Mt. Kenya, and rests with unconformity on the soils and ashes beneath. This soil is repeatedly seen sloping down into the present day valleys, and has been incised by more recent stream erosion. The superficial deposits can therefore be divided into three groups, as is indicated in Fig. 8. The first group (B, C, D, E, F in the figure) is sub-horizontal in attitude and is composed largely of unconsolidated pyroclastics, mainly fine ash rarely with small lava fragments, and is in variable stages of weathering. In each section there is normally one lateritic ironstone bed, with a soil profile above, indicating prolonged breaks in the deposition. The bedded silts and grits, which can locally be traced over wide areas probably represent eluviated pyroclastics, from which the finer fractions have been washed out. The uppermost layer (G) is the present soil cover, which is lateritic towards the base, and which extends over the greater part of the surface of the western slopes. This soil layer is largely eroded away on the sides of valleys, in the floors of which are brown alluvial silts with gravel lenses (H). In most rivers and streams on the lower slopes these alluvial sheets are incised to some degree by the present drainage, but the underlying bed rock is seldom exposed.

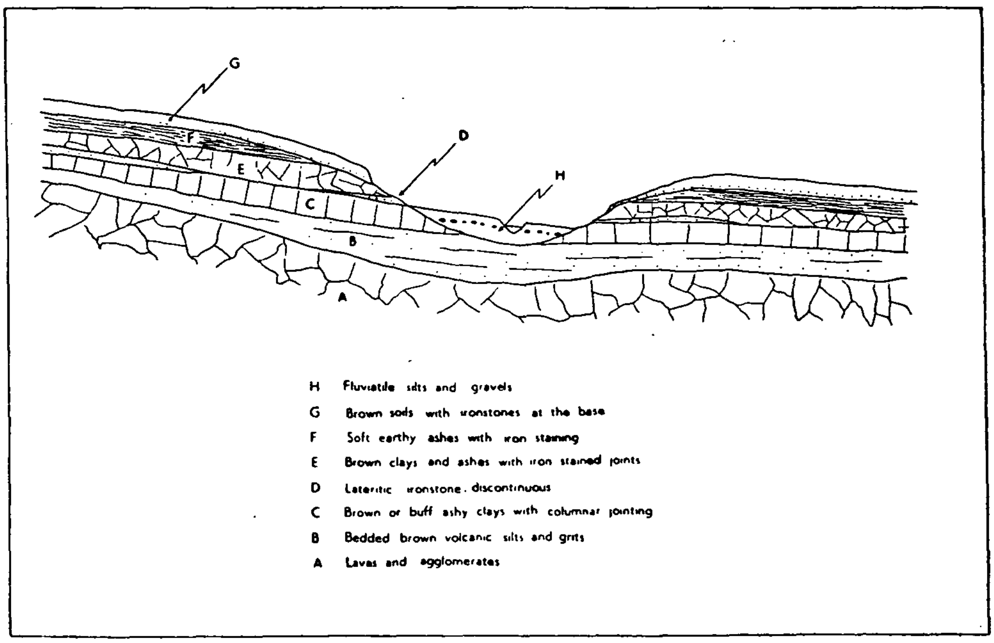

Fig. 8—Diagrammatic section in superficial deposits of the western slopes.

There are, however, many variations of the sequence outlined above. On the broad interfluves many of the middle members of the succession are absent, and the lateritic soils rest directly on agglomeratic ashes of the lower part of the succession, as is seen in the borrow pit by the main road immediately north of Naro Moru township, where the section is:—

	Feet
lateritic brown soil with many lava boulders	2
brown soils with lava and syenite blocks	10
grey sandy agglomeratic ash with 2″–3″ rounded lava pebbles	5
brown finely agglomeratic ash	>4

The grey sandy agglomeratic ash of the tabulation above is probably the Naro Moru ash referred to by Shackleton (1945, p. 5). Finely agglomeratic ash of variable colour was found at several localities on the plain between Naro Moru and Nanyuki, and is probably widespread beneath the lateritic soils, and may be equivalent to the occurrences of stratified tuffs which are common in the majority of river valleys higher on the slopes of the mountain, and which can be seen in the Liki Central and Nanyuki rivers at the crossing of the Gathiuru-Kongaita-Ontulili forest road, and in most of the stream sections in the sector west of Gathiuru and Nanyuki Forest Station. An easily accessible exposure of flaggy brown siltstones with gravel lenses, which may be fluviatile equivalents of the ashes of the plains, can be seen on the fishing path along the Burguret river one hunrded yards east of the bridge carrying the Naro Moru-Nanyuki road. These fluviatile deposits are described in the succeeding section.

A section which illustrates the complexity of the superficial deposits, and which shows the typical occurrence of two lateritized horizons, is seen in a gulley at the edge of the forest nine-tenths of a mile south-east of the crossing of the Naro Moru track and the Naro Moru river. The section shows:—

	Feet
brown soil, grading to	3
soil with ironstone nodules	1½
soft earthy silt	3
soil with ironstone nodules	3
hard nodular ironstone with calcareous matrix	2
soft earthy silt with iron staining	3
fine ashy grit	2
coarse brown pumiceous ash	2

The sections in the Liki and Nanyuki river which have been referred to by Shackleton (1945, p. 5; 1946, pp. 41–44) are outside the area to the north, but similar beds occur exposed at intervals up these rivers up to the 7,000 foot level. The sections referred to by Shackleton and previously described by Solomon (in Leakey 1931, pp. 261–262) are of alternating earths and fluviatile gravels in which artefacts of Kenya Fauresmith type have been found. It seems from the accounts that the artefacts have been found in and above the lowermost lateritic ironstone in these beds, and this would agree with the writer's observations of scattered loose artefacts occurring generally above the lower of the two massive lateritic ironstone beds of the western slopes of Mt. Kenya.

Artefacts were found loose on the surface on the upper part of an eroded slope above the Burguret river two miles north-west of the main road bridge over the river, and consist of obsidian scrapers, waste flakes and cores. Further scrapers were found loose on the surface of lateritic soils on the slopes leading down to the Nairobi river at 6,800 feet, on Graham's farm six miles south-east of Naro Moru. Scattered artefacts were seen over a wide area, mainly between the Nairobi and Liki rivers, and between the forest boundary and the Kiganjo-Nanyuki road.

The details of the superficial deposits on the western slopes of Mt. Kenya were not worked out due to lack of time. The abundance of exposure, the varied nature of the deposits and their association with artefacts, however, suggest that this area would repay detailed study by persons interested in later Quaternary geology and archaeology.

(2) Fluviatile Deposits

The occurrence of laminated silty sediments in the Nanyuki and Liki rivers has already been mentioned. This type of deposit, which is confined to river valleys, is wide-spread on the western slopes and is generally older than the gravel sheets which occur sporadically in the same river valleys. The silts are water-laid ashes containing rare volcanic boulders and thin gravel lenses. In the Thego river a mile above the Fishing Camp, at 6,000 feet, interbedded agglomerates and ashes occur resting on conglomerate; these beds form valley-fill deposits in process of incision at the present day.

The Nanyuki river exposes extensive sheets of gravel between Nanyuki township and the 7,000 foot level, and the gravels extend up to 100 yards from the river in places. Fluviatile deposits are, however, very rare on the south-western and southern slopes of the mountain—the valleys are generally choked by unsorted alluvium with scattered boulders, or are cut in bare rock.

(3) Superficial Deposits of the Moorland and Alpine Zones

The deposits referred to here are those of the zone of diurnal freezing, in which screes, stone glaciers, fluviatile and glacio-fluvial deposits are dominant. Above the 14,000 foot contour the effects of solifluction in its broadest sense become apparent. Moraine deposits on the crests and slopes of the ridges are margined by smooth sheets of pale reddish brown "scree" consisting of fine gravel and particles down to silt grade. These sheets frequently show the effects of mass flow in the form of linear furrows on the upper surface—furrows which bifurcate around obstacles and which mark adjacent bodies of "scree" of different texture and rates of movement. Towards the lower margins of these scree slopes the scree is commonly enriched in the gravel component by the eluviation of the finer fractions, and these gravel sheets sometimes form small stone "glaciers" which move by the alternate freezing and thawing of interstitial water, and which engulf grass tussocks, bushes and trees. All gravels and screes which are in active movement are devoid of vegetation, but colonization of the more stable marginal parts of the sheets by tussock grasses and *Senecio telekii* is in progress at the lower levels. On the more level parts of the scree slopes, at elevations generally above 14,000 feet, polygonal freeze and thaw structures of small size are commonplace, and consist of earthy material in slightly raised mounds some four to eight inches in diameter, surrounded by ill-defined stony borders. These structures grade imperceptibly into flow aligned bands of alternating gravelly and earthy scree (plate IV, Fig. 2), showing that they have developed on moving soil. These frost structures were studied by Zeuner (1949), who concluded that they were formed by the action of "needle" ice.

On more level ground in the alpine zone the commonest deposits are of ground moraine, which is normally covered by dark peaty bouldery soils. But at the higher levels there are patches of ground where the finer fractions of the moraine have been washed out, and concentrates of boulders litter the surface, such as in the hollows on the ridge immediately west of Two Tarn Hut.

In the various swampy depressions in the floors of the valleys, many of which contain unexposed lake deposits, the surface deposits are stiff clays or peats with sheets of fluviatile gravels accumulating at the inflow ends of the swamps. Apart from these sediment-filled depressions no significant deposition is taking place in the valleys of the upper part of the mountain. Most of the streams are choked with boulders from moraines, and bed-rock outcrops are scarce.

The soils of the moorland are sharply differentiated from those of the forest. The latter are reddish brown and brown sticky clays, while the former are dark peaty soils, permanently wet in the lower moorland, even on steep slopes. These peat and bog soils grade upwards into slightly better drained soils with a high gravel content and a brownish grey colour. In swampy depressions, however, black wet soils occur up to at least 14,000 feet. These dark soils are developed on the western, southern and eastern sectors of the mountain where the rainfall is highest. On the northern sector, approximately between the Liki and Nithi rivers, the soils of the upper moorland are normally dry, friable, very gravelly and of red-brown to grey-brown shades. This is due only partly to the lower rainfall on these slopes, for much of this northern sector is composed of tuffs which are highly pervious and well-drained, and on which thin brown soils are developed.

