



GOVERNMENT OF KENYA

MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

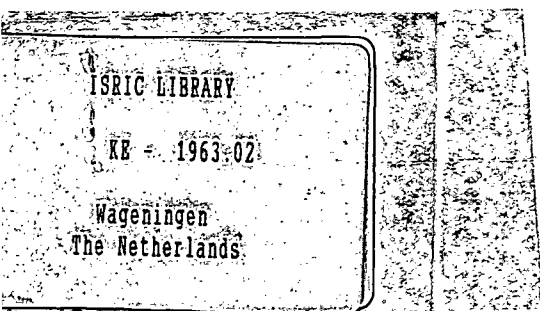
GEOLOGY OF THE NAIVASHA AREA

EXPLANATION OF DEGREE SHEET 43 S.W.
(with coloured geological map)

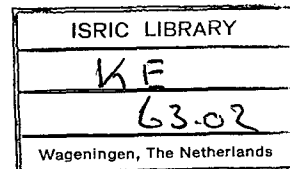
by

A. O. THOMPSON M.Sc. and R. G. DODSON M.Sc.
Geologists

Fifteen Shillings - 1963



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GEOLOGY OF THE NAIVASHA AREA

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FOREWORD

Previous to the undertaking of modern geological surveys the Naivasha area, in the south-central part of Kenya Rift Valley, was probably the best known part of the Colony from the geological point of view. This resulted partly from ease of access, as from the earliest days the area was crossed by commonly used routes of communication, and partly from the presence of lakes, which in Pleistocene times were much larger and made the country an ideal habitat for Prehistoric Man and animals that have left their traces behind them in the beds that were then deposited. The area straddles the Rift Valley, and with the shoulders of the Rift, Lake Naivasha and its Pleistocene exit the Njorowa Gorge, Mount Longonot a young volcano, and numerous other volcanic cones, is to be accounted one of the more scenically beautiful parts of Kenya.

Mr. Thompson and Mr. Dodson have succeeded in making a reasonably detailed map of the area showing the distribution of the Pleistocene to Recent sediments and volcanic rocks, and of the faults that slice through them. The mapping was greatly assisted by the large amount of work done previously by archaeologists, with whose results the authors are in general agreement. No new work was done on the tilting of the lake basins, but a review is given in the report of the results of earlier investigations, which had shown that tilting occurred in various directions at several stages of the Pleistocene.

One of the most interesting aspects of the Naivasha area is the presence of steam-jets on Eburru and south of the lake. Detailed consideration is given to them because of the attention that has recently been devoted to the possibility of obtaining subterranean steam for the generation of power from several areas. The authors conclude that there is no basin of heated ground-waters around Naivasha, but that juvenile fluids are escaping from depth at places and mixing with the ground-water, conditions being suitable at certain places where there are fissures for the production of steam, which escapes at surfaces. Recently a deep bore-hole has been sunk into one such area by a private company and, though steam in quantity was not released, the results obtained in the lower part of the hole are encouraging in so far as considerable temperature increases were recorded, and the rocks penetrated are clearly altered by the passage of fluids.

Nairobi,
8th November, 1958.

WILLIAM PULFREY,
Chief Geologist.

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MAP

Geological Map of the Naivasha area (Degree Sheet 43, S.W. quarter); Scale 1:125,000 at end

ABSTRACT

The report deals with an area of about 1,200 square miles lying between longitudes 36° 00' E. and 36° 30' E., and latitudes 0° 30' S. and 1° 00' S. The greater part of the area lies within Rift Valley Province though the south-western part is in the Narok District of Southern Province. The area embraces the two flanks of the Gregory Rift Valley, with the Kinangop platform commonly called the Kinangop "Plateau" on the east and the Mau escarpment on the west. On the Rift floor there are Lake Naivasha, Njorowa Gorge, the Eburru mountains and Longonot volcano, besides numerous volcanic craters and steam-jets, all of which make the area of considerable scenic attraction.

The rocks of the area fall into two main groups; (1) lavas and pyroclastics and (2) lacustrine deposits. The lavas range from undersaturated basic rocks (tephrites) to acid rocks (rhyolites and obsidians) with numerous gradations in between. The pyroclastics, some consolidated and others incoherent, cover the greater part of the surface area, and compose great thickness in the flanks, particularly in the Mau escarpment, where they rise to heights of over 10,000 feet.

The lake deposits, though covering large areas are not thick. Their configuration is closely allied to the present-day Rift Valley lakes which are the remnants of the much greater lakes that existed in Pleistocene times.

The petrography of the rocks, the origin of the steam of the steam-jets, and its possible use for generating electric power are discussed.

GEOLOGY OF THE NAIVASHA AREA

I—INTRODUCTION AND GENERAL INFORMATION

A geological reconnaissance of the area forming the south-western quarter of degree sheet 43 (Kenya) was carried out largely between the months of September, 1955 and February, 1956. Two short periods were also spent in May and June of 1956 completing the investigations in those areas that were inaccessible previously on account of terrorist activity and weather conditions.

The Naivasha area lies between longitude $36^{\circ} 00' \text{ E.}$ and $36^{\circ} 30' \text{ E.}$, and between latitudes $0^{\circ} 30' \text{ S.}$ and $1^{\circ} 00' \text{ S.}$ (Directorate of Colonial Surveys Sheet No. 133). The greater part of the area, which is approximately 1,200 square miles in areal extent, is within Rift Valley Province, administered by the Provincial Commissioner at Nakuru. The western and south-western sections are in the Narok District and come under the jurisdiction of the Provincial Commissioner, Southern Province, who resides at Ngong.

The greater part of the area is farmed in many ways, agriculture and stock-farming being often carried out side by side. The greater part of the agricultural crops, chiefly wheat, is farmed on the high ground, particularly on the Kinangop plateau and Mau escarpment. On the escarpment farming is carried out at heights varying from 7,000 feet to over 9,500 feet (2,135—2,900 m.) and though wheat is the main crop, in recent years less restricted agricultural developments have taken place, both with crops and stock. Around the shores of Lake Naivasha about seven crops of lucerne are cut annually. The cattle farming is confined largely to the Rift floor, and in the Masai Reserve i.e. in the part of Narok District within the area, where the indigenous people lead a semi-nomadic life with their cattle. Prior to the Emergency declared in November, 1952, other indigenous people, the Wanderobo, wanderers in the forests, existed by hunting and on honey. The growing of vegetables was also formerly carried out on a fair scale along the shores of Lake Naivasha, but was restricted greatly at the beginning of 1956 in order to deny food to *Mau Mau* terrorists that frequented the papyrus swamps around the periphery of the lake at that time. Since then the level of the lake has been rising and many acres of land have been swamped.

A small amount of game still persists in the area but is rapidly being exterminated in the forests and settled areas, largely through snaring by the African labour on the farms. Despite the fact that some settlers are endeavouring to make their farms sanctuaries for the game, the toll through poaching is still great.

The rainfall over the greater part of the Naivasha area is not good—it is inclined to be very local, with irregular periods of precipitation. Although it is generally expected that the wettest month is April, heavy falls can take place during several other months as is evidenced in the following table:—

TABLE I
RAINFALL IN THE NAIVASHA AREA
(From the published records of the Meteorological Department)

Station	Locality and Elevation in feet	TOTAL RAINFALL		No. OF RAINY DAYS		Yearly Average 1955	No. of Years Recorded	Average Wettest Month	Wettest Month, 1955
		1954	1955	1954	1955				
Mau Narok	Mau escarpment 9,500	47.62	33.09	164	101	41.12	30	April	August.
Nairage Ngare*	7,300±	incom- plete	36.99	incom- plete	84	35.55	3	May	December.
Soysambu Estates*	Rift Floor 6,066	32.65	28.77	92	95	25.71	18	April	August.
Gilgil Station	6,581	32.92	28.08	105	100	24.87	21	April	October.
O! O'bonge Eburru	8,000	31.35	25.02	111	104	31.37	38	April	February.
Marula Estates	6,700	25.46	25.24	100	100	22.65	14	April	August.
Korongo Farm	6,200	26.59	21.82	102	97	21.90	6	April	February.
Kenya Co-operative Creameries	6,200	23.55	23.57	99	103	20.98	21	April	July.
Naivasha Experimental Station ..	6,300	23.84	30.95	87	113	25.49	18	April	July.
Naivasha Meteorological Station	6,234	28.38	28.05	134	140	23.40	43	April	April.
Longonot Farm	6,200	31.27	26.03	97	100	21.56	6	April	August.

*Stations outside the boundaries of the Naivasha area, at co-ordinates 36°10' E., 1°05' S. and 36°11' E., 0°28' S. respectively. The height of the Nairage Ngare station is quoted by the Meteorological Department as being about 6,600 feet, but it is believed that it is in the vicinity of 7,300 feet above sea-level.

The local nature of the rainfall is borne out by comparing the figures for the three stations at the Kenya Co-operative Creameries, the Naivasha Experimental Station, and the Naivasha Meteorological Station. These three stations are scarcely five miles apart, yet their total rainfall for 1955 ranged from 23 to 28 inches.

Maps.—Four maps on the scale of 1:50,000 were used throughout the survey, almost to the exclusion of others. They are the G.S.G.S. 4786 Second Edition sheets SA 37 (133/I), SA 37 (133/II), SA 37 (133/III), and SA 37 (133/IV). A map on the scale of 1:250,000 compiled by the military authorities in 1945, and referred to as "Nairobi and the Aberdares EAF 1633" was also used.

Mapping was also done on aerial photographs, there being complete cover for the area. The photographs were taken by the 82nd Squadron R.A.F. during 1948.

Only a small portion of the G.S.G.S. maps on the scale of 1:50,000 are contoured at intervals of 50 feet. The whole area now mapped, however, has been "contoured" and linked with the contours on the G.S.G.S. maps, by interpolation and extrapolation from the contours at intervals of 250 feet on the military EAF 1633. The contours thus drawn for parts not contoured on the G.S.G.S. maps should be regarded as approximate only.

Communications.—The main line of the East African Railways passes through the eastern part of the area, and is closely followed by the tar-macadamized road from Nairobi to Nakuru. The railway, constructed in the early years of the present century and opened in 1901, originally also passed through the northern part of the area skirting around the southern edge of the "Badlands" lava flows from Gilgil to Elmenteita, but was re-aligned about six years ago.

Numerous roads exist in the area, serving the farming community principally. Their condition varies greatly according to their situation and according to the seasons, particularly as far as the rains are concerned. Some of the roads are unmetalled and are likely to deteriorate rapidly with the onset of bad weather. In the forested western parts of the area tracks are generally in poor condition and rarely suitable for travel other than in Landrovers and vehicles of a similar nature. Several roads have been made or are in the process of being made for security reasons. One such road is that being made northwards from Nairage Ngare along the Nasampolai ridge, to link up with the track from Narok to Sabutiek and Mau Narok. This road, when completed, will traverse the ground and forest of the Mau escarpment from Nairage Ngare to Mau Narok*.

The steepness of the scarps and the abrupt rise from the Rift floor at about 6,500 feet to the 8,000-foot level of the Kinangop has necessitated the construction of zig-zagging roads to reach the plateau, though generally flat upper surfaces of the down-faulted blocks reduces the overall gradient. Unfortunately on account of the soft nature of the rocks composing the plateau and the down-faulted blocks, coupled with poor construction of the roads, there is a great deal of erosion. The western and south-western slopes of the plateau are generally well wooded and forested, but the high flat plains of the Kinangop proper are bleak and grass covered.

Acknowledgements.—The writers wish to extend their gratitude to those officers of the Kenya Police, and of the Administration of the Rift Valley and Southern Provinces, who assisted in diverse ways in the execution of the survey. The supply of Police escorts for the geological party during the *Mau Mau* Emergency was no mean task, and is deeply appreciated. To the numerous farmers and residents in the Naivasha area the writers also wish to express their sincere gratitude for generous hospitality.

* This road was completed in 1958.

II—PREVIOUS GEOLOGICAL WORK

Much has been written on the geology of East Africa and in particular on the Gregory Rift Valley, in which the Naivasha area is included. Often papers and books have been written on the area without the authors having visited it. On the other hand, the writers of the present report wish to take this opportunity of stating how indebted they are to the various previous workers in or on the area.

Dr. G. A. Fischer (1885) * was the first European to travel through part of the Naivasha area. He reached Lake Naivasha via the Njorowa Gorge in June, 1883, but was unable to proceed further as the Masai were troublesome at that time. He collected various rocks which were described by O. Mügge (1885, reprinted 1886), who also analysed water collected by Dr. Fischer from a hot spring in the Njorowa Gorge. Joseph Thomson passed through the Naivasha area during 1883, a few months after Fischer. He, also described the thermal springs, steaming vents, lakes and volcanic cones and craters that abound in the area (Thomson, 1884; Loftus, 1951). In 1887 L. von Höhnelt whilst accompanying the Teleki expedition travelled through the Naivasha area, and in a paper published in 1890 dealt with the orography of the area and noted the volcanic nature and features of much of the country he traversed.

In 1893 J. W. Gregory made his first visit to the Rift Valley. He travelled through the Kedong valley where he recorded the presence of lake terraces of a former lake which he named "Lake Suess" (Gregory, 1896, p. 94). He also climbed to the peak of Longonot and noted the presence of a steam-jet in its crater. In addition, he visited several craters in the "Badlands" area, west of Gilgil.

J. W. Gregory (1894, 1920, 1923) in several papers as well as in his books (1896, 1921) dealt with the geography and geology of the Rift Valley, particularly of the part between Lakes Magadi and Rudolf. He also propounded his theory of the sinking "keystone" as an explanation for the origin of the Rift Valley.

Walcott Gibson (1893, p. 563) noted that pyroclastics forming the high central plateaux of the Mau, Kamasia and Laikipia were composed of acid rocks ("acid" presumably meaning "light-coloured"). He believed these issued from a north-south fissure, and that the lakes in the Rift Valley were formed by the damming of the drainage by the pyroclastics.