In the area between Mugi hill and Lake Ellis, and extending down approximately one mile towards the forest edge, there are areas of curious mounds of earth some two to three feet high, and between eight and 12 feet in diameter (plate IV, Fig. 1). These mounds consist of grey-brown soil containing angular fragments of lava, the centres of the mounds being noticeably more stony than the intervening depressions. These areas of earth mounds were first noticed by Mr. Raymond Hook of Nanyuki, and his account of them is given by Zeuner (1948, pp. 14–15). Hook interpreted the mounds as the cultivation areas of primitive people, and observed some regularity in the arrangement of the mounds and in the limits of the areas in which they occur. The areas of mounds are, however, clearly distinguishable on air photographs, and a study of these shows that there is no regularity or linear arrangement. Nevertheless Hook found broken pottery in this area (*op. cit.*), though the writer did not observe any. The upstanding rocks referred to by Hook are in all probability blocks of Basement System gneisses and quartzites, which are particularly numerous on the ridge to the north of the Mutonga river, where Hook informed the writer that the "monumental" blocks were situated, but in this area they undoubtedly represent large blocks weathered out of agglomerate. Zeuner (1948, p. 15), however, refers to a substantial collection of artefacts collected from above 10,500 feet by Colonel Meinertzhagen (*op. cit.*, footnote on p. 13), consisting of 30 flakes of Levallois aspect and 23 blades related to the Gumban industry. The occurrence of these and other less diagnostic pots and iron implements do suggest that the moorland was occupied, or at least visited, on more than one occasion in the past.

(4) Soils

No attempt was made during the survey to sub-divide the soils or to record their occurrence except in the most general way. The dark peaty soils of the moorland and their relatives in the alpine zone have already been described. These types pass into reddish brown and brown very deep and poorly drained soils in the forest. These soils are generally pale on the phonolite outcrop but darker on the basaltic terrain on the southern sector of the mountain.

At the lower levels of the forest and on the plains on the western slope of the mountain pale lateritic soils are commonplace, this being the former transitional zone between savannah and forest, and marginal to the low-rainfall area of the Laikipia plateau. On the lower southern and south-western slopes, however, the soils are deep reddish brown in colour, and are of great depth. This is due to the basaltic parent-rock and to the fact that till recently the southern slopes were entirely forest-covered. On level, poorly drained ground, however, the soils tend to become dark tenacious clays allied to black cotton soil.

V—GLACIAL GEOLOGY

Evidence of a past period of greatly extended glaciers is widespread on the upper part of Mt. Kenya, and the deposits left by these glaciers at their maximum development and during their retreat are well-preserved (*see* Fig. 12 at end). Some other evidence is given for the existence of an older period of extended glaciation, but this evidence is fragmentary and indirect. In the following account the glacial deposits are described under the headings of the "older" and the "younger" glaciations.

1. The Older Glaciation

In 1932 Nilsson (1931, pp. 19–25; 1940, p. 54) mapped moraines on the east side of Mt. Kenya, in the vicinity of the lower Gorges valley. He found what he believed to be patches of old, much eroded moraine below the great terminal moraine of the Gorges valley, which lies at approximately 10,400 feet. He interpreted this terminal moraine as marking the maximum extension of the glacier during a later glaciation, and regarded the patchy eroded moraine as having been deposited during an older glaciation. The writer re-examined this ground and could not confirm Nilsson's observation. It is possible that Nilsson saw some of the trachytic agglomerate in this area and mistook this for moraine, for much of this agglomerate is incorporated in the younger moraines of the Gorges valley, and it is often difficult to distinguish between agglomerate transported and re-deposited by ice and undisturbed agglomerate.

To the south of the lower Gorges valley, however, there is a broad gently undulating platform at an average elevation of 11,700 feet (*see* Fig. 9) on the surface of which there is a low crescentic ridge open to the north. On this ridge are scattered well-rounded boulders of a variety of rocks, and the form of the ridge and the variety of the boulders on it suggest that it is composed of moraine. This moraine must be substantially older than the well-marked younger moraines within the Gorges valley to the north, which are confined to the valley. Furthermore the younger terminal moraines of the Ruguti North valley, which traverses the platform, are above the platform, showing that the younger glacier could not have over-ridden the platform in the younger glaciation. It is therefore suggested that the moraine of the platform belongs to an "older" glaciation.

A small cliff exposure at the northern end of the platform mentioned above occurs one and a quarter miles west-south-west of the Nithi waterfall and further similar small cliff exposures of moraine occur on the north side of the Gorges valley one and a half miles west of the Nithi waterfall. These exposures are of cemented moraine containing boulders

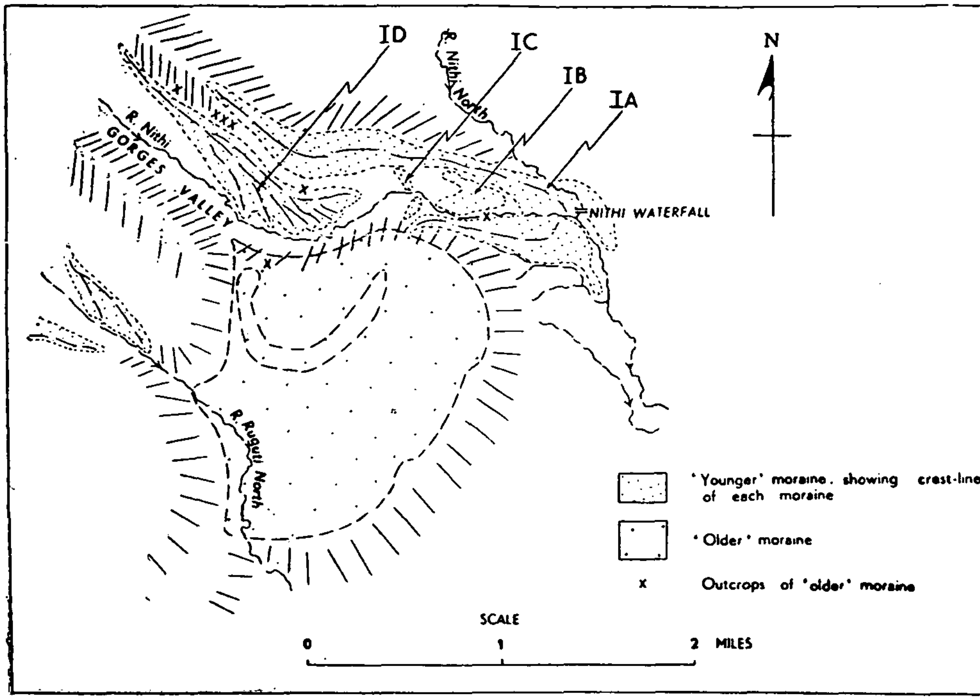

Fig. 9—Sketch-map of the Gorges valley terminal moraines.

of a variety of rocks in a matrix of pebbles and silt. A further similar occurrence of such moraine is found as a group of pillars one mile west of the Nithi waterfall (*see* plate III, Fig. 1). These moraine occurrences are in contrast to the well preserved younger moraines of the Gorges valley, in which cliff exposures are never seen except where the Nithi river cuts through the terminal moraine near the waterfall. The scattered outcrops of cemented moraine are tentatively regarded as parts of a sheet of older moraine laid down partly within and partly outside the Gorges valley at a time when it was shallower than at present, and which was later cut through by the erosion preceding and accompanying the younger glaciation.

On the western slope of a hill with a spot-height of 14,117 feet, on the south side of the Teleki valley, a series of caves and overhangs expose the base of the basaltic lavas and tuffs which form the hill. A variety of boulder beds, gravels, and silts is exposed in these caves, the deposits being up to 20 feet thick. The boulders range up to 12 feet in diameter and all the larger ones are conspicuously rounded. They occur in a generally unbedded and unsorted matrix of pebbles and silt. A search among the boulders revealed one with striated surfaces and another with a well-developed ice-smoothed surface. In some exposures there is a semblance of coarse bedding, and in one case there are irregular pockets of finely laminated silt up to six feet in thickness. This deposit is interpreted as moraine on account of the wide variety of rocks it contains, some of which are of varieties of syenite originating from the central peak, and because of its lack of grading and the shape of the boulders. The moraine was laid down previous to the eruption of the overlying basalts, which occur as an isolated outlier on the top of the ridge. These basalts are tentatively correlated with those that occupy the ground between the Ontulili and Sirimon valleys, and those that occupy the floor of the Rupingazi valley.

The floor of the Rupingazi valley is occupied by basalts which flowed down the valley are confined to it. These basalts are extensively ice-eroded and were clearly erupted before the younger glaciation. The depth and width of the valley previous to the eruption of the basalts suggests that it may have been formed, in part, by glacial action. No moraine deposits were seen beneath the basalts, at the few places where their contact with the confining walls of the valley is exposed, but a careful search may well reveal some. It is not known whether the sub-basalt moraine and the older moraines of the Gorges valley region belong to the same glacial phase. The evidence for "older" glaciations is fragmentary, and little can be concluded from it.

2. The Younger Glaciation

The widespread glacial deposits which occur generally above the 10,000 foot contour, and the obviously glaciated topography on which they occur, can be confidently ascribed to a comparatively recent glaciation. The terminal moraines laid down at the maximum development of the glacier system, and the moraines formed during the fluctuations during the general retreat from this maximum, are subdivided into stages for ease of description (*see* map of glacial deposits, at end). The criteria employed to assign the moraines to the correct stages are various, and mostly depend on a careful study of air photographs with a stereoscope, for photo-geological methods were found to be most useful in determining the shape, size, distribution and inter-relationships of the moraines. Care was taken, however, to check as many as possible of the photo-geological interpretations in the field. The criteria employed are the size, position, and shape of the moraines in relation to the valleys in which they occur, and the relationship of the moraines of each stage to the reconstructed snow-line of that stage. In this connection a useful fact is that lateral moraines are not deposited above the contemporaneous snow-line. The stages adopted are numbered from the oldest to the youngest, stage I representing deposits laid down at the maximum extension of the glaciers.

(1) *Terminal moraines—stage I*

The best developed terminal moraines occur on the eastern sector of the mountain, there being few recognizable on the western and southern sectors. The lowest point on each terminal moraine in different valleys is indicated in the following tabulation:—

	Feet
Hinde valley (Nithi north)	11,500
Nithi north, right bank tributary ..	11,200
Gorges valley	10,400
Ruguti..	10,700
Thuchi	10,600
Hobley valley..	10,400
Kazita West	12,300
Kazita East	11,900
Ithanguni	10,500–11,000

From the shapes of the valleys, the occurrence of ice-smoothed valley sides and the occurrence of parts of lateral moraines, approximate estimates of the maximum extensions of the glaciers down other valleys can be made:—

	Feet
Sirimon valley	10,600
Mackinder valley	9,200
Hausburg valley	8,600
Nanyuki south valley	7,700
Teleki valley	10,000
Höhnel valley	10,700
Nyamindi west valley	11,000

These figures show that the ice sheet was broadest in a north-west south-east direction, and that the ice reached the lowest levels on the north-western section.

The stage I terminal moraines of the Gorges valley show with diagrammatic clarity the sequence of events during the maximum glaciation and the early stages of the retreat (Fig. 9). The moraines are divisible into four sub-stages—stage IA is represented by the large terminal moraine exposed at the Nithi waterfall and in the canyon immediately to the west. This moraine is approximately 300 feet thick at its maximum development in the canyon area, and some 60 feet are exposed in the canyon sides. At the Nithi waterfall 20 feet of moraine is seen overlying trachyte bed-rock. Here, as in the canyon, most of the cliff sections are inaccessibly steep. On the north side of the valley the stage IA moraine is in the form of a long lateral moraine capping the ridge.

The floor of the Nithi canyon is formed of heaps of fallen blocks of partly cemented moraine, with the river itself running some tens of feet down among the blocks. The adjacent cliffs are of crudely bedded silts and thin gravel lenses with occasional boulders up to six feet in diameter. These beds are largely fluvio-glacial and are overlain by boulder moraine. The upper part of the moraine is well exposed in the Nithi river above the waterfall, where hard, well cemented moraine with numerous boulders in matrices of pebbles and fine gravels are seen.

The more bouldery nature of the upper part of the moraine is also seen in a series of caves on the south side of the valley 100 feet above the river and five-eighths of a mile upstream of the waterfall. Here approximately 60 feet of moraine is exposed; the lower 20 feet is of scattered boulders in a silt matrix into which a number of caves have been eroded, and the upper 40 feet consists of boulders up to four feet in diameter in an unsorted gravel matrix.

There are few exposures of the stage IA lateral moraine which forms the ridge on the north side of the Gorges valley. Where the path (Carr's 'road') climbs the lateral moraine a few small exposures of loose brown trachyte rubble are seen. These are indistinguishable from the trachyte agglomerate occurrences on un-glaciated ground to the north, but the trachyte rubble forming the moraine also contains scattered large blocks of porphyritic phonolite derived from higher up the mountain.

The stages IB and IC are represented by small arcuate moraine ridges belonging to two phases of limited re-advance after the retreat from the stage I moraine had begun.

The stage ID moraines are a complex of lateral and partial terminal moraines confined to the north side of the valley, and all are connected to one large lateral moraine some distance upstream. This main lateral moraine divides into three large moraine ridges, between which are minor short ridges. The fact that all the moraines join into one upstream suggests that they were laid down during a series of short-lived glacial re-advances of decreasing amplitude.

The moraine sequence described above is observed also among the terminal moraines of the Ruguti, Thuchi and Rupingazi valleys. In each case the lowest terminal moraine is the largest, those of the Ruguti valley being among the largest on the mountain. Behind each terminal moraine are closely spaced narrow moraines marking the period of limited re-advances—mostly those of stage ID of the Gorges valley.

The moraines of the Ruguti valley are of particular interest in that the stage IA moraines appear to be cut through by the ID moraines on the north-east side of the valley. The distinction between the form of the two moraine groups is most marked and is generally similar to that of the equivalent moraines of the Gorges valley. The stage IA moraines in the Ruguti valley are broad and deep, and erosion and landslipping have affected the steeper slopes. In contrast the stage ID moraines are narrow, with sharp crest-lines, and are much less deep. They also characteristically show numerous small but easily visible halt-stages. The lowermost of these moraines is overlaid on the side of the north-eastern lateral of the stage I moraine, showing that there must have been an interval of retreat followed by re-advance leading to the deposition of the stage ID moraines.

The same situation is seen in the Thuchi valley, but not in the Rupingazi valey, where it seems that the stage ID re-advance may have reached the IA level or even exceeded it slightly.

Further terminal moraines occur in the Kazita East and Kazita West valleys, and differ in shape and composition from those of the eastern slopes. A well-marked, shallow lateral moraine occurs on the ridge separating the Kazita East and West valleys between the 12,400 and the 13,600 foot levels. At the lower margin of this moraine, at approximately the 12,350 foot level, there is a line of extremely large boulders or boulder-like outcrops which descends into the Kazita West. The boulders, the largest of which reach 30 feet in longest dimension, are composed of hard, well-cemented moraine in the form of unsorted boulders grading into a pebbly matrix. The ground between the moraine blocks is littered by large exotic blocks derived from the moraine by weathering. The composition of the moraine is mostly of olivine basalt boulders with a minor number of pieces of fissile phonolite. The origin of the boulders is in some doubt, for some appear to be weathered out hummocks of cemented moraine, and others give the impression of having been transported to their present position.

Exposures of lake sediments and moraine occur in the Kazita West river a short distance north of the moraine described above, at the 12,250 foot level. The lava bed-rock at this locality is overlain by thin basaltic agglomerates containing lava blocks up to one foot in diameter, and the agglomerate matrix contains thin curving or undulating ferruginous layers similar to those in the underlying agglomerates. The colour laminations average three or four to the inch, and are due to rhythmically repeated graded beds, and are possibly diurnal varves. At the southern end of the exposure the sediments and the underlying agglomerates are overlain by moraine with marked unconformity.

The section is interpreted as showing sub-aerially deposited agglomerates which were subsequently eroded. A shallow lake formed on the agglomerates, possibly due to volcanic damming downstream, and varved ashes were deposited in this lake. The presence of varves suggests either that the lake was pro-glacial and liable to diurnal freezing, or that the glacier was nearby and that the ash was supplied from the glacier or the surrounding country. Daily melting of the ice or thawing of the adjacent terrain would explain the varves. The basaltic pyroclastics were probably derived from the nearby youthful vents west and north-west of the locality.

(2) *Stage I moraines on Ithanguni mountain*

Ithanguni (12,776 feet) is the largest of the sattelite volcanoes on the eastern slopes of Mt. Kenya, and was high enough to support a small glacier system of its own. The form of the mountain is of a slightly denuded conical volcano with an almost flat central plateau surrounded by low cliffs except on the north-western side, where the cliffs are large opposite a deep explosion crater occupied by Lake Alice. The mountain supported a small ice cap with lobes of ice extending down the slopes for varying distances. Well-marked terminal moraines show the maximum extent of the ice, which reached to a little below 11,000 feet on the south-east side, and to levels between 11,000 and 12,000 feet on the other sides. Most of the terminal moraine loops are breached by streams to a greater or less extent.

Except for the large moraine ridges in the Lake Alice basin, the ridges are single, there being no traces of recessional moraines, and very little ground moraine. At the western edge of the swamp which is enclosed by the Lake Alice moraine loop, however, there are four closely spaced small ridges in a space of 100 yards, which represent short halts in the decay of the glacier on this side of the mountain.

The terminal moraines on Ithanguni are certainly contemporaneous with the lowest terminal moraines of the main glacier system to the west, for the reconstructed climatic snow lines for each glacier system are approximately co-planar. It follows from the lower elevation and smaller area of Ithanguni compared to the main part of Mt. Kenya, that the whole Ithanguni glaciation was short-lived and lasted only while the main glacier system was at or near its maximum extent.

(3) *Stage I lateral moraines*

On the northern, western and southern sides of the mountain no complete stage I terminal moraines have been recognized, a fact which may be partly due to the extremely poor exposures at the lower reaches of the moorland and in the upper forest. Several large lateral moraines, which due to their low elevation and size must be assigned to stage I, were seen near the inferred lower limit of glaciation on the ridges bounding the Sirimon, Mackinder and Teleki valleys. Those associated with the Höhnel and Nanyuki South valleys are inferred from air photographs. The lateral moraine on the north side of the Mackinder valley is notable for the very large blocks it contains, and the other moraines visited, although no good exposure of them was seen, carried large blocks of a variety of rock types projecting above the peat. The larger valleys of the west and north sides are deeper and steeper-sided than those of the eastern side of the mountain, and in consequence complete terminal moraines are less likely to be preserved there.

(4) *Stage II moraines*

The stage II moraines are almost invariable found in small glaciated valleys and cirques on the middle levels of the moorland between 12,500 and 13,500 feet, mainly on the western and southern sides of the mountain.

A complete double-crested moraine loop is well preserved in the Liki North valley with its base at 12,900 feet, and a second moraine ridge of similar appearance and age occurs on the north slope of the ridge and a short distance to the east of the first. Behind the first moraine is a dry lake bed—the lake having been dammed by the moraine till recently.

Shallow terminal moraine ridges occur at the head of the Liki South valley, and in the head of the left bank tributary of the Nanyuki North, both at the 12,800 foot level. A shallow lateral moraine extends down the north side of the Southern Naro Moru valley near its head, and an ill-defined terminal moraine occurs in the Thego valley at 13,000 feet. Two short lateral moraines in the Nyamindi East and its right bank tributary are at or below the 13,000 foot level, and similar lateral moraines are seen at the same elevation two-thirds of a mile south-west of Carr's Lakes in the Sirimon valley, and in the Höhnel valley.