G. H. Gorges whilst on a journey from Naivasha to Lake Victoria passed round the southern end of Lake Naivasha and noted (Gorges, 1900, p. 78) that there are many volcanic peaks and ridges whose slopes are covered with volcanic dust, obsidian and volcanic rock.

In 1902 E. E. Walker (1903) visited Longonot, which he stated consists chiefly of fine volcanic ash. Blocks of vesicular trachyte, he found, contained large clear sanidine feldspars.

G. T. Prior (1903) described the rocks collected in East Africa by Gregory during his first expedition in 1893, and compared them with volcanic rocks from islands in the Atlantic Ocean, and the Mediterranean, Aden and Abyssinia. He noted that the majority of the rocks were rich in alkalis and of phonolite type.

H. B. Maufe (1908) in his report dealing with the geology of the East African Protectorate noted a line of "fumaroles" issuing along the course of a "comendite" dyke in the Njorowa Gorge. He also noted that one phase of vulcanicity preceded and another followed the Rift Valley subsidences. Maufe also described several rock types from the Naivasha area, as well as some of the soils, and discussed its water possibilities.

* References are quoted on p. 77.

A fragment of a fossil jaw was found by Mr. W. A. Macgregor in the Morendat valley, presumably in the lacustrine gravels that occur in that locality, and was described by Professor W. Ridgeway (1909) as undoubtedly belonging to one of the *Equidae*. It was the first mammalian fossil recorded from East Africa.

G. L. Collie travelled through the area in 1910, on a journey from the coast to Lake Victoria. In a subsequent paper he mainly dealt with the geomorphology of East Africa and noted that many of the fault-scarps in the Rift Valley are curved, and that the last phase of vulcanism in the valley was explosive in type (Collie, 1912). He also believed that through incision of the Nile drainage, the Rift Valley might ultimately disappear as a topographic feature.

Then in 1919 J. W. Gregory re-visited Kenya and soon after (1921) published his account of the geology of East Africa. Rocks collected by Gregory during this visit were described by Miss Neilson in an appendix to his book. His initial classification and pioneer labour have stood the test of subsequent work admirably, and much has been built on his investigations. His nomenclature for the Tertiary and Quaternary deposits (*op. cit.*, p. 105, p. 199) has been superseded, as he assumed that what are now known to be middle Pleistocene sediments were Oligocene or Miocene, the remaining sediments and volcanic rocks being distributed below and above in the stratigraphical column to fit in with that conception. None the less, his sequence for the lavas does form a general basis for the classification of the main phase of volcanic eruptions. Frequent reference is made in this report to Gregory's comprehensive work.

H. L. Sikes (1926) in dealing with the structures of the Rift Valley regarded the "parallel valleys of the grid structure [south of the present area] as having been initiated and given direction by gravity faulting and jointing in a region of east-west tension, and as having been widened and deepened by erosion." These conditions apply equally well to the Naivasha area, part of which came under consideration by Sikes. He also evidenced four or possibly five major movements following periods of vulcanicity. He pointed out that he found no evidence of transverse folding amongst the volcanic rocks (*op. cit.*, p. 400), nor any evidence of north-south compression along the major cross faults in his north-south grid-faulted structure.

Diatomites from the Nderit river and Naivasha were used in experiments carried out at the Imperial Institute (1921) with diatomite/clay mixtures that yielded tiles of suitable quality. A summary of the diatomaceous earths known in Kenya at that time was made in a publication of the Institute in 1928.

L. S. B. Leakey commenced archaeological studies in East Africa in 1928, and has continued them up to the present day. J. D. Solomon, who worked with Leakey in the early stages dealt with the geology of the various sites being excavated in the Naivasha area at that time (Leakey, 1931, appendix A). Frequent reference is made in this report to the admirable work done by Dr. Leakey, his wife, and his other colleagues in the sphere of archaeology and Pleistocene geology in the Naivasha area. The understanding of the Pleistocene in this region is largely attributable to these industrious and enthusiastic workers.

In 1928 L. S. B. Leakey (1942) located a prehistoric living site at the base of a cliff a few miles from Naivasha, which was excavated and examined in detail in 1939. Amongst the finds made was a skull and skeleton which Leakey believed probably represented a male of *Homo sapiens* type living in the closing phase of the Gamblian Pluvial.

In 1929, Leakey and J. D. Solomon, although preliminary work in the Nakuru-Elmenteita basin had suggested to them that there had been five distinct wet periods, concluded after more detailed work that there were only two Pluvials of the first magnitude. They believed that the first ante-dated much of the faulting in this part of the Rift Valley. In an appendix to Leakey's 1931 account, A. T. Hopwood

described fossil mammals from several localities including Gamble's cave, the Melawa (Morendat) valley, and the Nderit river in the Naivasha area.

E. Nilsson, during two expeditions in 1927-1928 and 1932-1933, collected many details regarding the Pleistocene lakes in the Rift Valley (Nilsson, 1932, 1935, 1938, 1940). Much of the research he undertook in the Naivasha and Nakuru lake basins, and he believed that most of the lake terraces in the area are tilted.

W. Campbell Smith (1931) gave petrographic descriptions of rocks that had been collected from Njorowa Gorge and east of Naivasha. Rocks from the Public Works Department's quarry at the latter place, he referred to as aegirine pantellerites (*op. Cit.*, p. 220).

In his publication on the underground water resources of Kenya Sikes (1934) stated that drilling for water in the Rift Valley had not been very successful, and was not hopeful about the success of bore-holes drilled on the Kinangop. He also mentioned that a steam-jet in the Njorowa Gorge was discharging vapour "under considerable pressure." He believed that where local conditions are favourable power could be generated from the steam-jets.

Florence Rich (1932) noted that the alkalinity of the water in Lake Naivasha increases towards its northern shores.

C. Arambourg (1935, pp 41, 42, 46) whilst passing through the Naivasha area with the scientific mission to the Omo river at the northern end of Lake Rudolf collected fragments of lava, one of which he described as oceanite, from one of the tuffs on Crescent Island. He also described comendite from the Njorowa Gorge, and stated that it contains fluorite (*op. cit.*, p. 23).

In 1929-1930, a study of the rift valleys and plateaux of East Africa was conducted by Bailey Willis. He traversed and worked in the Naivasha area, and concluded that the Gregory Rift Valley "conforms to the zone of inferred downdraft", lying "on the margin of a hypothetical asthenolith" (Willis, 1936, p. 311). The Mau escarpment Willis (*op. cit.*, p. 263) stated is but a gentle swell or flexure with here and there a steeper declivity of volcanic rocks. The faults along the flanks of the Rift Valley he believed are structural effects of the up-arching of the high plateaux of East Africa.

Annually varved sediments found along the Makalia, Nderit and Melawa rivers by Nilsson (1932) during the Swedish expeditions to East Africa were studied and teleconnected with the glacial varves in Europe by G. de Geer in 1934.

In 1933, E. Lönnberg described a fossil buffalo found in lacustrine sediments near the Melawa river, and later, in 1937, more fossils including some mammalian remains from a site in the south-eastern region of the Naivasha basin (Lönnberg, 1933, 1937).

The properties and descriptions of the soils in the Rift Valley and on the Kinangop were given by G. Milne (1936) in a memoir published by the East African Agricultural Research Station at Amani in Tanganyika.

N. L. Bowen (1935, 1937) described acid lavas from the Naivasha area, and noted the existence of "ferrosilite" in obsidian from the Njorowa gorge.

S. J. Shand dealt with rocks from Kijabe and the escarpment, a few miles from the south-eastern corner of the Naivasha area. He described a basalt from Kijabe hill which is very similar to a basalt in the present area.

H. G. Busk (1939), in an explanatory note to a block diagram of the Rift Valley between lakes Magadi and Nakuru, briefly described certain features of the Naivasha area. He expressed the opinion that nearly all the physical features displayed in this section of the Rift Valley are tectonic, erosion playing only a secondary part.

In 1943 Lieut. P. C. Spink, R.N.V.R. (1945) visited Eburru, Orgaria and Njorowa gorge, and described the steam-jets occurring in these localities.

In 1945 E. Nilsson (1945) described the skeleton of a fossil buffalo found in lake sediments along the Melawa river.

Mrs. Sonia Cole (1950) in her book summarizing the geology of Kenya reiterated the conception that the freshness of Lake Naivasha is due to capture in the upper reaches of the Melawa river, thereby allowing more fresh water to flow into the lake. The steam-jets in the Njorowa gorge she believed have been exposed by erosion. She also considered that the steam-jets in the Naivasha area are of meteoric origin.

In 1953, G. Wilson, a geologist in the Public Works Department conducted a hydrological survey covering part of the Naivasha area, particularly that region between Lake Naivasha and Kinangop mountain. In his report on the ground-water conditions he concluded that "the area is well supplied with ground-water, and that the former poor results of drilling were due mainly to misinterpretation of the conditions prevailing—both geological or geophysical."

J. Scott (1953) postulated a theory for the formation of the Rift Valley by means of ice-cap squeezing, and developed therefrom the idea that juvenile steam may be trapped beneath the rocks in the Rift Valley floor.

Mrs. Cole (1954) summarized the current archaeological data in a valuable book, and dealt briefly with the geology of the different cultural sites in the Gregory Rift Valley, including the Naivasha area.

R. M. Shackleton (1955) published a paper in which he dealt with Pleistocene movements in the Gregory Rift Valley, and recorded at least three pre-middle Pleistocene phases of faulting. He also recorded an unconformity on the Kinangop between Kanjeran beds and underlying tuffs, which are probably of Kamasian age. The main faulting in the Rift Valley he believed may be of Pliocene or Miocene age.

In the same year McCall dealt with underground water conditions and geology of the Nakuru area, including part of the northern section of the Naivasha area of the present report. He described a basalt, which is comparable with the porphyritic Kijabe-type basalt found in the Mahindu valley during the course of the present survey.

In recent years hydrological and geophysical investigations have been conducted in the Naivasha area by the Hydraulic Branch of the Ministry of Works, Nairobi, largely in connection with water-supplies for the farming community. Geologists of the Geological Survey have reported on minerals of economic importance in the area at various times in the post-war years.

III—PHYSIOGRAPHY

To most people who live in or have seen the Naivasha area, its physiography and scenery are impressive and beautiful. Also the majority of people who have become acquainted with the Rift Valley are inclined to be exuberant over its magnitude and aspect, but in reality as Shand (1936, p. 308) has stated "the depth of the African rifts, although impressive when stated in feet, is quite insignificant in relation to their width." He also drew attention to the fact that if a section were drawn on true scale from the coast to Lake Victoria across the deepest part of the Rift Valley, the valley would be all but invisible. Nevertheless, the various volcanic masses and the scarps formed both by faulting and erosion create a topography of impressive proportions (Fig. 1) when dealt with on a local scale and when compared with the peneplaned areas east of the Rift Valley. The Njorowa gorge (Hell's Gate) with its sheer faces carved from sheets and plugs of intrusive comendite, its steep and deeply incised stratified deposits and its steam-jets is also a picturesque place.

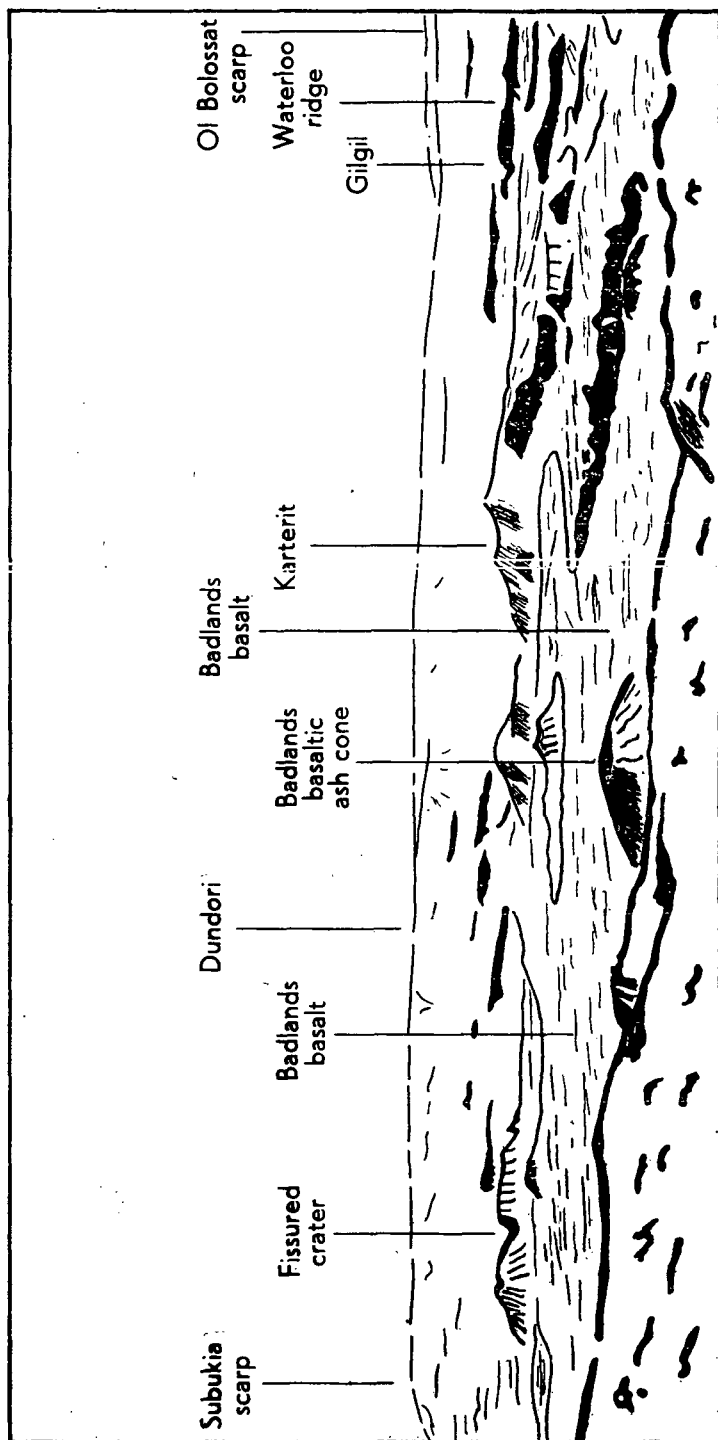


Fig. 1—View of the Rift Valley in the north-eastern part of the Naivasha area and in the area further north from the northern slopes of Eburru, looking north-east. The eastern wall of the Rift Valley forms the horizon. Fault-scarps of the Rift floor occur on the right and in the centre of the view, with fissured craters on the left. Recent basalt flows and basaltic ash-cones form the middle distance, while the foreground is part of the northern slopes of Eburru. (Drawn from a colour photograph by A. O. Thompson.)