These moraines occur near the heads of subsidiary valleys whose head-cirques are generally entirely below 15,000 feet, with the exception of the moraines mentioned in the Nyamindi East and Sirimon valleys. In every case the valleys downstream of these moraines bear ample evidence of glaciation in the form of glaciated topography and scattered erratics, and the stage II moraines are invariably nearer the heads than the lower glaciation limits in the same valleys. Due to the small vertical distance between the level of the snow accumulation area and the moraine in each valley the level of the stage II snow-line can be estimated with fair accuracy at between 13,000 and 13,500 feet. This snow line elevation is only a little higher than that inferred from the moraines of stage I, and raises considerable difficulties, such as the observations that the stage I moraines clearly mark the limits of the glaciers, while the stage II moraines are well above the glaciation limit. A difficulty of the view that the stage II moraines mark a halt or re-advance succeeding stage I is the notable absence of stage II moraines in the major valleys.

A satisfactory solution to these difficulties emerges when it is considered that at an early stage of the retreat of the glaciers from their maximum at stage IA, the ice sheet which covered the upper part of the mountain continuously above the inferred snow-line of that stage at approximately 12,500–13,000 feet, began to thin as well as retreat (cf. Flint 1957, pp. 31–33) This thinning would result in the emergence of most of the ridges below 14,000 feet, in the reduction in the size of the continuous ice dome, and in the separation of the ice in the small valleys below the 14,000 foot level from the main ice sheet which had nourished them previously. Once the connections between the small valleys and either the large glaciers or the ice sheet above had been cut, and the external supply of ice had ceased, the glaciers of the small valleys would retreat rapidly, either to disappear or to stabilize as small cirque glaciers if their accumulation areas reached sufficiently above the snow-line of the time.

The reason for the scarcity of stage II moraines in the larger valleys is unknown, but in view of the poor preservation of the earlier moraines, especially on the western side of the mountain, this scarcity may not be significant.

(5) *Stage III moraines*

The moraines of this stage are found only in the Nyamindi and Nyamindi West valleys, in the valley one mile south-west of Carr's Lakes, and in the Teleki, Hausburg and Nanyuki North valleys. They mark positions of the ice fronts at elevations between 12,700 and 13,000 feet, and the lateral moraines extend up to 14,000 feet or a little above. The snow-line at stage III is estimated at approximately 14,200 feet.

The moraines of this stage, although not widespread, are deeper and wider than the stage II moraines, the terminal moraine one mile south-west of Carr's Lakes being an excellent example.

The lateral moraine on the north flank of the Nanyuki North valley between 13,000 and 14,000 feet is of interest, for it abuts against the side of a very deep lateral moraine forming the crest of the southern ridge of the Mackinder valley. The relationship of the two lateral moraines proves that the Nanyuki North valley moraine was formed before the great lateral moraine which occupies the ridge above. This being so a little ice from the Mackinder valley glacier must have spilled over into the Nanyuki North valley, and this explains why a disproportionate length of the glacier in the latter valley occurred below the inferred snow line.

By the time stage III in the general recession of the glaciers had been reached the central ice cap was much reduced in size and was continuous only above approximately 14,500 feet. Valley glaciers existed only in the larger valleys whose accumulation basins extended well above the 14,500 foot level.

(6) *Large lateral moraines of stages II and III*

The long and deep lateral moraines which occupy the tops of some of the ridges in the upper part of the glaciated area cannot be attributed to any single stage of the glacial retreat but have been shown as stage III on the map for convenience. The largest of these moraines occurs on the top of the south ridge of the Hausburg valley between 12,800 feet and 14,800 feet, and is three miles long. A further example occurs on the south ridge of the Mackinder valley between 13,100 and 14,700 feet, and a third smaller occurrence is at the north end of the Hall Tarns platform. Although sections in them are entirely absent the width and steep-sided nature of these moraines suggests that they are up to 150 feet thick. The moraines of this type, due to their size and position on ridge tops, give rise to extensive tracts of scree and pale reddish brown gravelly solifluction deposits, and they support very little vegetation.

The position and length of these ridge moraines suggests that they formed progressively as the ridge tops emerged during the thinning of the ice cap, and as the ice cap fragmented into separate valley glaciers. The moraines formed during the periods of the stage II and III moraines and in the intervening period.

(7) *Stage IV moraines*

The moraines of the fourth and of subsequent stages were laid down by valley glaciers after the final break-up of the mountain ice-cap. The stage IV moraines are best preserved in the upper Teleki valley, and the succession there is taken as the type for the stage. They occur on the north side of the Teleki valley between 13,600 and 13,800 feet as bouldery ridges up to 60 feet high projecting from the valley side. The best development is the group of overlapping ridges and hillocks between Klarwill's Hut and Mackinder's Camp, consisting of large heaps of boulders, almost all of which are of syenite from the peaks. In the centre of the valley up to 300 yards east of Mackinder's Camp isolated small groups of boulders often have a linear arrangement, and represent the tops and remnants of end-moraines buried by the glacio-fluvial outwash which fills the floor of the valley between the 13,650 and 13,800 foot contours.

The upper members of stage IV occur between the small Naro Moru Tarn and 1,000 feet to the west, on the north side of the valley (*see* map of glaciers and glacial deposits of the peak area). Five narrow, low boulder ridges occur here descending the lower north side of the valley. The upper two descend on to the flat topped, ice-smoothed and striated rock boss on which Naro Moru Tarn is situated, the tarn being dammed by the uppermost end-moraine of the stage.

A very well formed double ridge moraine approximately 100 feet deep projects from the west face of Shipton Peak for a short distance into the valley and represents the southern end-moraine of the glacier which deposited the moraines 200 yards east of Mackinder's Camp. The relatively large size of the moraine below Shipton's Peak is due to the quantity of debris that must have fallen from the highly fractured lavas of which it is composed.

The small end-moraine loops which occur below the entrance to the Teleki Tarn cirque, and in the cirque south-west of Teleki Tarn are probably contemporaneous with the earlier phases of stage IV. Similarly the moraine impounding Lake Höhnel, at 13,800 feet, and the moraine loops in the Gorges valley at 14,300 and 14,350 feet probably belong to this stage.

In the Hausburg and Mackinder valleys small, narrow, bouldery end-moraines are recognizable as a closely spaced series, the shape and elevation of which leave little doubt that they belong to stage IV of the Teleki valley. The moraines occur at elevations of 13,400–13,500 feet in the Hausburg valley, and 13,650–13,800 feet in the Mackinder valley.

(8) *Stage V moraines*

Two closely spaced narrow ridges of boulder moraine similar to that formed in the later phases of stage IV are found in the Teleki valley between 14,150 and 14,400 feet, in the Hausburg valley between 14,150 and 14,350 feet, and a larger bifurcating lateral moraine occurs in the Mackinder valley between 14,150 and 14,600 feet. The double ridged moraines enclosing Kami Tarn, below the Northey glacier, also belong to this group, and are probably equivalent to the two upper boulder moraines of stage V in the Teleki valley. The larger size of the Kami Tarn moraines is due to the much slower rate of retreat of the glacier than those of the southern and western slopes, and to the greater supply of avalanche material on to the Northey glacier of that time. These deposits were laid down during a brief halt in the retreat before the glaciers shrank further and split up into the isolated cirque glaciers which characterize stage VI and those of the present day.

(9) *Stage VI moraines*

The moraines of stage VI form an incomplete fringe around the base of the main peaks of Mt. Kenya, and occur at distances less than 2,500 feet from the fronts of the existing glaciers (*see* map of glaciers and moraines of the peak area—at end). They are the most recent constructional moraines to be formed on the mountain, and two of the glaciers which gave rise to moraines of this stage have disappeared in the last 35 years.

The moraines of this stage are distinguished by their very fresh appearance, the unweathered nature of the boulders and the almost complete absence of vegetation. It is the vegetational contrast between these moraines and the adjacent ground which is most marked, for the ground surrounding the stage VI moraines is well covered with sedge glass (*Agrostis*), small ground cover plants (*Arabis alpina* and *Carduus platyphyllus*), and there are stunted *Lobelia telekii* and a yellow-flowering herb *Senecio* (*S. keniophytum*). The rocks and boulders are dark, weathered and almost entirely covered by lichens and mosses. The material of the moraine, on the other hand, is very sparingly colonized by vegetation, there being scattered *Senecio keniophytum*, *Arabis alpina* and small young lichens and mosses in scattered patches on rocks of favourable aspect. The coverage of rock surfaces by mosses and lichens is approximately 10 per cent to 15 per cent, compared to 90 per cent to 100 per cent cover on the lower ground, and it has been estimated from biological considerations that the outer moraine of stage VI could have been exposed for 100–150 years, and the inner moraine ridge for some 80–100 years. The contrast between the stage VI stage of colonization and weathering and that of the older stage V moraines and the intervening ground is so large that it has been estimated that the stage V moraines must be several thousands of years older (M. J. Coe, Biologist, University College, Nairobi; personal communication).

The stage VI moraines occur at elevations between 14,200 and 15,600 feet, and the lowest moraines are between 1,000 and 200 feet below the present ice margins. The best preserved moraines are those of the Lewis Glacier, among which are two main ridges and several smaller ones. The tendency for the moraines to occur as two main ridges is most obvious in those deposited by the Cesar, Joseph, and Tyndall Glaciers, but this tendency is apparent in them all, as is the occurrence of many small, closely spaced ridges behind the uppermost of the main ridges.

With the exception of the western and eastern lateral moraines of the Gregory Glacier which are up to 60 feet in height (*see* plate I, Fig. 1) and those of the Northey and Krapf glaciers which are very shallow, the other main ridges are between 10 and 20 feet high, while the minor ridges are three to eight feet high. The moraines contain boulders up to ten feet in diameter scattered about on the surface or partly buried in a gravelly matrix which is almost completely devoid of fine particles. On steep slopes the form of the moraines is poor, partly due to non-deposition and partly to solifluction after deposition.

The stage VI moraines of the Krapf and Northey glaciers are notable for their very small size and proximity to the present ice-fronts. They are, in fact, composed mainly of fallen blocks, and the double ridge form can only just be made out. Their proximity to the present ice-fronts is due to the very much slower rate of retreat of these sheltered glaciers compared to the remainder, and this is borne out by measurements of their retreat in recent years, which are found to be much less than the average.