Lake Naivasha with its subsidiary lakes covers an area of about fifty square miles. In the south-western corner of the lake proper a portion was separated by the declining water-level to form a lake on its own about 1930. Soundings of the lake were made in 1927, but insufficient readings were apparently taken in the south-western corner, for according to the map drawn (see Fig. 2) the small lake that now exists in that region should have been drained dry with the fall of lake Naivasha to its present-day level. At the beginning of 1956 the lake stood at a height of approximately 6,184 feet above sea-level. The area of the lake proper was then thirty-seven square miles and without the water in Crescent Lake its volume was a little more than 169,500 acre-feet. With the body of the water contained in Crescent Lake the volume at this level is slightly more than 265,000 acre-feet and may, therefore, rank as the fourth largest body of water in Kenya, being surpassed by Lakes Rudolf, Victoria and Chala, in that order.

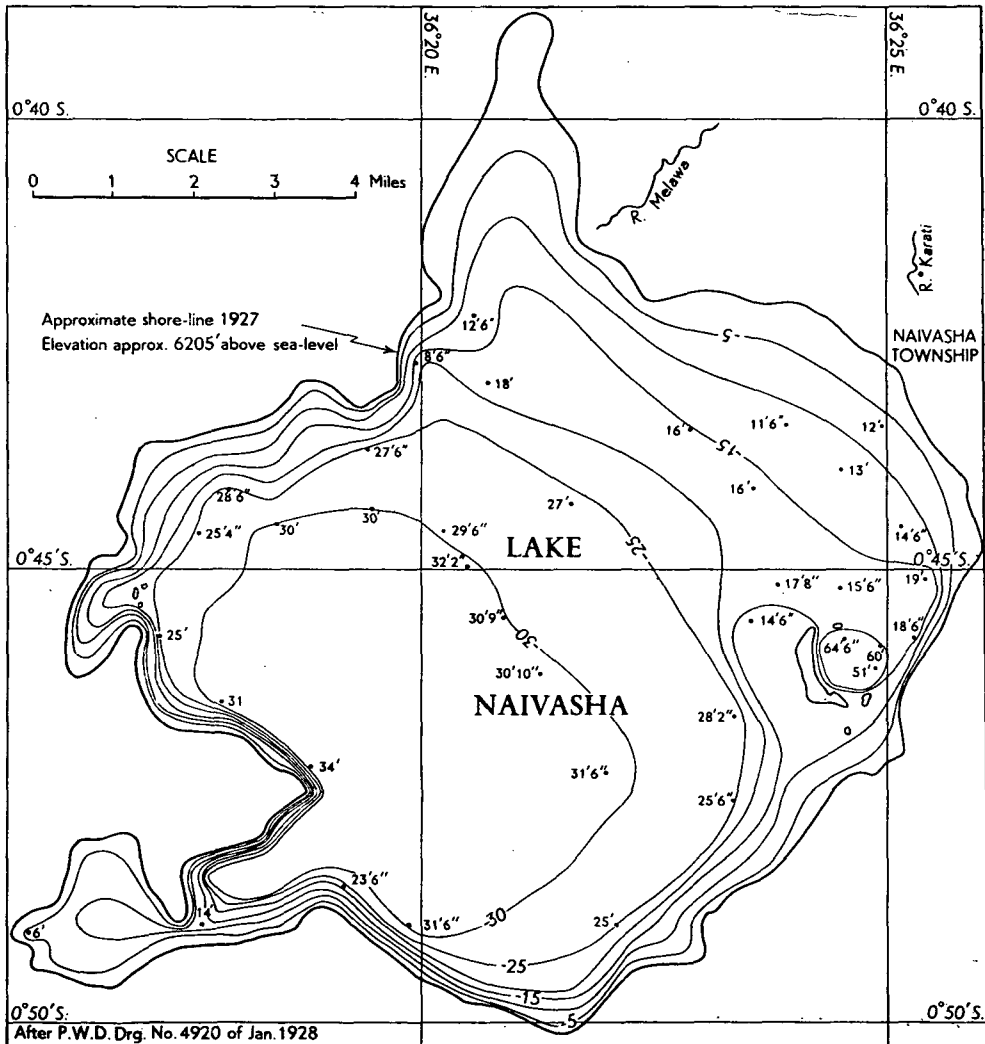


Fig. 2—Lake Naivasha; sub-surface contours in November, 1927. The contours are shown relative to the water surface at that time, when the altitude of the lake was approximately 6,205 feet above sea level. At the beginning of 1956 the water surface was approximately at the 6,184-foot contour, which almost corresponds with the 20-foot contour shown on this figure.

Accurate observations of the level of Lake Naivasha were commenced in 1908 and it is known that there has been an overall fall in the level since 1917 (Fig. 3a). Annual rainfall at Naivasha and evaporation figures for the lake, although fluctuating, have over the same period revealed no over-all decrease or increase (see Fig. 3 (b)).

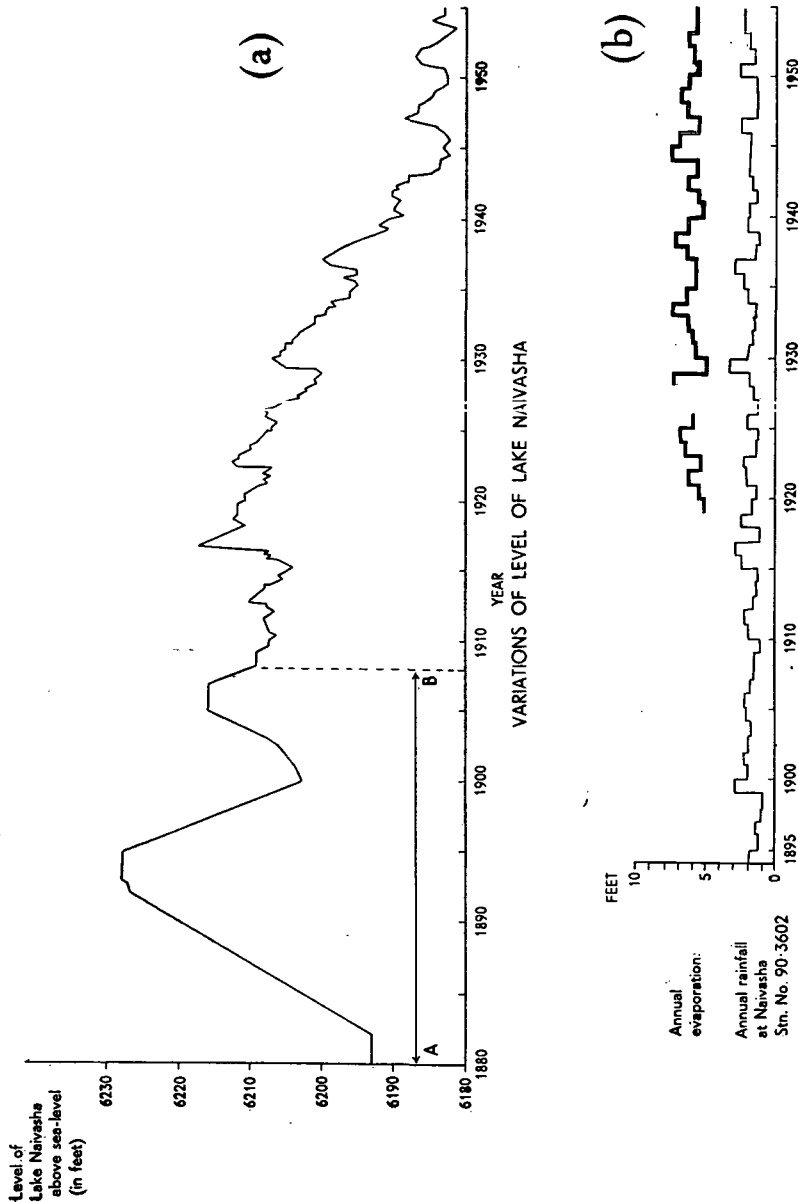


Fig. 3—(a) Variations of level of Lake Naivasha. Probable major fluctuations of level in the region A-B of the graph are taken from Sikes, 1936. From about 1860 to 1882 Crescent Island was joined to the mainland and acacia trees grew along the lake shore, but were then killed by the rise of the water level, their stumps remaining submerged until 1935. During the period of low level at the end of the nineteenth century, it is probable that the lake did not rise above the 6,195-foot level.

(b) Annual evaporation from Lake Naivasha and annual rainfall at Naivasha.

Another lake of interest in the area is Crater Lake on the western side of Lake Naivasha. The algae-rich green water is probably about fifty feet above the level of Lake Naivasha and, although it fluctuates slightly during the seasons, it does not dry out completely. It occurs in an agglomerate crater and has little surface recharge.

The Naivasha area is one of internal drainage, of which the greater part passes into Lake Naivasha. In the north-western part of the area the drainage is into Lake Natron in Tanganyika via the Seyabei and Uaso Nyiro rivers.

For convenience of description the area may be divided into three parts namely (a) the Kinangop plateau, (b) the Mau escarpment and (c) the Rift floor.

(a) *The Kinangop Plateau.*—The application of the term "plateau" to the Kinangop is not strictly correct but is employed because it is in common usage. More accurate terms for the feature would be "shelf" or "plain".

The plateau appears in the north-eastern part of the area only, where it lies between the southern mountains of the Aberdare range and the Rift floor. It is a broad flat plain ranging in height from about 7,800 feet (2,379 m.) to a little over 8,000 feet (2,440 m.) in altitude above sea-level. It is deeply incised by the Makungi, Kitiri and Engare Magutyu tributaries of the Turasha river, which forms part of the Melawa river—the largest river flowing into Lake Naivasha. Along the northern edge of the area gorges between 200 and 400 feet (61 and 122 m.) deep have been formed. The tributaries of the Melawa river within the area mapped flow in a general northerly direction, but are diverted to the south-west by their confluence with waters draining from Kipipiri to the north-east and beyond the limits of the present area, the combined streams soon joining the Melawa which flows in a southerly direction. This reversal of direction is believed to be due to capture of the Kinangop rivers by the Melawa river.

West and south-west of the Kinangop plateau, the rocks that form the plateau have been down-faulted in a series of steps. The majority of the faults are short, and can be seen to die in one direction or another. Several of the fault-line scarps suggests slightly curved faults, with the downthrown blocks on the convex side.

Where rivers have incised themselves on the western edge of the plateau deep valleys have been formed, the Mahindu valley being an excellent example of the incutting of the rivers into the soft rocks that form the Kinangop.

The Melawa river from the northern edge of the area flows in a graben at the foot of the Kinangop plateau. Along most of its course in the graben Gamblian lacustrine sediments are in juxtaposition with Kamasian deposits of the down-faulted blocks.

(b) *The Mau Escarpment.*—The Mau escarpment forms the western wall of the Rift Valley in the Naivasha area. It is composed largely of soft volcanic ashes and tuffs with only rare outcrops of agglomerate and lavas. Parts of the escarpment rise to over 10,000 feet (3,050 m.) in the region west of the Eburru volcanic pile, which is linked to the escarpment by a ridge standing about 8,500 feet above sea-level caused by the piling up of pyroclastics from Eburru against it. The ridge, like the escarpment, is deeply incised by water-courses.

The Mau escarpment is not flat on the top like the Kinangop—the divides separating the drainages to Lakes Nakuru, Natron and Naivasha are sharp. Examples of river capture were not seen, but through fairly recent earth movements drainages have been affected in various places—chiefly about Sabutiek. Swamps that must have formed through the damming of water-courses by faulting, have been drained or are being drained by the incision of the rivers. The Nasampolai river has drained a large swampy area north-west of Sabutiek, but has itself been dammed by small earth movements in the Sintekara and Nairage Ngare area. The latter place is just south of the boundaries of the present area, near the southern edge of the Mau escarpment. Drainage from the escarpment probably does not reach Lake Naivasha by means of surface water-courses. The Marmonet river is a tapering stream, which loses itself on the Ndabibi plain. Headward incision of tributary streams from the

Seyabei river is actively destroying the Mau escarpment from the south-western side, where valleys between 300 feet and 400 feet deep (92-122 m.) are common. The extremely soft nature of the rocks in the escarpment lends itself to rapid erosion. In the Masai reserve, on the western slopes of the escarpment in the south-western part of the area, destruction of the soil cover, probably due to overgrazing, is exposing many acres to active gully and sheet erosion.

The slopes of the Mau escarpment are heavily forested as well as portions of the highest parts. On the western dip-slopes the forests open out into grassy glades in the lower reaches, and on the lower ground the forest is largely confined to the valleys. Bamboo grows prolifically on the eastern slopes and on the highest hills of the escarpment in patches between the forest trees.

The rifting has produced blocks down-faulted to the east along the escarpment. The faults and fault-line scarps are often difficult to trace owing to vast accumulations of ejectamenta banked up against the escarpment. Recent earth movements along the old fault-lines have rejuvenated some of the fault scarps—an example being that along the Nasampolai river north of Sintekara, where a block is down-faulted to the east along a dip-slip fault, the dip of the fault being about 75° . Local inhabitants have stated that streams that once flowed to the Rift floor now disappear underground on their way down due to cracks which have opened up; it is probable that the cracks are openings formed along faults through slight earth movements. The porous nature of the rocks in the escarpment probably aids in the tapering off of the stream-waters as they plunge down the escarpment towards the Rift floor.

(c) *The Rift Floor.*—The Rift floor in the Naivasha area forms part of the Gregory Rift Valley, and is diverse in its structures and topography. Numerous volcanic cones and craters, scarps and lakes, stud its otherwise monotonous terrain. High points are formed by Longonot and Eburru, both of which rise to over 9,000 ft. (2,745 m.). On the western and south-western shores of Lake Naivasha numerous volcanic craters, some faulted, are built up of acid lavas and basaltic ashes. North of Lake Naivasha as well as on the slopes of Longonot, eruptions of lava have taken place in very recent times—some probably in the last hundred years.

The Rift floor is largely covered with sediments that accumulated in lakes during the Gamblian stage of the Pleistocene period. They contain a large proportion of volcanic ejectamenta, and a few diatomaceous beds are known to occur. Despite their extensive distribution the Gamblian lake beds are not thick and rarely exceed 100 ft.

The steep slopes of the various ash and lava cones are of striking appearance. The cones vary greatly according to the nature of the rocks of which they are built. The following table lists some measurements of the angles of repose of some of the ashes and lavas:—

Name of Cone	Rock Type	Angle of Repose
Parasitic cone on northern slopes of Longonot ..	Ash	35°
Northern slopes of Longonot	Ash	25°
Horseshoe Crater	Basaltic ash ..	24°
Cone in Badlands	Basaltic ash ..	32°
Crater lake	Agglomerate ..	18°
Cone at southern end of Njorowa Gorge	Rhyolite ..	35°
Cedar Hill	Obsidian ..	43°

The slopes of the cones of the acid rocks such as the rhyolites and comendites, are unusually steep on account of the viscous nature of the lavas at the time of their eruption.

It is the Rift floor that shows the greatest variety of topographical features caused by earth movements. It abounds with craters, remnants of pre-existing craters, fault scarps, fissures, and steam-jets (Plate I, b, c, d). The jets are confined chiefly to the zone of acid rocks as well as many well-defined fissures and recent fault-scarps. In the Badlands are found the most recent basaltic outpourings, one flow, the most recent covering an area of about 6,950 acres, and weighing, it is estimated, about 525 million tons. There are more extensive flows than this in the area, but for various reasons their magnitude cannot be assessed readily.

A curious type of air blow-hole occurs about half a mile on the Eburru side of the intersection of the Lake circuit and the Eburru road. These holes draw in air during the night, expelling it during the day. The expelled air is cool, and Spink (1945) reported a temperature of 59° F. as against the local shade temperature of 80° F. He suggested that the variation of the strength of air expulsion might be due to the strength of wind blowing into another crack. The most likely explanation of these blow-holes is the variation of daily temperatures. Thus, during the day, as the air in the volcanic layers is expanded by a rise in temperature, air is expelled from the surface vents while during the cool of the night the air contracts, sucking in air through the same vents. Similar blow-holes occur in the Nakuru District.

The rocks found on the Rift floor vary from undersaturated tephrites to highly acid rocks, such as rhyolites and sodic rhyolites. The latter are well exposed in the cliffs along the Njorowa gorge, where they exhibit excellent columnar joints. At the southern end of the gorge a peculiar radiating pattern of joints can be seen in a cliff of comendite, east of a bore-hole that encountered steam when drilled.

The Njorowa gorge, which formed the overflow of Lake Naivasha between lower and middle Gamblian times (*see* Table, p. 15) is striking in its appearance. It is possible to motor into it from the south lake-road for a distance of about four miles, between comendite cliffs between 200 and 400 ft. (61-122 m.) high. It is also possible to motor into it from the southern end but the track is not good and it is not possible to link up with the track from the north. Dykes and sills of intrusive comendite occur about the middle of the gorge in the vicinity of the steam-jets. Near one of these jets is a boiling mixture of water and mud which does not overflow its small depression.

Overlying the comendite and the sediments in the Njorowa gorge are grey and white pumiceous ashes. On either side of the gorge, but set away from it a little, are hills also composed of these ashes. Some of the hills no doubt represent former volcanoes, but craters are no longer visible. Erosion is rife on the ashy cones. A large area also has been sprinkled by ashes erupted from Longonot and the volcano that preceded it on the same site. Eruption of these ashes took place on a fairly large scale probably in Makalian times, because some were deposited in the then young Njorowa gorge. Subsequent erosion has exposed these deposits, which in places are 20 ft. or more thick, in the present-day Njorowa gorge. Resting on an unconformable surface of these white ashes are coarse drab or dark grey conglomerates—which suggest that vigorous erosion took place in the gorge on post-Makalian times, probably during the Nakuru wet phase. Present-day erosion has also exposed the conglomerates, which are seldom more than 10 ft. thick.

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL SUCCESSION

The oldest rocks in the area to which a definite age has been ascribed are sediments and pyroclastics on the Kinangop. On archaeological evidence these are dated as belonging to the Kanjeran stage of the upper middle Pleistocene. Beneath them are rocks the upper members of which are believed to be of Kamasian age, whilst the oldest rocks found *in situ* in the Naivasha area may belong to the Tertiary era, though, as there is a lack of decisive evidence, they are here taken to be of lower Pleistocene age. Some rock fragments ejected by the numerous volcanoes in the area may be Tertiary or older in age.

The rocks in the Naivasha area are thus tentatively classified as follows according to their age:—

5. Holocene volcanics, lake and fluvial sediments.
4. Upper Pleistocene volcanics and lake sediments.
3. Upper Middle Pleistocene volcanics and lacustrine sediments.
2. Lower Middle Pleistocene (?) volcanics and lake sediments.
1. Pleistocene (?) volcanics.

The volcanic rocks in the area consist of tephrites, basalts, trachytes, phonolites, ashes, tuffs, agglomerates and the acid lavas rhyolite, comendite and obsidian. The lake beds are mainly composed of reworked volcanic material or sub-aqueously deposited pyroclastics. The structures of the area comprise faulting on the flanks and in the floor of the Rift Valley, and slight folding in the Njorowa gorge. Slight unconformities are present in the lake beds, and can most clearly be seen along the Melawa river drainage. Details of stratigraphy are presented in Table II.

V—DETAILS OF GEOLOGY

1. General Discussion of the Succession and Geological History

(1) LOWER PLEISTOCENE VOLCANICS (?)

A Kijabe-type basalt (*see* p. 24) about 150 ft. in thickness occurs in the river-bed of the Mahindu river about five miles north-east of Morendat Station. It is overlain by a group of pyroclastics and sediments whose age may be lower Middle Pleistocene, but the rocks beneath the basalt were not seen. Shackleton (1955, p. 262) considered that the trachytic lavas and tuffs of the Kinangop scarps may be Pliocene or Miocene in age. There is, however, as yet no evidence by which the foundation rocks of the Kinangop can be dated, and it is tentatively suggested that the basalt of the Mahindu valley is lower Pleistocene in age. No evidence of unconformity between this basalt and the overlying pyroclastics and sediments was obtained during the course of the survey.

(2) LOWER MIDDLE PLEISTOCENE (?) DEPOSITS

Overlying the basalt of the Mahindu valley is a group of variegated pyroclastics, some of which have been deposited subaqueously. This group, in which certain beds are diatomaceous, is about 200 ft. (61 m.) thick. To date no artifacts or fossils have been found in it. The pyroclastics in turn are overlain by a trachyte lava not greater than 100 ft. (32 m.) thick.

A further collection of pyroclastics and lacustrine sediments about 400 ft. (122 m.) thick, overlies the trachyte. Near the top of this group of rocks, an artifact was found several years ago, which Dr. L. S. B. Leakey of the Coryndon Museum, Nairobi, has informed the writers may be equivalent to those found in the rocks of Kamasia of lower Middle Pleistocene age. It is tentatively suggested that the group is Kamasian in age.

TABLE II
SUMMARY OF THE SUCCESSION IN THE NAIVASHA AREA

AGE	Archaeological Stages	Climatic Stages	Kenya Cultures (after Leakey and Cole)	Rock types, Main Localities and Approximate Thicknesses	Remarks
Holocene	Neolithic	Recent	Wilton Gumban	Trachytes and ashes Longonot Southern slopes of Eburru and Cedar Hill	Climate as present day.
	?	Nakuran	Wilton and Gumban	Basaltic ash cones Badlands Basaltic flows Badlands Silts (10 feet) Nderit River	Wetter than present.
	Mesolithic	Dry	Wilton Gumban	Ashes Longonot	Drier than present day. Fissuring.
		Makalian	Wilton	Gravels and silts (20 ft.) Nderit	Slightly wetter than present day. Lake Naivasha 120 feet higher than modern lake
			Elmenteitan	Trachytes Longonot	Drier than at present.
Upper	Upper Palaeolithic	Dry	Magosian Upper Capsian	Obsidians Eburru	
		III Gamblian II I	Stillbay Capsian Lower Capsian	Lake beds (100 ft.) Lake Naivasha	Lake (III) 180 foot Naivasha (II) 200 foot. terraces (I) 400 foot.
Pleistocene	Middle Palaeolithic	Third	Fauresmith	Basaltic ash cones Rhyolites Phonolites with intercalated pyroclastics Trachytes Basalts Comendites Phonolites Trachytes	Drier than present day Faulting.
		Interpluvial		Badlands Eburru and S.W. Naivasha Eburru Lower Eburru Lower Eburru East of Karterit	Much volcanic activity in the Rift floor.

TABLE II—(Contd.)

AGE	Archaeological Stages	Climatic Stages	Kenya Cultures (after Leakey and Cole)	Rock types, Main Localities and Approximate Thicknesses	Remarks
Middle	Lower	Kanjeran	Pseudo-Stillbay Acheulian	Swamp deposits } (Min- Kinangop and Pyroclastics } imum Mau escarpments 50 ft.) (diatomite) of Kariandus	Intense rifting and faulting. Wetter than present day. Erosion.
		Second Interpluvial	Acheulian		Drier than present day. Erosion.
Pleistocene	Palaeolithic	Kamasian	Chellean	Welded tuff (3 ft.) Rift walls Pyroclastics and sediments (400 ft.) Trachytes (100 ft.) Pyroclastics and sediments with intercalated trachytes (200 ft.)	Wetter than present day.
		First Interpluvial			
Lower		Kageran	(Not represented)	Kijabe-type basalt (150 ft.) Mahindu River	Drier than at present. Wetter than present day.

Light-coloured trachytic pumice tuffs which are found in the Nyeri area were placed by Shackleton (1945, p. 3, *et. seq.*) in his Kinangop Tuff Series. These tuffs, underlying the Kinangop and Ol Bolossat plains, and which he states are more developed outside the Nyeri area and along the scarps east of Naivasha, he found were underlain by the Thomson's Falls phonolites, but overlain by one of the Laikipian basalts. In his provisional correlation table of the Tertiary and Pleistocene rocks east of the Rift Valley, Shackleton ascribed a Pliocene age to his Kinangop tuffs. The series in fact embraces sediments that are believed to be of Kamasian and Kanjeran age in the Naivasha area.

Separating the possible Kamasian beds from the overlying Kanjeran rocks is a thin band of welded tuff, which forms a prominent marker horizon in the Kinangop escarpment. It is seldom more than 3 ft. thick. For convenience it is placed stratigraphically with the Kamasian rocks.

At the base of the Mau escarpment both on Creswell's and Deighton's farms, there are trachyte outcrops. It cannot be stated definitely that this trachyte corresponds with the trachyte that occurs at numerous places along the Kinangop escarpment, but the presence about 600 ft. higher up the Mau escarpment of a partly welded tuff, which looks similar to the welded tuff on the Kinangop escarpment suggests that there may be a correlation. The rocks overlying the partly welded tuff in the Mau escarpment are also of Kanjeran age. The partly welded tuff in the Mau escarpment is thicker than its probable equivalent in the Kinangop escarpment, namely about 25 ft. (7.6 m.).

A sequence of bedded sediments in the Njorowa gorge are also believed to be of Kamasian age. The sequence of about 300 ft. is slightly thicker here than its equivalent on the Kinangop scarp.

(3) UPPER MIDDLE PLEISTOCENE DEPOSITS

The Kanjeran beds of upper Middle Pleistocene age overlie the Kamasian rocks. On the Kinangop escarpment they consist of pyroclastics, portions of which were deposited subsequently, lateritic types being believed to be paludal. Artifacts of the Pseudo-Stillbay and Fauresmith cultures have been found in the Kanjeran deposits. In the Mau escarpment the Kanjeran deposits are much thicker than those on the Kinangop. A few relics of the Kanjeran deposits also cap a number of the fault-blocks in the Rift floor along the north-eastern part of the area.

North of Gilgil, a few miles beyond the limits of the area mapped, there are large deposits of diatomite and lake sediments, also of Kanjeran age. It is stated that more than 100 ft. of diatomite have been encountered in a bore-hole. The Kariandus beds contain artifacts of stage four of the Acheulian culture (Cole, 1954, p. 145) whereas the Kanjeran beds on the Kinangop contain implements of stage six. The Kariandus beds may thus be presumed to be slightly older than the Kanjeran beds on the Kinangop. The stages of the Acheulian culture are tabulated by Mrs. Cole (*op. cit.*, p. 193) in her book on the prehistory of East Africa.

The rocks underlying the lake sediments at Kariandus are stated to be alkali quartz trachytes (McCall, 1955, p. 20; Shackleton, 1955, p. 260). Such trachytes are not present in the Kinangop scarps directly beneath the Kanjeran deposits. If the alkali trachytes correspond with the trachytes exposed on the lower Kinangop scarps, and believed to be intercalated in the supposed Kamasian beds already described, then the unconformity between the Kamasian and Kanjeran deposits is considerable. The unconformity has already been discussed by Shackleton (1955, p. 261) for the country slightly to the east of the present area.

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The floor of the Kanjeran lake in the vicinity of Kariandus probably underwent gradual warping and sinking to allow the accumulation of the large quantities of the diatomite found there. During the period of down-warping and possible faulting, portions of the underlying Kamasian beds must have been exposed and subjected to erosion. The Kanjeran deposits of stage six of the Acheulian were laid down in shallow swamps and gentle hollows. During this time further faulting and down-warping took place, and centres of vulcanicity provided much of the ejectamenta that constitutes the Kinangop Kanjeran sediments. No doubt at some of these centres of vulcanicity, acid lavas of comendite type were erupted; obsidian which is commonly allied with this type of lava was probably the source-rock from which the Pseudo-Stillbay artifacts of the Kanjeran beds were hewn. Fragments of comendite were found in the Kinangop Kanjeran deposits (e.g. in specimen 43/333 *).