A small moraine occurs below the north face of Pt. John, and testifies to the former existence of a small hanging glacier on this face.

A feature of the stage VI moraines on the south side of the Lewis Glacier is the merging of three terminal moraine ridges into one lateral moraine as they are traced upwards, a tendency which also marks the older ID moraines of the Gorges valley. This could be explained by regarding the snow-line as having remained static during the deposition of the moraine ridges, although how glacial retreat can take place under such conditions is not clear.

The very well marked difference in state of weathering and plant colonization between the stage VI moraines and the older stage V and IV moraines proves that the average rate of glacial retreat has not been constant, for if it had been no sharp difference in the moraines should be apparent. It is likely therefore that the stage VI moraines were deposited during the retreat following a re-advance of the glaciers. The degree to which the glaciers retreated during the interval between stages V and VI is not known, but it is possible that there was complete de-glaciation of the mountain at this time. Facts which support the idea of a re-advance of the glaciers to the stage VI positions are:—

(1) The relatively large size of the moraines compared to the small size of the glaciers responsible for them (cf. Charlesworth 1957, p. 409), i.e. the moraines contain much re-deposited material;

(2) Gregory's observation in 1893 (1896, p. 177) that ". . . numerous dead lobelia stems lay on this (moraine), though there were none then living at this elevation" an observation which was confirmed by Mackinder in 1899 (Mackinder 1930, p. 531). The moraine referred to is evidently the lower of the stage VI moraines of the Lewis Glacier. If the glaciers had retreated previous to the re-advance which gave rise to the outer stage VI moraines, it is likely that lobelia would have become established on the ground above this moraine, and a re-advance would incorporate the woody lobelia stems in the moraine. No stems are to be seen at the present day, however, nor is it likely that they should have survived, for many people have ascended by this route, and would have picked up all the stems for use as firewood.

The two main moraine ridges are therefore regarded as due to re-advances of the glaciers, while the much smaller ridges, such as the "washboard" moraines north of the gravelly ledge at 14,700 feet below the Lewis Glacier, are due to temporary halts in the retreat.

Much of the moraine of the two small occurrences on the north-west and south-west faces of Pt. Piggott is composed of large often bruised and fractured angular blocks, and these are largely pro-talus ramparts (Flint 1957, p. 98) which are accumulations of blocks of rock fallen from the cliffs above the glaciers, either to slide down the ice or to be carried down superglacially. Such accumulations are still forming at the present day around the termini of the Northey and Krapf Glaciers, both of which are of steep slope and are surrounded by cliffs.

3. Glacier Fluctuations During the Past 70 years

The first European to reach the upper levels of Mt. Kenya was Count Teleki (Von Höhnel, 1894, pp. 371–377), in 1887, but Teleki did not reach the glaciers, and recorded no information of use for fixing the positions of glaciers. The first person to do this was Gregory, who visited the southern and south-western glaciers (in 1893), and wrote several accounts of his observations (1894(*c*) pp. 516–530; 1896, pp. 169–188). Mackinder (1900) made a remarkably accurate map of the peak area in a very short time, and a further map, based largely on Mackinder's, is reproduced in Dutton's book (1929). Since Mackinder's successful ascent of the mountain in 1899 many people have visited the mountain and have taken useful photographs, but no attempt at serious scientific work was made till Nilsson mapped moraines in 1927 and 1932 (1931), and Troll and Wien made a study of the Lewis Glacier in 1934 (Troll and Wien, 1949). Aerial photography taken in 1947 and 1958, and measurements of the positions of the glacier termini in 1950 by D. Cameron (Ministry of Works) comprise the main evidence for glacier fluctuations in the last 15 years.

From sketches and sketch maps made by Gregory in 1893 (*op. cit.*) it is clear that the Lewis, Darwin and Tyndall Glaciers were very much more extensive then than they are now. The Tyndall and Lewis Glaciers are shown close up against the stage VI inner moraine, no Tyndall Tarn existed, and it seems likely that the 1893 glaciers occupied a position close to the stage VIB moraine, for Gregory describes the Lewis Glacier as ending on a platform (1896, p. 177) and as being margined by four concentric end-moraines. The platform is certainly that gravelly flat-floored hollow at an elevation of 14,670′*, and the glacier terminus of 1893 was approximately 1,600 feet from the position in 1959.

Mackinder's observations (1900) do not permit an estimate of the glacier positions to be made, but his map is of interest in that it shows the Kolbe Glacier on the north-east face of Pt. Lenana, which has disappeared since 1926, and it shows four glaciers between the Joseph and Gregory Glaciers where there are now only two. Neither Harris Tarn nor Tyndall Tarn are shown, the present sites of these tarns were then covered by the Kolbe and Tyndall Glaciers respectively.

Some photographs taken by Ross in 1908 (1911, plates on p. 469) show the Cesar Glacier terminus at an elevation of 14,500 feet, 350 feet lower than its 1959 position, and a further

*Gregory's height observations as given on his sketch map (1894, Fig. 2) are often about 2,000 feet too high.

photograph (p. 467) shows the western face of the mountain and the un-named small glacier on the north-west face of Pt. Piggott. This un-named glacier is shown on the map by Dutton (1929), but disappeared between 1926 and 1947. A description of the Cesar Glacier by Arthur (1921) shows that it underwent negligible retreat in the decade between 1908 and 1918 (cf. Charnley 1959, p. 484).

Further information of value is contained in Dutton's (1929) account of his and Melhuish's journey on the mountain in 1926. Some of the many excellent photographs by Melhuish were taken in 1926, but others were evidently taken earlier, for some are in Gregory's book (1921, plates VIII, p. 102; XII, p. 146, XIII, p. 150; XIV, p. 152) and were taken prior to 1921. From photographs in Dutton (*op. cit.*, plate 20, p. 62; plate 32, p. 90) the terminus of the Lewis Glacier in 1926 or not long before can be reconstructed; it was at an elevation of 14,680 feet and 900 feet from the 1959 ice-front in a horizontal plane. At this time the Tyndall Glacier terminated in Tyndall Tarn, which was then pro-glacial (*op. cit.*, plate 33, p. 44; plate 44, p. 126). The Tyndall Glacier then terminated at the 14,600 feet level and 400 feet from the 1959 terminus.

From the map at the end of Dutton's book it can be seen that by 1926 the Kolbe Glacier had retreated sufficiently to allow Harris Tarn to form, and that the Curling Pond at the margin of the Lewis Glacier had formed, although it stood higher than at present and periodically threatened to flood Top Hut. In addition to the glaciers that have survived to the present day, Dutton's map shows the Krapf Glacier in two parts on either side of the rock buttress on the east side of the present-day Krapf Glacier. That the Krapf Glacier and its eastern part extended to the level of the col west of Thomson Flake, and was in fact still joined to the Lewis, is shown on one of the photographs (Dutton, 1929, plate 39*, p. 110). Further small glaciers that have disappeared since 1926 are the Barlow Glacier, the small glacier on the north-west face of Pt. Piggott, and a small glacier (possibly a firn bank) on the west face of Pt. Peter.

The 1934 photogrammetric survey by Troll and Wien (1949), photographs taken in 1938 by R. A. Russell-Smith, and R.A.F. air photography taken in 1947 show that the Lewis Glacier began to recede over the old ice-fall on top of which the Lewis Tarn now stands probably about 1935 and that the terminus reached the top of the cliff in about 1945. A small pro-glacial tarn was already in existence in 1947 and this continued to grow till early 1959, when moraine became visible under the ice at the eastern edge of the tarn, showing that the glacier terminus was about to retreat out of the tarn.

The estimations of past glacier termini positions for the Lewis Glacier are given in the following tabulation:—

Year	*Elevation of Terminus feet*	*Horizontal distance of terminus from 1959—feet*
1893..	14,670	1,550
1926..	14,680	970
1934..	14,680	850
1938..	14,800	700
1947..	15,020	310
1950..	15,020	235
1958..	15,020	*c.* 15
1959..	15,020	0

The average rates of retreat for the various periods between estimates in the table above are:—

Period—years		*Average rate of retreat—feet per annum*
1893–1926	..	21
1926–1934	..	27
1934–1938	..	37
1938–1947	..	32
1947–1950	..	22
1950–1958	..	29
1899 – 1958	..	24·2

***Note that the photograph has a misleading caption. The pinnacle in the foreground is Thomson Flake, and Pt. Thomson is partly hidden behind it.**

The unusually high rates of retreat for the period 1934–1947 is due to the fact that during the greater part of this period the ice-front was receding up a steep, locally vertical cliff. Under these circumstances an overall constant rate of ice-wasting in the terminal region of the glacier is likely to give rise to accelerated rates of retreat up steep slopes.

There is less information available for the Tyndall Glacier; the following figures are based on Charnley's (1959, p. 485) account:—

Year		*Elevation of Terminus—feet*	*Horizontal distance of terminus from 1959 terminus—feet*
1926	..	14,600	415
1947	..	14,700	150
1950	..	14,700	120
1958	..	14,760	12
1959	..	14,770	—

The average rate of retreat for the period 1926–1959 is 12·6 feet *per annum*, a rate approximately half that of the Lewis Glacier.

The recession of some other glaciers in the period 1950–1958 is known as a result of the marking of glacier snouts by D. Cameron (Ministry of Works), and the amounts of retreat during this period for all the measured glaciers is given below for comparative purposes:—

	Retreat of glacier termini between 1950 *and* 1958—*feet*	*Average rate of retreat feet per annum*
Lewis Glacier..	220	27·8
Tyndall Glacier	107	13·5
Darwin Glacier	56	7·07
Krapf Glacier	30	3·8
Cesar, Joseph and Northey Glaciers	<20	<2·5

From the figures given above it can be seen that the rates of retreat of the glaciers measured at their termini are functions of the size of the glaciers and to a lesser extent of their aspect. Thus the smaller glaciers of the north face, which lie in deep clefts beneath high rock faces, have retreated relatively slowly, due to the sun being in the southern hemisphere during the main January-March ablation season. Further factors are the accumulation of snow on north-facing lee slopes during the south-east monsoon (April-June), when most of the snowfall takes place, and the afternoon cloudiness which minimizes the insolation on west-facing slopes.

4. Glaciology

The ten named glaciers of Mt. Kenya are mainly small cirque and hanging glaciers, the largest of which, the Lewis, is only 4,550 feet long, and the smallest, the Melhuish Glacier, is a 300 foot long steep ice sheet which may already be stagnant. The cirque glaciers are the Lewis, Tyndall, Darwin, Gregory and Krapf Glaciers. The Heim and Forel Glaciers hang on the west face of Batian; the Forel ends in a precipitous ice-cliff which periodically discharges ice-avalanches on to the Tyndall Glacier below, and the Heim is lower down the face and also ends in an unstable ice-cliff, but is connected to the head of the Tyndall Glacier by a narrow strip of ice. The Diamond Glacier, so named by Mackinder on account of the extreme toughness of the ice, is the highest of the hanging glaciers, and discharges ice-blocks and rock debris on to the Darwin Glacier by means of a very steep ice-couloir. The upper part of the Northey Glacier consists of two disconnected steep hanging glaciers.

The Darwin Glacier is in a category of its own, for it receives the greater part of its accumulation from the ice-couloir descending from the Diamond Glacier and from another similar couloir descending from the south face of Nelion. It is a re-constructed glacier formed of two coalescent ice cones.

The Cesar and Joseph Glaciers are derived from a common firn-basin west of Pt. Dutton. The northern branch, the Joseph Glacier, is now thin and is likely to disappear within a few decades.

The most heavily crevassed glacier is certainly the Tyndall, which has a system of large, gaping transverse and marginal crevasses in its middle section. The Lewis Glacier has well marked longitudinal crevasses in its lower section where it spreads a little downstream of the constriction caused by the projecting rock rib immediately west of Top Hut. A group of large transverse crevasses cross the Lewis Glacier between Top Hut and Pt. Thomson, and are caused by a high in the sub-glacial surface. Ice-falls with groups of seracs are not seen in spite of the very steep slope of some of the glaciers, owing to the small size of the glaciers, their relatively low rates of flow (*see* below), and their temperate character.

The areas of the glaciers in 1958 are tabulated below. The figures are approximate only, for the 1958 glacier outlines shown on the 1:10,000 map (at end) are sketched, not surveyed.

	Area in 1958 *square kilometres*
Lewis Glacier	0·360
Tyndall Glacier ..	0·105
Gregory Glacier ..	0·073
Cesar and Joseph Glaciers	0·067
Krapf Glacier	0·040
Northey Glacier ..	0·033
Darwin Glacier ..	0·031
Forel Glacier	0·016
Heim Glacier	0·011
Melhuish Glacier ..	0·006
Total glacier area ..	0·742

Fossil stagnant ice is well exposed on the steep slopes immediately south and east of the Lewis Tarn, between the stage VI lateral moraine and the southern margin of the Lewis Glacier. It occurs beneath a skin of slipped moraine, which has served to minimise its ablation, and is exposed in small west-facing cliffs and stone-chutes where recent slips of the superincumbent moraine have occurred. The observed fossil ice occurs up to 100 feet above the present level of the glacier and some of the stage VI lateral moraine in this area, which is being undermined by melting of the fossil ice and is daily discharging boulders and other debris onto the glacier margin, is probably still ice-cored.

The scree slopes immediately north of Thomson Flake are frozen below a depth of a few inches, and it is possible that there are substantial hidden bodies of stagnant ice on these slopes.

The elevation of the present day snow-line (firn-line on the glaciers) is difficult to estimate due to seasonal and annual fluctuations, and due to the strong effect of topography. In 1934 Troll and Wien (1949, p. 265) estimated the firn-line on the Lewis Glacier at 15,500 feet (4,730 metres), at the change from convex to concave transverse glacier profile, and Charnley (1959, p. 486) estimated it at the same height in 1958. In March 1959, however, at the end of the ablation season, the writer estimated the firn-line at 15,700 feet.

Observations by the writer in January 1959 and 1960, and the air photography of February 1947 and January 1958, together with conventional photographs taken at various times, show that the ablation areas of the glaciers on the northern and north-western slopes are small relative to their size, and suggest that the snow-line on this side of the mountain is at 15,300–15,400 feet.

Topography has a strong effect on the local elevation of the snow-line, and the climatic régime in the peak region is equally important. Among the more obvious effects is the localization of snow-fields and glaciers on west-and north-facing slopes, and this is due to several factors, the more important of which are:—

(*a*) the prevailing south-east wind during the season of maximum snow-fall,

(*b*) the greater insolation on east-and south-facing slopes during the January-March ablation season, when the western slopes are protected by the afternoon cloudiness, and the sun is in the southern hemisphere. The efficacy of these factors have been noted by the writer in three successive seasons (January, 1958, 1959 and 1960). Snow-fields survive longest on the north-facing slopes between Pt. Lenana and Nelion, on the north side of the col between the Gorges and Hobley valleys, and on the north side of the ridge linking Shipton Peak and Pt. Lenana. Similarly, even towards the end of the ablation season, when large areas of the Lewis, Tyndall and Darwin Glaciers are free of snow, the north-facing glaciers are either still completely snow covered or nearly so. The small amount of retreat of the Northey and Krapf Glaciers since the deposition of the stage VI moraines, compared to the other glaciers, is due to their occurrence in steep sided cirques in which snow drifts can accumulate, and in which insolation is at a minimum. In addition these glaciers receive increments of avalanche snow from the high, steep rock faces surrounding their accumulation areas.

The Mt. Kenya glaciers are certainly of the temperate kind characteristic of low latitudes, in which the ice is at pressure melting point throughout their volume. This is evidenced by the complete lack of super-glacial melt water streams, by the occurrence of melt-water in crevasses at various depths, and by the common presence of sub-glacial melt-water which feeds the Lewis and Tyndall Tarns and the Curling Pond. Only the Tyndall and Lewis Glaciers have visible melt-water streams, in the remainder their melt-water passes underground to emerge, as in the case of the Gregory Glacier, as springs from moraine some hundreds of feet below the glacier terminus.

Rates of movement have been measured on the Lewis Glacier by Troll and Wien (1949, p. 263) and in 1958 by Charnley (1959, p. 487). Maximum rates of movement in the central region of the glacier were approximately five metres (15½ feet) per annum. This is a very slow rate of movement considering that the glacier is moderately steep and temperate in character, and it may be due to high basal friction (Charlesworth 1957, pp. 98–104), and to presumed thinness of the ice. Troll and Wien (1949, p. 264) calculated the average depth of the Lewis Glacier to be 60 metres (197 feet). Rates of movement among Alpine glaciers are between 30 and 150 metres per annum.

Further details on rates of movement, physical characteristics of the ice and firn, seasonal firn stratification etc. are given by Troll and Wien (1949) and estimates of ice loss for the Lewis Glacier during the period 1934–1958, and other information is given by Charnley (1959).

5. Conclusions

(1) *Summary of glacial fluctuations*

Very little can be deduced from the deposits of the older glaciation, beyond the fact that it extended down to 11,200 feet on the eastern sector of the mountain, and that there was a substantial interval in which minor volcanic eruptions and erosion took place previous to the advent of the younger glaciation.

At the maximum extension of the younger glaciation the snow-line stood at approximately 13,000 feet on the eastern and southern sides, and somewhat lower, nearer 12,000 feet, on the western and northern sides of the mountain. Following the deposition of the stage IA terminal moraines retreat began, broken by two short-lived re-advances which deposited the IB and IC moraines. There was then a more substantial retreat followed again by a re-advance with three main diminishing maxima, marking the complex of stage ID moraines.

A period of steady retreat then ensued, accompanied by thinning of the central ice cap, and the separation of small ice-masses in the lower valleys, in which the stage II moraines were deposited. The snow-line at this time stood at 13,000–13,500 feet.

The substantial stage III moraines mark a period of stability or re-advance following further general wasting of the ice-cap and its fringing valley glaciers; the level of the snow-line stood at 14,200 feet.

The stage IV and V moraines are mainly small boulder ridges occurring in closely spaced series, and mark short periods of stability during the general retreat. By the time stage IV had been reached the central ice-cap had disintegrated into a radial system of valley glaciers.

Following the deposition of the stage V boulder moraines a prolonged period of retreat is inferred, possibly culminating in complete de-glaciation, previous to a re-advance which took place in the last 250 years to form the stage VI moraine complex. The stage VI moraines contain two closely spaced main ridges with significant difference in degree of plant colonization, and these two ridges may represent two advances of the glaciers, dating from 150 and 100 years before present. During the last 100 years several very small end-moraines have been deposited, but during the last 60 years retreat has been rapid and steady, without the deposition of constructional moraines.

(2) *Climatology*

Between the time of the maximum of the younger glaciation and the present day the climatic snow-line has risen between 2,500 and 3,000 feet (760–915 metres), a rise which, in the absence of evidence of vertical movements of the mountain, must be attributed to climatic change. This difference in the elevation of the snow-lines is of the same order as has been found in the Cordilleran region of the United States (Flint 1957, p. 304), and in other parts of the world (Charlesworth 1957, pp. 652–654). Flint (1959, pp. 351–353) has calculated that the former depression of the snow-line on Mt. Kenya implies a reduction of mean temperature of approximately 5°C., but this estimate neglects the reduction of precipitation with increasing altitude, a factor of minor significance which would tend to reduce the difference in mean temperatures necessary to account for the change in snow-line elevation. The estimates of present and former snow-lines on all the high East African mountains is as follows:—

	Lower limit of glaciers of last glaciation feet	*Snow-line at maximum of last glaciation feet*	*Present snow-line feet*	*Difference between present and former snow-line feet*
Mt. Kenya	8,600–12,300	*c.* 12,500	15,600	3,100
Kilimanjaro	9,800–11,600	*c.* 14,000	above 19,300	>5,300
Mt. Elgon	11,400–*c.*13,500	not known	above 14,140	—
Ruwenzori	11,000–?7,500	not known	*c.* 14,500	—
Aberdare Range	12,000–?10,700	not known	above 13,104	—

The great height of the present day snow-line on Kilimanjaro is due to the extremely small annual precipitation in the summit area, which is believed to be less than ten inches per annum. On the Ruwenzori range, on the other hand, the snow-line is lower due to the much higher precipitation. The levels to which the glaciers of the last glaciation descended on Mt. Kenya and on Satima (Aberdare Range) suggest a snow-line of approximately 12,500 feet at that time. The rainfall statistics for Mt. Kenya (Fig. 1) show that the level of the present day zone of maximum rainfall is at elevations between 8,000 and 12,000 feet on differing sectors. A fall in mean temperatures would therefore depress the snow-line towards the zone of maximum rainfall and would bring about a much greater accumulation of snow and a reduction in ablation. The effect would be most marked on the western and north-western sectors of the mountain, where the zone of maximum rainfall is highest and the rainfall intensity moderately high. On the eastern slopes, however, although the annual rainfall can exceed 90 inches, the level of maximum rainfall is well below the inferred lowest position of the former snow-line, and on this sector the extent of the former glaciation would not be so great. These conclusions agree very well with those deduced from the glacial deposits, and suggest that climatic régime on Mt. Kenya did not differ markedly from that of the present day in wind direction and distribution of precipitation, and that a fall in mean temperature was the main factor responsible for the former extended glaciation.