(4) UPPER PLEISTOCENE DEPOSITS

At some stage between the deposition of the Kinangop beds and the onset of the Gamblian Pluvial period, presumably during the third Interpluvial at the beginning of the upper Pleistocene, erosion, faulting and many extrusions of lava and pyroclastics took place. The faulting that occurred at this time largely set the pattern of the present-day topography in this part of the Rift Valley. The sum total of the movements along the faults was in the region of about 2,000 ft. (610 m.)

Erosion of the Kanjeran beds resulted in the exposure of the diatomite in the Kariandus area to subaerial agencies. One of the lava flows of this period was erupted on to the eroded surface—the diatomite beds about Kariandus being unconformably covered by trachyte. The unconformity is well-exposed in a scarp near the junction of the Gilgil-Elmenteita road with the tarmac road from Gilgil to Nakuru, the southerly extension of the scarp occurring in the present area about half way between the Karterit crater and Gilgil. The Kanjeran beds beneath the trachyte are not exposed, however, at this locality.

Probably of comparable age with the trachyte between Karterit and Gilgil is the trachyte at the southern end of the Njorowa gorge. Its exact relationship to the sediments, believed to be of Kamasian age, composing the bulk of the rocks in the gorge, is not definitely known; but it is believed to overlie them.

During the third interpluvial vulcanicity at Eburru was growing, and probably a number of lavas flowed out in the area about the old Eburru station, which is on the northern foothills of the present-day Eburru hills. (The old railway-line in this region is now used as a road). Overlying the trachyte near Karterit is a phonolite (Plp₁), which in turn in the Eburu area is succeeded by flows of comendite, rhyolite, trachyte, phonolite, and basalt. Interspersed between the different flows and sprinkled over them are accumulations of pyroclastics of varying types. Very coarse pumiceous beds are intercalated with fine black ashes, and some bands have hardened to form agglomerates and tuffs. No doubt some of these extravasations occurred in Gamblian and more recent times, but it is not possible to state accurately when they took place. Some of the rhyolites on the south-western shores of Lake Naivasha were extruded before the peak of the Gamblian I lake, but there are no means of proving that the rhyolites on Eburru belong to the same volcanic phase. It is assumed, however, that they were extruded at this period and, from their stratigraphical position high up on the Eburru massif, it is assumed that they also are of Pre-Gamblian age.

* Numbers 43/333, etc., refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

The sequence of lavas during the third interpluvial is believed to be as follows:—

7. Rhyolites (Plr₂) .. Eburru, Kongoni farm, Njorowa gorge.
6. Phonolites (Plp₂) .. S. E. Eburru, Hornsby-Wright's farm.
5. Trachytes (Plh₃) .. E. Eburru, Nagum, Ndabibi, Maiella (Ol Orugo).
4. Basalts (Plb₃) .. Waterloo Ridge, Badlands, Nagum, Ndabibi.
3. Comendites (Plr₁) .. Eburru station, Waterloo Ridge, Njorowa gorge, Hopcraft's farm.
2. Phonolites (Plp₁) .. Eburru station.
1. Trachytes (Plh₂) .. Karterit, Njorowa gorge (?).

The *trachyte* (Plh₂) at the southern end of the Njorowa gorge is overlain by comendite and possibly by the basalt at the southern tip of the gorge.

The *phonolites* (Plp₁) are generally confined to small localities. In the vicinity of the former Eburru station there are scarps of phonolite against which comendite and pyroclastics have been down-faulted. This phonolite also overlies the trachyte in the vicinity of Karterit.

Overlying the lower phonolites is a group of rocks composed largely of *comendite* (Plr₁) and agglomerates containing numerous fragments of comendite. These agglomerates are generally light-coloured as opposed to the obsidian agglomerates, which are nearly black. Intrusive comendite and flow comendites that lie unconformably on Kamasian sediments in the Njorowa gorge are probably of equivalent age. A ridge running north-south on the northern shores of Lake Naivasha probably also belong to this phase of extrusion of comendite lava.

Most of the exposed comendites show little sign of erosional decay. That there were still older comendites is evidenced by the inclusion of small blocks of comendite in agglomerate interbedded with sediments dated as Kanjeran (middle Pleistocene). No exposures of the older lava were discovered, however, so it must be presumed that together with early obsidian flows, relics of which can be seen as artifacts of Kanjeran age embedded in sediments at Cartwright's site on the rim of the Kinangop escarpment, east of Naivasha, they are now covered by younger volcanics and sediments.

On Waterloo ridge a *basalt* (Plb₃) overlies the comendite, and may belong to the phase when the first basalt at Badlands was extruded. This first flow in the Badlands was covered by the Gamblian lakes as well as by the lake that formed in Makalian times. It is probable that the basalts of the small exposures at Ndabibi, Denning's farm and at the southern end of the Njorowa gorge were connected with this period of vulcanicity too. On Ndabibi a tephrite was found which probably also belongs to this phase of basaltic extrusions. Other isolated localities of basalt occur on Begg's farm, at Nagum on the Cole estates, and on Kongoni farm on the shores of Lake Naivasha. It is probable that several flows of basaltic lava were extruded between Longonot and Lake Naivasha at this time too and are now concealed. A basalt in a small scarp on the western flank of the Ndabibi plain may also belong to this phase.

While the basalts were being extruded it is probable that the basaltic ash-cones and craters of the area were also built up. Karterit was formed at this time, as well as the other basaltic ash craters along the northern edge of the area. Those around the western edge of Lake Naivasha (Neilson's, Korongo and Kongoni farms) were probably formed at this time too. Marula house on the north-eastern side of Lake Naivasha near the Morendat river is built on the faulted remnants of a former basaltic ash-cone. These basaltic ash-cones are frequently riddled with faults and fissures, a classic one being that about 1½ miles west of Karterit on the Cole estates

(Plate I (c)). Other cones built up of basaltic cinders or scoriae also occur in the area, for examples near the southern end of the Njorowa Gorge. Faulted remnants of basaltic ash-cones occur in the Badlands and have been enveloped by younger basaltic flows.

With the close of the phase of basalt extrusion a great deal of faulting took place. All the existing lavas and pyroclastics were heavily faulted and dissection by erosion of the volcanic rocks that had recently been laid down commenced. The succeeding lava flows and rocks are relatively undisturbed.

During the next phase trachyte flows (Plh₃) were erupted—examples are seen on the north-eastern side of the Eburru massif near Nagum, as well as on the eastern side, north of the Eburru-Naivasha road. Outcrops of other trachytes occur on the Ndabibi plain west of the group of rhyolite and ash craters, and on Maiella estate a few miles west of the Njorowa gorge.

Flows of *phonolite* (Plp₃) on Eburru mark the next lava extrusion. Three of these flows that occur above the Masai Gorge on the eastern slopes of Eburru are text-book examples of lava flows. They have been extruded from breached ash-cones. There are also flows of phonolite on the slopes of Eburru on Hornsby-Wright's farm and also on the southern side of the Eburru road.

The succeeding lavas are *rhyolites*, the younger acid lavas of the upper middle Pleistocene, and are largely confined to a narrow zone running in a north-south direction through the area on the western side of Lake Naivasha. This part of the area is greatly fissured and most of the steam-jets of Eburru are confined to it. The zone passes through Eburru beacon. The rhyolites on Kongoni farm and about the Oserian plain can be proved to be of pre-Gamblian age but the age of those on Eburru and the obsidian flows that also occur there, is uncertain. Evidence of earlier rhyolite extrusions is provided by the presence of rhyolite boulders in the upper lacustrine beds exposed in the Njorowa Gorge believed to be of Kamasian age (middle Pleistocene). Associated with the rhyolites there are frequently large deposits of pumice and ash often covering many of the flows. West of Eburru the pyroclastics are banked up against the Mau escarpment.

Numerous craters of agglomerate and ashes of Upper Pleistocene age occur in the area, and one of the greatest of these was the original Longonot crater. Relics of this former crater are still to be found on the western and south-western sides of the present Longonot cone. The diameter of the older crater was probably about four miles whereas the present-day crater is only a little more than one mile in diameter. The pyroclastic cones sometimes, but not always mark the final phase of volcanicity from a particular centre. In the vicinity of Eburru there are excellent examples of ash-cones that have been breached by later lava flows, for instance that south-east of Ol O'borge from which were extruded three separate phonolite flows.

In the upper part of the Upper Pleistocene, during the Gamblian Pluvial period and its subsequent dry phase, relatively stable conditions existed in the area. Lacustrine deposits were laid down during the pluvial period and were eroded during the falls in the level of the lake. Three levels have been recorded for the Gamblian lakes in the Naivasha and Nakuru-Elmenteita basins, where beaches and terraces were formed and cut in the respective basins at different heights above the lakes' present levels (Nilsson, 1932 and Leakey, 1931). It was only during the first maximum of the Gamblian pluvial that the lake of the Naivasha basin was joined with the lake of the Nakuru-Elmenteita basin (Fig. 4). At this time the respective lake levels were

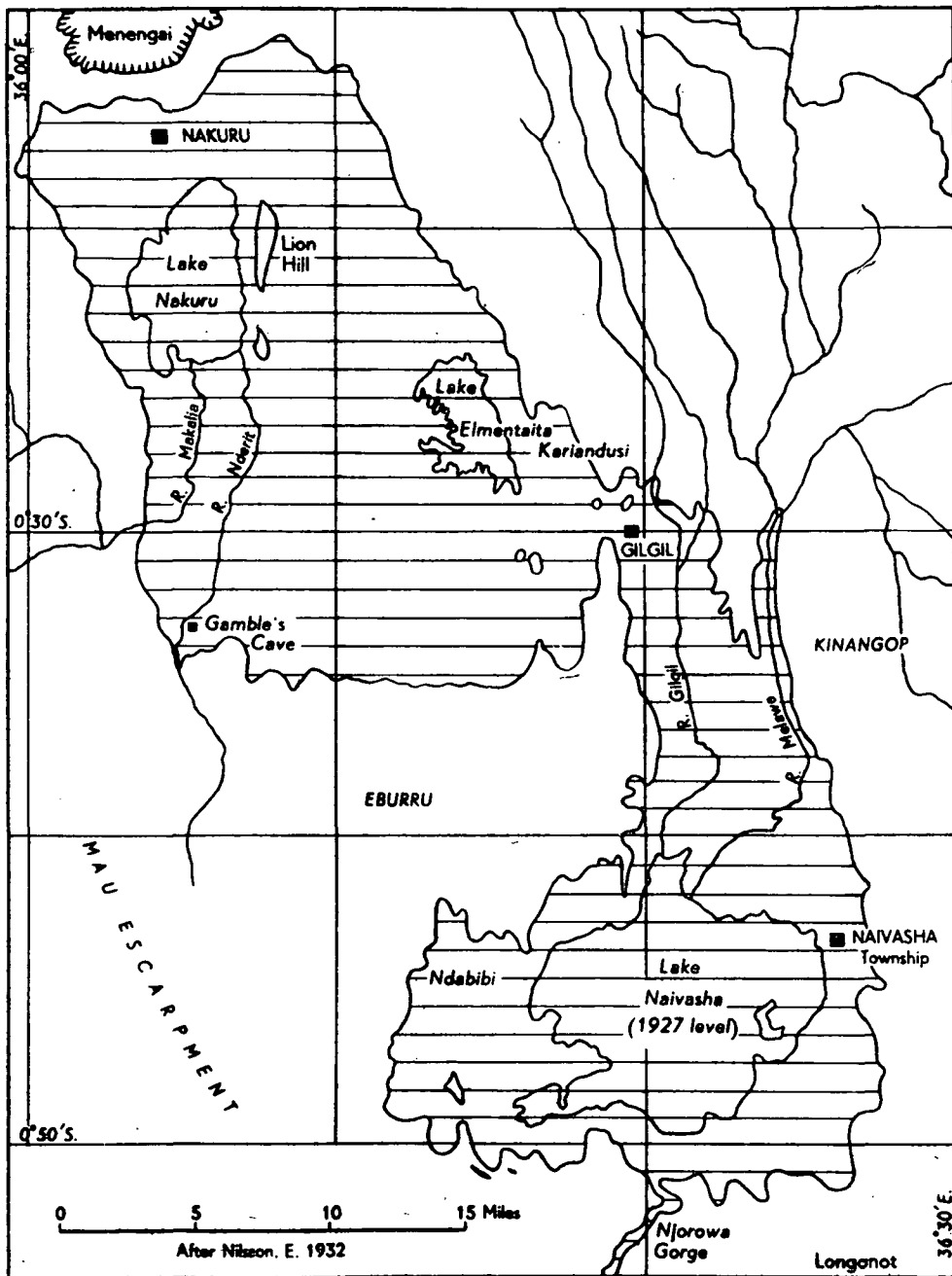


Fig. 4—The maximum extent of the Gamblian lake between Longonot and Menengai.

about 400 ft. (122 m.) and 720 ft. (220 m.) higher than at present. The subsequent maxima were lower; the different Gamblian lake levels are tabulated below (Cole, 1954, p. 45) (*see also p. 15*):—

Maximum	HEIGHTS IN FEET ABOVE PRESENT-DAY LAKE LEVELS	
	Lake Nakuru— Elmenteita basin	Lake Naivasha basin
Gamblian III	375	180
Gamblian II	510	200
Gamblian I	720	400

The Gamblian lake deposits in addition to clays, silts and a few bands of diatomite contain a large proportion of recognisable volcanic material in the form of ashes. The diatomite deposits are not so thick nor so extensive as those in the Kanjeran beds. The sediments are comparatively undisturbed by faulting, but it has been stated that they have been tilted (Nilsson 1932, p. 50 *et seq.*). During the course of the present survey nowhere were the Gamblian deposits seen to exceed 100 ft. in thickness nor were any lavas found intercalated in them.