(3) *Correlations*

There is a close parallel between the glacial history of Mt. Kenya and the other high East African mountains Kilimanjaro and Ruwenzori. On the other mountains traces of an "older" glaciation have been recognized, and the phases of the last glaciation are markedly similar (C. Downie (Kilimanjaro) personal communication; J. de Heinzelin, 1953; Bergstrom 1955; de Heinzelin, personal communication). On all three mountains the stage VI moraines which mark a recent "historic" re-advance are easily recognized, and on Ruwenzori were correlated with the "Little Ice Age" of Europe (de Heinzelin 1953, pp. 15–17, Charlesworth 1957, p. 1494). Both Downie and de Heinzelin have remarked on the close similarity in the form, sequence, state of weathering and plant colonization of the moraines of Kilimanjaro and Ruwenzori to those on Mt. Kenya (personal communications). The amount of depression of the snow-line at the last glacial maximum was not the same on these mountains, due to differences in climate and elevation, but suggests a lowering of mean temperatures of the same order. These facts strongly suggest that the glacial fluctuations on the East African mountains were contemporaneous.

Nilsson (1929) mapped the moraines of Mt. Elgon, and did some pioneer work on the lake levels and deposits in the eastern Rift Valley, and on the moraines of Mt. Kenya and the higher mountains of Ethiopia (1931). He concluded that the fluctuations of the Rift Valley lakes and the mountain glaciers were essentially synchronous, and were the expression of world-wide climatic changes. Nilsson's interpretation of the moraine sequence on Mt. Kenya (1931 p. 78, pp. 84–92) was strongly influenced by his conviction that the lake fluctuations could be correlated with the glacial stages on Mt. Kenya, and he postulated complete deglaciation after the deposition of the stage I moraines, a postulate with which the writer does not agree.

The development of the climatic sequence in East Africa has recently been reviewed by Cooke (1957) and Flint (1959). Nilsson's correlation of the climatic sequence with the moraines of Mt. Kenya, using the more refined sequence lately developed by Leakey (cf. Flint 1959(B), table 1, p. 268) can be summarized as follows:—

Climatic Sequence *Leakey* 1948, *p.* 63	*Moraines of Gorges Valley, Mt. Kenya.* *Nilsson* 1931, *p.* 78.
(Gamblian 2 Pluvial)	recent small moraines (*Stages IV-VI*).
recession of Gamblian lakes	complete deglaciation.
Gamblian 1 Pluvial	"great" and "very marked" moraines (*Stage I*).
Third Interpluvial	complete deglaciation.
Kanjeran Pluvial	"oldest" moraines (*older glaciation*).
Second Interpluvial	
Kamasian Pluvial	
First Interpluvial	
Kageran Pluvial.	

The correlations above are based entirely on the theory that phases of expanded glaciers on the high mountains are likely to be contemporaneous with periods of increased rainfall (pluvials) at lower levels. This theory has never been substantiated in the tropics, but appears to have been proved in some areas elsewhere, notably Lake Bonneville in the western United States (Flint 1957, pp. 226–232).

Nilsson suggested that Mt. Kenya was de-glaciated after the deposition of the stage I moraines, apparently on the grounds that the Gamblian lakes dried up at this time and that a marked warm dry period intervened during the Gamblian Pluvial. Nilsson's climatic interpretation of the Gamblian beaches and other deposits is complex and in some respects unjustified, and in any case it should not influence the interpretation of the glacial deposits. Nevetherless it is generally believed that the Pleistocene climatic changes were world-wide, and radio-carbon dating of climatic events of the last 30,000 years support this view (Flint 1957, pp. 491–492; Charlesworth 1957, pp. 1533–4). It is reasonable therefore to correlate the younger glaciation on Mt. Kenya with the Gamblian pluvial, and it is likely that a clearer correlation between the Gamblian lake fluctuations and the glacier fluctuations will be made in future, especially when some radio-carbon dates and pollen sequence have been worked out. These arguments can be extended, with less confidence, to a correlation between the East African glacial fluctuations and those of Europe and North America, as was done by Nilsson (1931, pp. 84–92), de Heinzelin (1953, pp. 16–17) and Bergstrom (1953 p. 475), whereby the younger glaciation on Mt. Kenya is regarded as concurrent with the Würm glaciation of the European Alps.

A graph showing inferred snow-line levels since the younger glacial maximum plotted against time although largely hypothetical in terms of the time-scale and the position of the snow-line between the stages, can be compared with the stages of retreat in the Alps. Thus the stages IA, IB, IC are comparable to the main Würm maximum, stage ID to the

Neo-Würm re-advance which locally reached or over-ran the main Würm maximum, and stages II, III and IV correspond to the Buhl, Gschnitz and Daun stages of the Alps. The substantial interval between stages V and VI when the snow-line of Mt. Kenya was higher than at present may well correspond with the European Climatic Optimum, which is firmly dated in Europe at 6,000–8,000 years before present. The stage VI moraine complex corresponds to the "Little Ice Age" of Europe which took place between 100 and 300 years ago, the maximum being at about 1820 A.D. and 1850 A.D. (Charlesworth 1957, pp. 1,472–1,503). These correlations are, however, very tentative, but may serve as a working hypothesis which needs careful testing.

De Heinzelin (1953, pp. 16–17) has pointed out that if the correlation of the European and East African glacial maxima is accepted, then the climatic sequence and chronology based on the variations in solar radiation advocated by Milankovitch and supported by Zeuner (1959, pp. 266–270) must be called in question, for this theory demands that the climatic fluctuations should be out of phase between the northern hemisphere and the equatorial regions, and further it suggests that there should have been some 28 pluvial/glacial phases in the equatorial belt in the last 600,000 years. The circumstantial evidence suggests that the equatorial and European glaciations were concurrent, and there is no evidence of more than four pluvial phases in the East African Pleistocene, and some of these are of doubtful validity.

VI—STRUCTURE

1. Basement System

The only notable occurrence of Basement System outcrops in which structure can be made out are in the Thego and Sagana river valleys, near their confluence. Here the gneisses and schists strike to the north-north-west, and the dips are steep to the west. Lineations plunge to the north at low angles. Foliation of similar attitude is seen in the Basement System inlier at Marua. No major or minor folds were observed in these rocks and nothing can be deduced of their structure.

2. Volcanic structures

The structure of the Mt. Kenya volcano and its satellites is that of a large volcanic pile with radial outward dips centred on the plug, which forms the present peak of the mountain. Within the volcanics of the satellites, however, various attitudes of the beds are found. The trachytic formations which outcrop in the head of the Höhnel and Teleki valleys, and underlie the kenytes, dip to the south and south-east, and suggest that they were erupted from a centre to the west of the peaks. Similarly the Ithanguni volcanics show a radial outward dip about that centre. It is implicit in the account of the stratigraphy given earlier that the volcanic structures are complex, especially in the latter stages of the history of the the volcano, due to alternating quiescence, erosion and periods of eruption, with the result that the younger lava effusions are often scattered and confined in widely separated valleys. Examples of these are the olivine trachytes, mugearites and olivine basalts of the northern slopes.

A most interesting series of minor volcano-tectonic structures are found in the area one mile south-west of Mugi hill (Fig. 6). In this area the volcanics have been fissured and faulted in a very recent movement which is younger than all the volcanic formations of the neighbourhood, including the very youthful and undissected basaltic crater to the south of Lake Ellis. The fissures are almost entirely within the olivine trachyte outcrop, and gape to a maximum width of 20 feet, and are up to 30 feet deep, the floors being formed of fallen blocks. The faults, which are the more numerous, rarely throw more than 20 feet, mostly to the north-west, and form a series of small sinuous entirely uneroded escarpments traversing the uneven ground including the outflow valley of Lake Ellis, which has become blocked in consequence. The system of fractures trends north-east—south-west, and passes into the olivine basalt crater, and is probably in some way connected with the activity of this crater. These very young structures may well be the result of the intrusion at shallow depth of a small sill, causing slight doming of the surface, and slight elevation of the eastern side of the faulted area relative to the western side.

A suggestion of a fracture or fissure running across the southern slopes of the mountain is offered by the occurrence of ten of the basaltic craters of this area nearly on a straight line trending east-north-east. The craters are Tagwa, Kehari, Gerere and the craters of the upper Nyamindi, Rupingazi, Ruguti and Nithi valleys. These craters are comparable in age and appearance to those of the Nyambeni volcanic series, whose main outcrop is to the north-east, and which are also undoubtedly aligned along fissures of similar but more northerly trend.

VII—ECONOMIC GEOLOGY

1. Building stone

The Nyeri Tuff has been used for some considerable time as a building stone. It is easily worked and trimmed and is of adequate strength for moderate sized structures, and its outcrops are widely spread in this area and to the west. The principal areas where the tuff has been quarried are in the Nairobi river valley north-east of Kiganjo, where two large quarries on the eastern side of the valley are in use—those to the west being abandoned, and at intervals in the Sagana valley between the Marua village area and the southern margin of the area.

The Nairobi valley quarries are near the northern limit of the Nyeri Tuff outcrop—further north the Tuff is covered by Mt. Kenya volcanics. The two large quarries here are favourably situated for exploitation because the stone is of good quality, the overburden is small and the access is easy. One or two small quarries in the Thego valley south-east of Ngondi are not so favourably situated, and have not been worked for some time. Further small abandoned quarries were seen to the south, in the southern part of Chieni forest, and at Gatunganga village. The largest quarry in the area is Kahiga quarry immediately north of the Sagana-Chania confluence. Here, however, as in all the more southerly quarries, the overburden of weathered tuffs and Laikipian Basalts is substantial, and further development of the quarry can only take place laterally. A short distance to the north-west of the quarry the Nyeri Tuff abuts against a Basement System inlier, which means that development of the quarry in this direction would be abortive.

Several small mostly disused quarries occur in the lower parts of the Sagana valley between the Sagana Falls Power Station and Kahiga quarry, but south of the power station there is only a small quarry in the Kagumo valley on the Kaigonde-Muruguru motor track, and a large disused quarry near the southern margin of the area at Kathangaini.

The Laikipian Basalts overlying the Nyeri Tuff thicken from north to south, with the result that all quarries in valley sides south of the latitude of Kirichu Trading Centre suffer from excessive overburden. The Nairobi valley quarries are, however, well sited for development, and it is anticipated that these will be utilized should any substantial increase in stone production be required.

In one small area, however, the tuff forms a marked feature in the side of the Chania valley between 550 and 1,200 yards north-west of Marua village, on the 5,500 foot contour. Should additional quarries be required within the Kikuyu reserve they should be sited here, for a large quantity of stone could be excavated without serious overburden difficulties.

2. Road Metal and Ballast

The foundation of the new Sagana-Karatina-Nyeri tarmacadam road is of stabilized earth obtained from a quarry immediately north of Kahiga building stone quarry, one mile north of Marua village. The material used is the highly weathered upper part of the metamorphic inlier, and is soft, friable muscovite-biotite gneiss. It is said to be suitable as the cement-stabilized road foundation on account of its sandy nature and the low proportion of clay minerals. There should be sufficient remaining weathered rock for future requirements, such as the reconstruction of the Marua-Kiganjo road.

The surface of the remaining roads of the area is either stones and soil ('all weather'), lateritic soils high in ironstone pebbles (*murram*) or local earth. The Marua-Kiganjo-Nanyuki road is mostly surfaced with stony earth, derived from numerous borrow pits in weathered lava and agglomerate, and many of the roads serving the Naro Moru-Nanyuki area are surfaced with *murram*, which is plentiful among the lateritic soils of this area.

Within the Kikuyu reserve the majority of roads are earth surfaced, and are liable to deteriorate during the rainy season. Unfortunately suitable surfacing material is not common in this area. No specific search was made for road metals in this area, but lateritic ironstone was observed in quantity along the Katheraini-Gatunganga road four miles south-east of Kiganjo. The friable basaltic ashes on Kilima Kamuruana and in the neighbourhood, in Inoi location, should be suitable as road dressing, and there are sporadic outcrops of lateritic soils in the Kabingazi-Gatundori area north of Embu.

3. Graphite

Muscovite-biotite-graphite schists were found outcropping in the Thego river 100 yards north of its confluence with the Sagana. The outcrop width of the graphitic schists was estimated as 75 feet, the dip being nearly vertical. The schists are only notably graphitic in thin bands, and the low percentage of graphite and the extremely fine flake size render the deposit uneconomic. The tonnage available is in any case very small.

4. Water Supply

In the upper levels of the area there is an adequate rainfall, and the efficiency of the indigenous forest as a water storage area ensures that the majority of streams are perennial. The lower cultivated slopes represent one of the richest agricultural areas in Kenya, on account of the good water supply, adequate rainfall, and the fertile volcanic soil.

The drainage of the area is divided unequally between the Tana and Uaso Ngiro catchments; the watershed between the two catchments is shown on Fig. 3. The sum of mean daily discharge of all rivers draining the mountain in January 1958, was 1,807* cusecs (1,807 cubit feet per second, or 51·1 cubic metres per second), and this yields a figure of 1·06 cusecs per square mile for the discharge area, an area larger than the area mapped. In contrast to the total discharge from the mountain the discharge from the peak area above the 14,000 foot contour is 13·6 cusecs, which is the sum of individual readings made in January 1958, and this represents a yield of 1·05 cusecs per square mile. From gaugings made by the Hydraulic Branch, Ministry of Works, at various elevations on the Northern Naro Moru river it can be calculated that the yield per unit area is good in the peak area, that from the moorland is much less, that from the forest belt between 7,000 and 11,000 feet is by far the largest, while in the farming area there is a slight net loss. These calculations confirm that the forest belt yields the greater proportion of the surface discharge, a conclusion which is reinforced by a consideration of the dense drainage pattern in the forest belt, and by the fact that the rainfall is generally highest on the forest. The effects of groundwater re-charge, evaporation and transpiration are neglected, but are not likely to alter the conclusion that the forest belt is the source of the greater part of the water discharged from Mt. Kenya.

The flow of the rivers on the lower western slopes between Kiganjo and Nanyuki is insufficient to supply all the requirements of the farms, and the perennial rivers are in any case too far apart. For these reasons a number of bore-holes have been sunk to provide additional water supplies. The positions of these bore-holes are indicated on the geological map (at end). Details of the bore-holes and some logs extracted from the records of the Hydraulic Branch, Ministry of Works, are given below:—

Bore-hole No.	*Location*	*Depth-feet*	*Depth to which Water rises ft.*	*Yield in Gallons/24 Hrs.*
164	Bastard's Fm., Nanyuki	284	150	5,760
167	Bastard's Fm., Nanyuki	211	140	1,440
C286–D	Graham's Fm., ... Naro Moru.	400	210	10,800
C290	Fowler's Fm., Nanyuki	419	123	21,600
C291	Paice's Fm., Burguret	356	78	17,280
C462–D	Kagumo School.. ..	500	237	34,360
C514–D	Graham's Fm., ... Naro Moru.	515	380	33,600
C574	Kagumo School.. ..	453	237	50,400
C1619	Allens Fm., Burguret ..	522	77	78,000
C1704	Poolman's Fm., Nanyuki	360	225	8,000
C2030	Kianyaga Police Post ..	623	298	11,135
C2371	Walkers Fm., Ndathi ..	400	106	21,600
C2638	Paices Fm., Burguret ..	227	45	215

*The discharge figures have been obtained from the Hydraulic Branch, Ministry of Works.

Log of bore-hole C462–D (Kagumo School)

Feet	
0– 47	red clay soil.
47– 63	yellow clay with lava fragments.
63– 78	chocolate clay with lava fragments.
78– 85	dark grey clay with basalt fragments.
85– 93	weathered basalt fragments.
93–125	dark grey fresh basalt (Laikipian Basalts).
125–153	grey basalt.
153–160	grey clayey tuff.
160–168	light grey vesicular or tuffaceous basalt.
168–170	yellow mottled grey tuffaceous basalt.
170–177	greenish yellow clayey tuff.
177–200	drab grey soil or river wash.
200–209	mottled soil.
209–212	grey soil.
212–260	dark grey tuffaceous basalt.
260–284	grey vesicular basalt.
284–365	black rhyolitic tuff.
365–400	black to grey vesicular basalt.
400–408	(no record).
408–442	black clay.
442–500	black vesicular lava.

The rhyolitic tuff between 284 and 365 feet may well represent the Nyeri Tuff, in which case the black basalts below are Simbara Series.

Log of bore-hole C514–D (Graham's Farm, South East of Naro Moru)

Feet	
0– 20	light chocolate clay with lava fragments.
20–104	grey mixed lava and pebbles.
104–215	light grey fissured "kenyte".
215–320	felspathic "kenyte"(?).
320–335	pale brown and mottled yellow soils and sediments.
335–346	grey and yellow mottled coarse gravelly sediments with grey lava fragments.
346–350	pale grey sediments with lava gravels.
350–420	drab old lake sediments.

It is possible that much that has been recorded as sediment in the log above is actually pyroclastic.

The records of the bore-holes suggest that in the lower western slopes, where most of the bore-holes have been drilled, there is no difficulty in finding adequate water at depths between 100 and 300 feet, there being ample re-charge from the perennial rivers traversing the area. There is no risk with the present low density of bore-holes of depletion of ground water.

The Sagana river is the largest in the area and has been used for the generation of hydro-electric power at the Sagana Falls Power Station. The height of the falls is 97 feet, but the head on the turbines has been raised to 118 feet by the construction of an earth dam, with a 60 yard wide concrete spillway. Two intake pipes lead to two Gilkes turbines of 750 horse-power each driving two alternating current generators. The installed capacity totals 1,200 kilowatts, but the plant is normally run at 1,000 kilowatts. A diesel-powered stand-by alternator is used to supplement the turbines when one of the latter is shut down during periods of low river flow. The generators feed a transmission line at a voltage of 11 kilo-volts, and the lines carry electricity to Nyeri, Kiganjo, Kagumo and Karatina.

A small diesel-powered generating station is situated on the Liki river just inside the northern boundary of the area, and supplies Nanyuki township.

There are no possibilities for the construction of new large-scale public hydro-electric undertakings in the area, for the flows of individual rivers are too variable and small to make such ventures economic. Several private small-scale hydro-electric plants are in use, however, especially in the upper part of the farming area, where contour trenches are dug to lead river water to a suitable spot to utilize the head for driving small generators.

In several places in upper Embu district water power is utilized to drive simple water-wheels for grinding maize. Two such mills are at Kabonge village in Rutue Location, and Rutue mill near Thaita village in Inoi location. There is much scope for the expansion such small water-driven mills, which could be also be used for saw-milling on a small scale.

5. Economic possibilities of the area

Since the geology of the area is almost entirely volcanic there is virtually no possibility of the discovery of valuable mineral deposits. It is likely that the building stones will continue to be exploited, and it is possible that small brick and tile industries may be started if suitable clay deposits can be found.

The major economic activity in the area will continue to be based on agriculture, with forestry and timber products providing a small but potentially important second industry.

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