During Gamblian times the Njorowa Gorge was initiated. It is believed that when the Gamblian I lake was at its maximum height subsurface drainage through the rocks at the south end of Lake Naivasha began and "foundation scouring" took place. The lake deposits began to subside and fracture causing the comendite to subside also. It is unlikely that the lake actually overflowed when the Gamblian I phase was at its maximum, because if it had done so erosion would have been excessive as the southern end of the gorge is about 1,200 ft. (366 m.) lower than the Gamblian I maximum lake level, and there would have been no Gamblian II and Gamblian III lakes. Thus there appears to have been overflow down the gorge during the decline of the Gamblian I lake, down-cutting continuing to a base-level at about the 6,370-foot contour. This was sufficient to expose the obsidian skin at the base of the comendite near Fischer's Tower at the northern end of the Njorowa Gorge, from which Stone Age man hewed blocks for the making of his obsidian implements. Apparently the level of the Gamblian I lake dropped more rapidly than the down-cutting, for it was halted at this level at the northern end of the gorge. During the retreat of the Gamblian I lake the deposition of further pyroclastics probably developed a barrier across the pristine Njorowa Gorge, for a terrace was cut inside the gorge at a height of 6,380 ft. (J. D. Solomon in Leakey, 1931, p. 259). Subsurface drainage no doubt continued after the maturation of the gorge and it is probably continuing at the present time. Seepages and springs issuing at the head of the watercourse below the water tank near the northern end of the gorge is approximately at the same level as the present-day Lake Naivasha, that is, just below 6,200 ft. O.D.

A small scarp about 4 ft. high in the Gamblian lake beds on Ndabibi may be evidence of late or post-Gamblian movement, though it may possibly be due to shrinkage of the sediments subsequent to the recession of the lake in post-Gamblian times. In exposures along the Melawa river, small faults with only a few feet vertical displacement can be seen in Gamblian beds.

(5) HOLOCENE DEPOSITS

It cannot be definitely stated when the later Longonot extravasations commenced, but it is provisionally suggested that the present-day Longonot cone began to grow after the Gamblian pluvial period and probably before the Makalian wet phase of Holocene times. The growth of the cone has continued, however, until historic times, and it is believed that one of the lava flows was erupted within the last hundred years.

The lava flows are trachytes and have been liberally sprinkled with pumiceous ashes. The intermediate phase of the vulcanicity of the younger Longonot appears to have been one in which many pyroclastics were ejected. The highest point on the crater rim (9,110 ft., approximately 2,780 m.), is composed of white ash and pumice. At a late stage in this phase of activity a parasitic ash-cone grew on the north-western slopes of the mountain. The final phase was the eruption of more trachytic lavas both on the north-western and south-western slopes. Both these recent flows are highly scoriaceous jagged ("aa") types, and are the lavas which are believed to have been erupted in historic times.

Other eruptions in Holocene times include the basalt flows (numbered II and III on the map) in the Badlands. These flows must have been poured out in post-Makalian times for they are not covered by sediments, as they would have been had they been erupted in pre-Makalian times. Their sparse vegetation cover and unweathered appearance suggests that they are of unusually recent age, like the latest lavas on Longonot. Very young and scarcely eroded basaltic ash-cones have also been built up in the Badlands. They are slightly younger in age than the basalt flows, for the ashes have been sprinkled for a limited distance over the basalt flows.

From their appearance obsidian flows on Eburru, such as those of Cedar hill and the flows immediately north of it, are probably also of Holocene age. The skeletal vegetation cover and undissected nature of these obsidian flows resembles that of the youngest flows on Longonot and the Badlands basalts. The obsidian flows north of Cedar hill are fissured, but Cedar hill itself is not and probably represents an eruption along one of the north-south fissures that are so frequent in this locality. The lava composing Cedar hill is only very slightly younger than the flows to the north of it.

During Makalian times erosion of the Gamblian deposits took place along the foot of the Mau escarpment, where coarse gravels and boulders of the welded tuff can be found in the vicinity of Gamble's caves. At Nderit drift Makalian deposits, usually drab in colour, rest unconformably on an eroded surface of Gamblian sediments. It is also believed that Makalian deposits in the form of coarse gravels and silts occur in the Njorowa Gorge. These rest unconformably upon the light-coloured ashes that were sprinkled in the gorge in Gamblian times. Approximately half way down the gorge a valley infilling of very white pumice and pumiceous ashes now being rapidly removed by erosion is probably not older than the Makalian stage. Similarly, the bedded layers of pumice now being quarried south-west of Gilgil township, north-east of Longonot and at several other minor localities, are believed to be the result of fairly recent volcanism.

Further Holocene deposits accumulated in the Njorowa Gorge, as they are doing even at the present time, in the form of rudaceous and arenaceous deposits in the watercourses that cut through the pre-existing sediments. Large blocks and pebbles of pumice and comendite are most prolific on the present-day floor of the gorge.

2. Volcanic Rocks

Lithologically the volcanic rocks of the Naivasha area can be classified as follows:—

- (1) Basalts.
- (2) Tephrites.
- (3) Phonolites.
- (4) Trachytes.
- (5) Rhyolites.
- (6) Comendites.
- (7) Pyroclastics.

All are believed to be of Pleistocene or Holocene age. The various types are described in subsequent sections.

(1) BASALTS

The oldest basalt in the area, which underlies the lower Kinangop volcanics and lacustrine sediments in the Mahindu river gorge about five miles north-east of Morendat station, in appearance and in its place in the general succession tallies with the Kijabe basalt described by Shand (1937, p. 263) and the Mbaruk basalt described by McCall (1955, p. 7). It is a highly porphyritic basalt completely different from any of the younger basalts. It contains abundant stout, waxy-looking plagioclase plates up to half an inch long, set in a fine bluish black groundmass. On weathered surfaces the plagioclase crystals, which account for about thirty per cent of the total rock composition, are particularly conspicuous as they stand out in relief. In a thin section of specimen 43/390 stout zoned labradorite crystals are surrounded by a fine-grained groundmass containing granular iron ore, plagioclase prisms and much-altered pyroxenes (?).

Nearly all the younger basalts are vesicular. They vary from finely porous rocks with pore space comparable in appearance with rubber sponges, to scoriaceous and coarsely vesicular lavas with vesicles up to an inch in diameter. The fine-textured basalts that form cones near the southern end of the Njorowa Gorge are usually purplish, maroon or reddish brown, finely porous but extremely tough rocks, containing few small plagioclase phenocrysts. The reddish colour is due to erosional oxidation hastened by the large surface areas of these porous rocks. As a rule, the coarse-textured basalts from that area are less prone to weathering and retain a typical bluish grey colour. Specimen 43/458, a porous basalt from that area, is composed of a fine-grained groundmass of small interlocking plagioclase prisms and minute specks of iron ore, together with abundant medium-sized plagioclases and augites as well as larger labradorite and augite phenocrysts. The bigger augite prisms exhibit curious eutectic intergrowth structures, while some of the larger plagioclase crystals are crowded with minute inclusions, variably along their margins and at their centres.

On the western banks of Lake Naivasha a few small lava flows are composed of much more compact bluish grey, slightly vesicular basalt with fairly abundant but small plagioclase phenocrysts. Texturally-similar basalt forms an isolated outcrop in the Kinangop escarpment above Pardoe and Schuster's farm. Here the basalt does not appear to be interbedded with the local mid-Pleistocene sediments and pyroclastics, but is probably a much later extrusion along a fault-line. Specimen 45/382 of this rock consists of a fine-grained groundmass composed of plagioclase, iron ore and pyroxene with idiomorphic phenocrysts of olivine, partly replaced by bowlingite, labradorite, augite, some of which is partly uralitized, and magnetite. Unusual biotite, dichroic from reddish brown to almost colourless, and a light green chlorite are minor constituents. The basalt that forms a few isolated flows north of Longonot is much more coarse-grained and non-porphyritic. The chief difference in composition of this basalt from the other basalts of this group is the presence of abundant purplish titaniferous augite prisms.

C. Arambourg (1935, p. 41) described a specimen of oceanite from agglomerates on Crescent island. The lava underlies the agglomerate which forms the greater portion of the walls of that crater. Arambourg compared the rock with the oceanite of Réunion in which the dominant ferromagnesian mineral is olivine. In the Crescent island oceanite, large clear olivine phenocrysts are abundantly scattered in a fine-grained matrix of augite and basic plagioclase.

The following is a chemical analysis of this lava (Arambourg, *loc. cit.*):—

			%						
SiO ₂	..	..	40.70				Norm		%
Al ₂ O ₃	..	..	3.90				Or	..	2.78
Fe ₂ O ₃	..	..	4.97				Ab	..	3.14
FeO	..	..	14.63				An	..	7.51
MgO	..	..	30.78				Ne	..	—
CaO	..	..	3.14				CaSiO ₃	..	3.36
Na ₂ O	..	..	0.36				MgSiO ₃	..	10.60
K ₂ O	..	..	0.51				FeSiO ₃	..	3.04
H ₂ O+	..	..	0.10				Mg ₂ SiO ₄	..	46.41
H ₂ O—	..	..	0.10				Fe ₂ SiO ₄	..	13.97
TiO ₂	..	..	1.14				Mt	..	7.19
P ₂ O ₅	..	..	trace				Ilm	..	2.13
MnO	..	..	0.17				An %	..	71
Cr ₂ O ₃	..	..	0.10				Σb	..	86.7
NiO	..	..	0.10						
			100.50						

The basalts that constitute the Badlands lava-flows are bluish grey, often porphyritic and highly vesicular rocks. The vesicles are large, often greatly lengthened, and some contain amygdaloidal infillings. Texturally these lavas vary from fine-grained types along the margins of the flows to coarser-grained types in the centres of flows where cooling was less rapid. There is, however, little variation in composition between the three lava flows that comprise the Badlands basalts. They are composed of a groundmass of iron ore, plagioclase and pyroxene, in which augite and olivine, phenocrysts are nearly always present. In specimen 43/492, a fine-grained highly vesicular basalt from a flow in the Badlands, zeolite infilling vesicles is unusually massive and exhibits well-defined cleavage. Its refractive indices were determined approximately as α 1.522, β 1.523, γ 1.525, suggesting that it is thompsonite, though in thin section an optically negative zeolite was also found. Specimen 43/535 from a basaltic dyke in the Karterit crater, described by McCall (1955, Fig. 5 at p. 17) as vitrophyric basalt, differs only in detail from the nearby Badlands basalt. It contains abundant, mostly untwinned plagioclase phenocrysts in place of the more common predominance of olivine and augite.

(2) TEPHRITES

West of Lake Naivasha, a few small volcanic plugs project through the Gamblian lake beds on the Ndabibi plains. These cones are apparently unrelated to any other volcanism in the area but since they are older than the surrounding Gamblian sediments, are believed to be of at least post-middle Pleistocene age, and probably extruded during the third Interpluvial in Upper Pleistocene times.

In the hand-specimen the lavas of these plugs are fine-grained bluish grey with sparsely distributed amygdaloidal vesicles. Examination of a thin section of specimen 43/428 from the Ndabibi plains revealed a fine-grained mesh composed of pyroxene, and infilled by felspar and feldspathoid. The pyroxene is augite and occurs as small granules and prisms. The natures of the felspar and feldspathoid are difficult to assess, but it is probable that the felspar prisms are medium plagioclase. The feldspathoid, which is isotropic or possibly pseudo-isotropic, can be recognized as irregular grains against which the plagioclase stands out in higher relief. An attempt to stain the feldspathoid proved valueless, possibly because of the fine texture of the rock. The stained slide took on an overall bluish colour which under a high power lens proved to be an accumulation of the dye, both interstitially and in cleavages. The pyroxene crystals seemed particularly prone to absorb the dye.

(3) PHONOLITES

The phonolites occur as upper Pleistocene lava flows north, east and south of Eburru at two horizons. The higher phonolites overlie the acid rocks at Eburru, but two flows are partly covered by comendite flows at the base of the mountain. No evidence of still older phonolites was found as boulders or blocks of included rock in the middle Pleistocene sediments or agglomerates.

Despite the slightness of difference between the phonolites and trachytes with regard to the proportions of light and dark minerals present, most of the phonolites are totally unlike the trachytes in appearance. They are tough dark bluish black to greenish fine-grained rocks, often not unlike fine-grained basalts in general appearance. In thin sections of typical phonolites, for example specimens 43/395, 43/399, 43/406 and 43/508 from the slopes of Eburru and from flows to the east, the fine-grained greenish groundmass is composed of pyroxene, feldspar, nepheline and sodic amphibolites. Insets of feldspar slightly longer than the usual in the matrix, are aligned in subparallel arrangement. The pyroxenes of the groundmass are small bright green, pleochroic, acicular prisms and are believed to be aegirine. The feldspars are soda-orthoclase and anorthoclase. Nepheline occurs as fine granules, sometimes in aggregate form, and its recognition is usually difficult. As an aid to the discovery of nepheline the value of staining colloidal silica derived from it following treatment with syrupy phosphoric acid is often doubtful. The dye tends to collect around edges and in cleavages of crystals and is liable to stain all zeolitic material. In some cases, however, staining proved to be reasonably successful. Amphiboles in the groundmass are nearly opaque cossyrite and mauvish red kataphorite. Phenocrysts of feldspar, pyroxene, amphibole and sometimes magnetite are present in some of the phonolites. What appears to be greenish yellow nepheline phenocrysts are sometimes visible in the hand-specimen but no nepheline grains of that size were recognised in thin section. The feldspar phenocrysts include both carlsbad twinned soda-orthoclase and anorthoclase. Idiomorphic aegirine-augite and cossyrite phenocrysts occur in most of the phonolites.

(4) TRACHYTES

Trachytes are found in most parts of the Naivasha area, occurring in both the Kinangop and Mau escarpment successions, as valley floor lava flows, and in the more recent volcanic series of Longonot. They range in age from Kamasian (middle Pleistocene), which is represented by the trachytes interbedded with the middle Pleistocene sediments in the Kinangop escarpment, to the Recent Longonot lavas.

Prior (1903, p. 241), Gregory (1921, p. 394), Sikes (1939, p. 17) and McCall (1955, p. 7) have adopted the term "phonolitic trachyte" to describe the sodic trachytes which occur in the Naivasha and other areas. The writers agree with Shand (1937, p. 263), who considered the term phonolitic inappropriate to rocks free of feldspathoid. In this report the term trachyte includes only the intermediate lavas free of detectable feldspathoid.

The trachytes, interbedded with the supposed Kamasian lacustrine-deposited pyroclastics in the Kinangop escarpment, are typically grey, medium to coarse-grained trachytic-textured porphyritic lavas. Weathering alters the characteristic grey colour to lighter shades of greenish grey and in more advanced stages of alteration iron oxides stain either the phenocrysts alone, or the rocks as a whole, to a pale shade of maroon. Weathering frequently accentuates a fissility not apparent in fresh specimens. In thin sections of specimens such as 43/319 from the Naivasha-South Kinangop road near Marshall's stream, the textures include both well-defined flow and haphazard (bostonitic) patterns. The felsic constituents of the groundmasses consist of medium-sized potash feldspar prisms, which often outline well-defined flow curving around the phenocrysts. Rarely the prisms are arranged in spherulitic fashion. Dark minerals account for an appreciable proportion of the groundmasses, consisting

mainly of the sodic amphibolites aegirine, kataphorite and cossyrite. The aegirine occurs as small bluish green interstitial crystals, the kataphorite being similar in shape but distinguishable by its highly distinctive pleochroism—X yellow brown, Y dark reddish brown, Z reddish yellow. The cossyrite is present as nearly opaque velvety black grains, though in some pleochroism from light to dark chestnut brown is perceptible along the margins. The phenocrysts are variable-sized green pyroxenes of aegirine-augite composition, magnetite and feldspars, the feldspars being usually sodic orthoclase often with Carlsbad twins, or less commonly anorthoclase. The anorthoclase rarely shows faint cross-hatch twinning. Clear orthoclase (sanidine) phenocrysts are comparatively rare. Many of the feldspar phenocrysts have peripheral bands of minute inclusions and in some specimens, such as 43/310 from south of the Karati river, their margins show marked resorption corrosion. Accessory minerals are zircon and apatite.

Campbell Smith (1931, p. 225) described a kataphorite trachyte from the scarp to the east of Lake Naivasha, on the Kinangop road. The following is the chemical analysis and norm accompanying the description:—

			%				
SiO ₂	..	..	60.74	Norm			%
Al ₂ O ₃	..	..	15.58				
Fe ₂ O ₃	..	..	3.66	Q	..	..	3
FeO	..	..	3.55	or	..	..	27.24
MgO	..	..	0.38	ab	..	..	54.18
CaO	..	..	0.97	ac	..	..	1.15
Na ₂ O	..	..	6.59	di	..	..	3.56
K ₂ O	..	..	4.68	hy	..	..	0.99
H ₂ O + (+110°)	..	..	1.20	mt	..	..	4.64
H ₂ O - (-110°)	..	..	1.21	il ..	..	..	1.98
TiO ₂	..	..	1.05	ap	..	..	0.07
P ₂ O ₅	..	..	0.07	z ..	..	..	0.27
MnO	..	..	0.26				
			100.18*				
Sp. gr.	..	..	2.632				

Analyst—M. H. Hey.

*Including Cl 0.006, FeS₂ 0.08, (Ce, Y)₂O₃ 0.054, ZrO₂ 0.19; less O-equivalent of Cl' and FeS₂ 0.017; F', S'', SO₃, NiO, BaO, SrO absent; CO₂ trace.

These old trachytes frequently appear as fragments in the younger agglomerates, as for example in specimen 43/533, an agglomerate from the Nairage Ngare area on the Mau escarpment. Specimen 43/453, an inclusion in an agglomerate exposed at the southern end of the Njorowa Gorge, is a trachyandesite. In addition to potash feldspars it contains sodic plagioclase feldspars as small phenocrysts and as prisms in the groundmass.

Younger trachytes are exposed in the vicinity of Gilgil township, and in a few flows south of Lake Naivasha. Generally these trachytes are finer-grained than the older trachytes and while generally similar in composition are more sodic. Specimen 43/363 collected from an upfaulted trachyte ridge alongside the main road about ten miles north of Naivasha township is an example. A trachyte from the Langalanga area east of Gilgil is a coarser-grained type (specimen 43/515) and contains abundant riebeckite and dark reddish cossyrite in its matrix.

Some of the youngest trachytes are the lavas, which, together with ashes and tuffs, make up the impressive volcanic mountain Longonot, which consists of a large number of lava flows that form terrace-like steps down the cone sides. In addition to the lava flows there are ashes and ill-consolidated ashy tuffs. There are no exact indications dating the commencement of volcanic activity of Longonot, but there is evidence that the last volcanic phase took place very recently. Dr. L. S. B. Leakey, curator of the Coryndon Museum, Nairobi, informed the writers that as a young man he spoke to an old Masai tribesman who claimed to have witnessed volcanic activity in Longonot. It is thus possible that Longonot erupted in some form or another during the last hundred and twenty years (Plate 1 (a)).

The youngest Longonot trachytes are fine-grained, often highly vesicular and, with few exceptions, non-porphyritic. A certain amount of trachytic glass occurs in the flows on the eastern slopes. The best example of a porphyritic type among them is specimen 43/384, from a lava which flowed down a valley on the south-western slopes of the mountain. Apart from the porphyritic texture, however, there is no difference between this and the other Longonot trachytes, which are typified by specimens 43/379 and 43/411, from the southern and south-eastern slopes of the cone respectively. In composition the Longonot trachytes are similar to the older trachytes of the area, but are more fine-grained than both the Kinangop trachytes and the Rift floor trachytes. Specimen 43/357, collected from the crater floor below the eastern edge of the crater rim, reveals in thin section a compact fine-grained texture with, in addition to the trachytic mineral assemblage considered typical of the older trachytes, an abundance of the soda-amphibole riebeckite.

(5) RHYOLITES

Most of the non-comenditic rhyolite extrusions of the present area are confined to an irregular area which curves around the south-western shores of Lake Naivasha. Other rhyolite craters and plugs are scattered along a line roughly parallel with the Njorowa Gorge. The rhyolites are younger than the comendites and may represent a later phase of vulcanism involving a common parent magma. Some, in fact, have compositions approaching those of the comendites, and it would be difficult to draw a hard and fast line between the two types. Much of the pumice in the area is probably of normal rhyolitic composition, and it is known that some of the most recent phases of vulcanicity have been pumice ejection.

In the hand-specimen the typical rhyolites are whitish, pinkish or pale grey felsitic to porphyritic rocks, usually containing visible quartz. The pumiceous rhyolites are spongy, highly porous whitish to dirty grey rocks, usually able to float on water for a limited period. There are textural gradations from compact rhyolites to pumice. Obsidian of common rhyolitic composition is rare in the area and only a few instances of obsidian interbedded with or capping rhyolite flows were recorded.

In thin section the rhyolites are found to consist typically of a medium to coarse granular-textured quartzo-felspathic groundmass with quartz, orthoclase and less commonly, anorthoclase phenocrysts. Accessory minerals are magnetite, often in euhedral octahedra, and amphiboles, usually with a tendency towards a sodic composition. Specimen 43/430 from the Ndabibi estate, south-west of Lake Naivasha and specimen 43/440, a boulder from sediments in the Njorowa Gorge, are typical porphyritic rhyolites of different textures. In thin section specimen 43/430, the finer-grained of the two, the groundmass exhibits both flow structure and rapid crystallization patterns, akin to orbicular structures. The coarser-grained example has a simple unorientated granular groundmass. North of Orgaria, a plug of pumiceous rhyolite forms a small but prominent feature, and is interesting in that steam issues from fissures in it. The steam-jet is probably youthful as it has apparently caused little decay of the rock. Texturally the rock (43/448) is midway between rhyolite

and pumice, being a pale greenish grey finely porous rock with a slight pearly lustre. In thin section it is seen to be hyaline but includes a high proportion of pore space, originally occupied by gases. The pores are usually oval but some have drawn out tubular shapes.

Some of the rhyolites are spherulitic and are similar to the spherulitic comendites in colour, general field appearance, texture and composition. Specimens 43/432 and 43/434 are of this type and, as they occur within the rhyolite zone south-west of Lake Naivasha, are presumed to be of rhyolite composition. They are slightly lighter coloured than the texturally similar comendites.

(6) COMENDITES

The sodic rhyolites of the Naivasha area have been variously described as comendites, pantellerites, quartz soda-trachytes and simply soda-rhyolites. The terms comendite and pantellerite are derived from the localities Comende in San Pietro island, south of Sicily, and the island of Pantellaria. Johannsen (1941, p. 64) has described comendites as "porphyritic rocks . . . which contain phenocrysts of quartz, alkali-felspar and aegirite, arfvedsonite, or riebeckite, or less commonly biotite, in a grey, bluish, or yellowish microgranitic or granophyric groundmass of quartz and alkali-feldspars. The colour is usually very light." He described pantellerites as "generally green to almost black . . . they are porphyritic with phenocrysts of aegirite-augite or diopside, anorthoclase, and cosyrite. . . ." He concluded that there is little difference between the two rock types. Sodic rhyolites from the present area were described by Prior (1903, p. 242) as riebeckite-rhyolites (comendites). Despite the fact that most of the sodic rhyolites in the Naivasha area are roughly divisible into dark- and light-coloured types, a division that might allow their description as pantellerites and comendites according to Johannsen's definitions, the writers consider that subdivision is undesirable as there is a large number of intermediate-coloured sodic rhyolites, and in some flows both types merge into each other. For the purposes of this report the term comendite is adopted to describe rhyolites sufficiently sodic to contain either or both soda-amphiboles and soda-pyroxenes.

The comendites are fairly evenly distributed throughout the central portion of the area, the most important exposures being the imposing lava flows at the northern entrance to the Njorowa Gorge (Plate II (a); Fig. 5). These columnar-jointed flows are as much as 350 ft. thick and form steep cliffs often capped by a skin of black obsidian, presumably of the same composition. Scenically some of the most impressive features of the Njorowa Gorge are two comendite lava plugs known respectively as Fischer's Tower (Plate II (b)) and The Horse or *El Barta*, the original Masai name. Fischer's Tower is roughly conical, terminating in a point, while *El Barta* is cylindrical with a blunt rounded crest. Towards the centre of the gorge other comendite plugs, similar in shape to *El Barta*, project from the floor (see Fig. 6). North of Lake Naivasha several comendite flows form prominent features, such as the southern portion of the Waterloo Ridge and part of the Eburru volcanics.

In the hand-specimen, the comendites vary from dark-coloured fine-grained or in extreme cases glassy types, to paler, coarse-grained lavas. The fine-grained varieties are often finely banded, usually dark greenish grey rocks consisting of alternating yellowish green and dark grey layers between one twentieth and a quarter of an inch in thickness. The coarse-grained comendites are usually pale bluish or greenish grey banded rocks, the individual bands being up to an inch across. Sometimes the ferromagnesian minerals are evenly distributed, producing a speckled effect which gives the rock a superficial resemblance to acid granulites typical of the Basement System of Kenya.

In thin section the comendites vary from hyaline and hemi-crystalline to micro-granular and paisanitic types. Blotchy or eutaxitic texture, frequently apparent in the hand-specimen, is not always detectable in thin section.

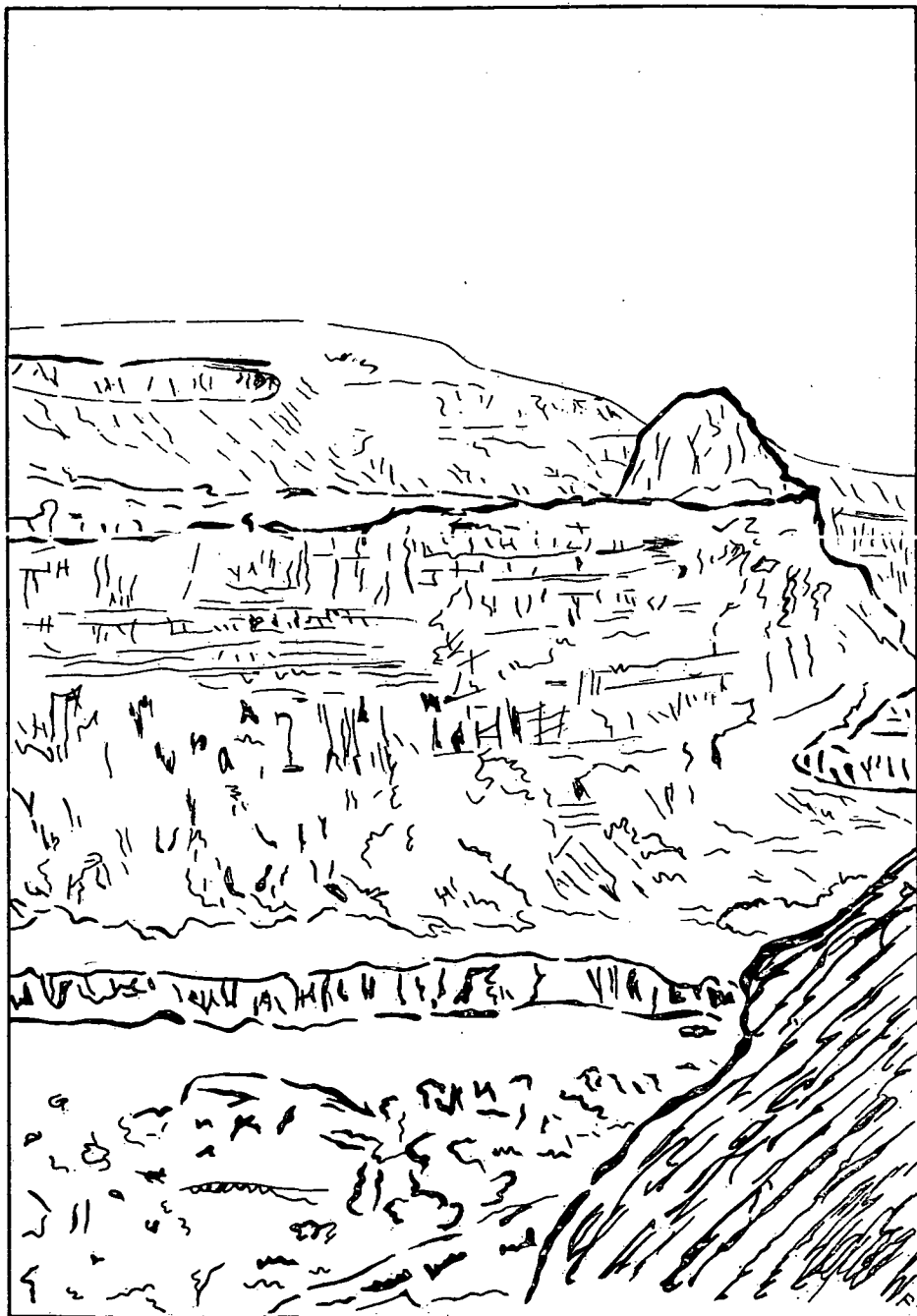


Fig. 5—The Njorowa Gorge.—Kamasian lake-beds constitute the greater part of the cliffs in the gorge. A flow of comendite forms a small ash-covered scarp along the skyline in the view shown in the illustration. An intrusive plug of comendite forms the conical mass, and the edge of a comendite sill occurs on the right. Holocene erosion of the previously partly-filled gorge has exposed white Makalian ashes at the base of the Kamasian cliffs. (Drawn from a colour photograph by A. O. Thompson.)

Thin sections of two examples of hemi-crystalline material were prepared. Specimen 43/503 from the northern slopes of Eburru is almost completely devitrified, consisting of an indistinct quartzo-felspathic mosaic with fine in-set needles of cosyrite, and aegirine-augite, with euhedral to subhedral grains of anorthoclase and quartz set in pale green isotropic glass. Most of the quartz grains exhibit a certain amount of resorption. Specimen 43/455 from the southern end of Njorowa Gorge is far more vitreous. Fine inset needles of amphibole form well-defined flow textures curving around large euhedral phenocrysts.

Specimen 43/364, which outcrops near the Gilgil river, is typical of the fine-grained comendites. In thin section it is seen to have a fine even-grained granular texture composed of potash feldspar, rare quartz and abundant riebeckite. The riebeckite occurs as granular mossy aggregates with highly characteristic pleochroism —X deep indigo blue, Y bluish green, Z greenish yellow. Rarely it forms irregular phenocrysts about half a millimeter in length. Alteration of the amphibole leaves skeletal structures of iron oxide. The coarser-grained comendites such as the Fischer's Tower rock, specimen 43/436, and specimen 43/462 from a nearby flow in the Njorowa Gorge, are of similar texture but tend to be more porphyritic and usually include more free quartz. The phenocrysts are usually quartz and anorthoclase feldspar, and rarely riebeckite. In addition to riebeckite, specimen 436 contains slender prisms of a soda-amphibole, pleochroic from reddish brown to greenish blue, which are probably kataphorite. A colourless mineral associated with a large grain of riebeckite is believed to be fluorite.

Texturally the most remarkable comendites are spherulitic varieties, typified by specimens 43/449 and 43/447 from northwest of Lake Naivasha. The spherulites are composed of radiating feldspar rods, sometimes inter-fingered with amphibole prisms and rarer acicular quartz. While most of the spherulites consist of a single structure, some are composed of up to three radiating layers, probably representing successive crystallization. The layers are not in optical continuity. Some of the spherulites have quartz or feldspar nuclei. In specimen 43/447 the amphibole has been altered and is now represented almost entirely by reddish brown tufts of fibrous iron oxide.

Obsidian and pumice of probable comenditic composition are most abundant south and west of Lake Naivasha. Obsidian believed to be of comenditic composition forms a considerable portion of the volcanics of the northern and north-eastern slopes of Eburru. Cedar hill is a notable example of obsidian. It is a large volcanic plug representative of one of the latest phases of vulcanicity in the Naivasha area. There is no means of distinguishing by appearance glasses of comenditic and normal rhyolitic composition, but most of the obsidian and some of the pumice is found in areas occupied by comendite, so it is considered likely that they are of comenditic composition. The glass occurs both as frozen skins covering comendite flows and as separate flows of massive obsidian sometimes interbedded with acid lavas. Rarely, obsidian is present as glassy lenses in pumiceous agglomerate-like rock.

Obsidian is a dark greenish to nearly black shiny volcanic glass formed by rapid freezing of an acid magma. Typically, it is extremely brittle and breaks with a well defined fracture. Flakes chipped off obsidian masses possess extremely sharp edges, a characteristic that made it particularly useful to primitive man for the manufacture of artifacts. Liquid or gas inclusions are rare although microlites are fairly common; in some specimens quartz and feldspar phenocrysts account for up to twenty per cent of the rock. Concentric or perlitic cracks are found in a few of the flows.

Pumice is the more common form of acid glass in the area. Like obsidian, pumice* is a glass but is so filled with bubbles originally occupied by gas that the pore space may be much greater than the solid material. The frothy nature, and ability of pumice to float temporarily in water is well known. In the hand-specimen the pumices are sponge-like, pale grey rocks shading to pink. Freshly fractured surfaces

exhibit a pearly lustre. Some of the pumice may have formed as crusts on the acid lavas, but the greater proportion of it was laid down as accumulations of ejectamenta. Passage through the air tends to smooth off sharp edges of such material so that most blocks of pumice are rounded whether laid terrestrially or subaqueously. Locally this has led to some confusion. The writers believe that a considerable proportion of the pumice beds in the Kinangop and Mau escarpment successions were laid under lacustrine conditions.

* Partial analyses of two pumices from the Naivasha area are recorded as follows:—

	1 %	2 %
SiO ₂	66.85	70.35
Al ₂ O ₃	8.05	16.53
Fe ₂ O ₃	13.71	
MgO	n.d.	tr.
CaO	n.d.	0.54
Na ₂ O	3.67	n.d.
K ₂ O (by diff.)	2.27	n.d.
H ₂ O	0.57	n.d.
Loss on ignition	4.87	4.00

n.d. = not determined.

1. 4 m. south-west of Gilgil, at mile 416/8 on the old railway line. Anal: East African Industrial Research Organization.
2. South of Lake Naivasha. Anal. Mines and Geological Dept.

N. L. Bowen (1935, 1937) carried out detailed examinations of specimens of obsidian from Eburru, the southern shores of Lake Naivasha and the Njorowa Gorge. He recorded the presence of a rare monoclinic iron silicate mineral, clinoferrrosilite, as minute colourless to pale amber-coloured needles in lithophysae, or hollow spherulites, in the obsidian from south of Lake Naivasha. Other uncommon minerals in the obsidian observed by Bowen were anorthoclase, cristobalite, and fayalite.

The following analyses quoted by Bowen, Prior (1903) and Campbell Smith (1931) are of obsidian and comendite specimens from the Naivasha area:—

	1 %	2 %	3 %	4 %	5 %	6 %
SiO ₂	75.55	70.36	75.03	73.96	70.61	73.30
Al ₂ O ₃	12.31	9.63	11.10	11.40	8.59	11.56
Fe ₂ O ₃	0.69	1.72	1.31	1.65	2.52	1.68
FeO	1.17	5.42	1.84	1.95	5.96	2.41
MgO	0.04	0.06	—	0.03	0.07	0.24
CaO	0.23	0.30	—	—	0.61	0.78
Na ₂ O	4.55	6.73	5.09	5.41	6.77	4.84
K ₂ O	4.69	4.43	4.56	4.36	4.46	3.96
H ₂ O+	0.15	0.10	0.08	0.13	—	0.40
H ₂ O-	—	0.01	0.01	0.02	0.10	0.30
TiO ₂	0.13	0.33	0.19	0.17	0.15	0.33
P ₂ O ₅	0.01	0.03	trace	trace	—	0.03
Cl	0.21	0.40	0.27	0.41	—	—
F	0.28	0.17	0.42	0.68	—	—
MnO	0.04	0.25	0.06	0.05	0.34	—
S	0.01	0.02	0.01	0.01	—	—
	100.06	99.96	99.97	100.23	100.18	99.83
R.I.	1.488	1.514	1.495	1.495	—	—
S.G.	—	—	—	—	2.47	—

NORMS

	1 %	2 %	3 %	4 %	5 %	6 %
Q	32.7	26.6	32.5	33.1	27.12	27.23
or	27.8	26.1	27.2	26.1	26.69	23.35
ab	35.1	24.6	31.4	33.5	18.86	37.20
C	0.04	—	—	—	—	—
ac	—	5.1	3.7	—	7.39	3.23
ns	—	5.6	—	—	7.08	—
di	—	0.2	—	—	2.70	3.20
hy	1.4	9.7	2.9	2.1	9.97	2.33
mt	0.9	—	—	2.3	—	0.80
il	0.3	0.6	0.5	0.3	0.3	0.61
ap	—	—	—	—	—	0.09
CaF ₂	0.3	0.4	—	—	—	—
nl	0.4	0.6	0.5	0.7	—	—
NaF	0.3	—	0.8	1.4	—	—

1. Rhyolite obsidian, fayalite-bearing. South shore of Lake Naivasha. A. Williams, analyst; F by E. S. Shepherd (Bowen, 1937, p. 14)
2. Soda-rhyolite obsidian, Eburru. A. Williams, analyst; F by E. S. Shepherd (Brown, 1937, p. 14)
3. Comendite obsidian. Top of flow, north portal, Njorowa Gorge. A. Williams, analyst; F by E. S. Shepherd (Bowen, 1937, p. 14)
4. Rhyolite obsidian (comendite), southern shore of Lake Naivasha. S. Goldich, analyst; F by E. S. Shepherd (Bowen, 1937, p. 14)
5. Obsidian from Lake Naivasha area. G. T. Prior, analyst (Prior, 1903, p. 247)
6. Comendite. "El Barta", Njorowa Gorge. W. H. Herdsman, analyst. (Campbell Smith, 1931, p. 319).

(7) PYROCLASTICS

Ashes, agglomerates and tuffs make up a considerable proportion of the volcanics in the Naivasha area. The volcanic succession is best exposed on the slopes of the opposing shoulders of the Rift Valley, namely on the Kinangop and Mau escarpments, but while the volcanics on the Kinangop escarpment include a few bands of lava, the Mau escarpment is composed almost entirely of pyroclastic material. Indurated bands in the pyroclastics—chiefly yellow to buff-coloured agglomerates—tend to form ledges in the fault-line scarps, and often weather in much the same way as the intercalated lava flows. Even their joints are similar, with the result that every such horizon had to be confirmed during the survey. The welded tuff which forms the boundary between the Kamasian and Kanjeran deposits in the eastern rift wall in the Naivasha area is a very characteristic marker horizon in the Kinangop plateau. There are also small occurrences of the welded tuff on the top of the down-faulted blocks to the west of the Kinangop scarp. The greater portion of the Kanjeran deposits overlying the welded tuff has been eroded away on these down-faulted blocks.

It is noteworthy that around most of the volcanics or vents that have ejected ashes, the heaviest accumulations occur on the western sides of the craters. This, it is believed, was caused by prevailing easterly winds during the eruptions. Large areas of the Rift Valley floor are covered by ashes and many ravines or valleys, such as the Njorowa Gorge, reveal successions of bedded volcanic material which has often been laid subaqueously. The fact that a great proportion of the pyroclastic material was laid subaqueously in the Kamasian, Kanjeran and Gamblian lakes has led to confusion in their classification. An example of this is the banded sequence which makes up the Njorowa Gorge succession. The material forming the beds is obviously of volcanic origin but the presence of rounded pebbles and boulders, and

ferricrete nodules in some bands indicate sedimentary conditions. Some of the volcanic cones around the western shores of Lake Naivasha, such as the well-known Crater Lake, are composed of agglomerate.

The oldest pyroclastics in the area are exposed in the Mahindu river gorge where they overlie the Kijabe-type basalt. The succession is as follows:—

	<i>Approximate thickness (feet)</i>
10. Soils	
9. Grey agglomerate	50
8. Fine, buff-coloured ash	15
7. Massive grey agglomerate	60
6. Coarse pumiceous agglomerate	30
5. Fine-grained mauve to reddish-stained trachyte ..	20
4. Coarse-grained yellow agglomerate with included black scoriaceous material	10
3. Brick-red ashes and tuffs	20
2. Coarse grey agglomerate	100
1. Porphyritic Kijabe-type basalt	30

Overlying the Mahindu succession is a series of Kamasian lacustrine sediments that includes pebble-beds, gravelly layers and some clayey horizons which may contain diatoms not easily recognised, but in other respects shows marked similarity to the underlying pyroclastics. In the Turasha valley on the Kinangop plateau a succession of the Kamasian sediments is exposed and is tabulated below:—

		<i>Approximate thickness (feet)</i>
	16. Grey soils	
Kanjeran	15. Grey agglomerate	30
	14. Welded tuff	5
	13. Yellow to buff-coloured tuff	50
	12. Grey pumiceous agglomerate	30
	11. Narrow band of brownish pumi- ceous agglomerate	2
	10. Grey tuff	9
	9. Grey agglomeratic ash	8
Kamasian ..	8. Grey agglomerate with included black scoriaceous fragments	18
	7. Fine grey ash	4
	6. Buff-coloured massive agglomerate	20
	5. Light grey ashes	6
	4. Buff-coloured agglomerate with black scoriaceous inclusions	35
	3. Maroon to greyish tuff	20
	2. Grey slightly porphyritic trachyte	15
	1. Coarse grey agglomerate	—

With the possible exception of the Mt. Longonot volcanic formation the most recent pyroclastics are of more acid composition. North of Longonot station a variety of recent pyroclastics, some heavily faulted (Fig. 6) are exposed in pits and gully fans.

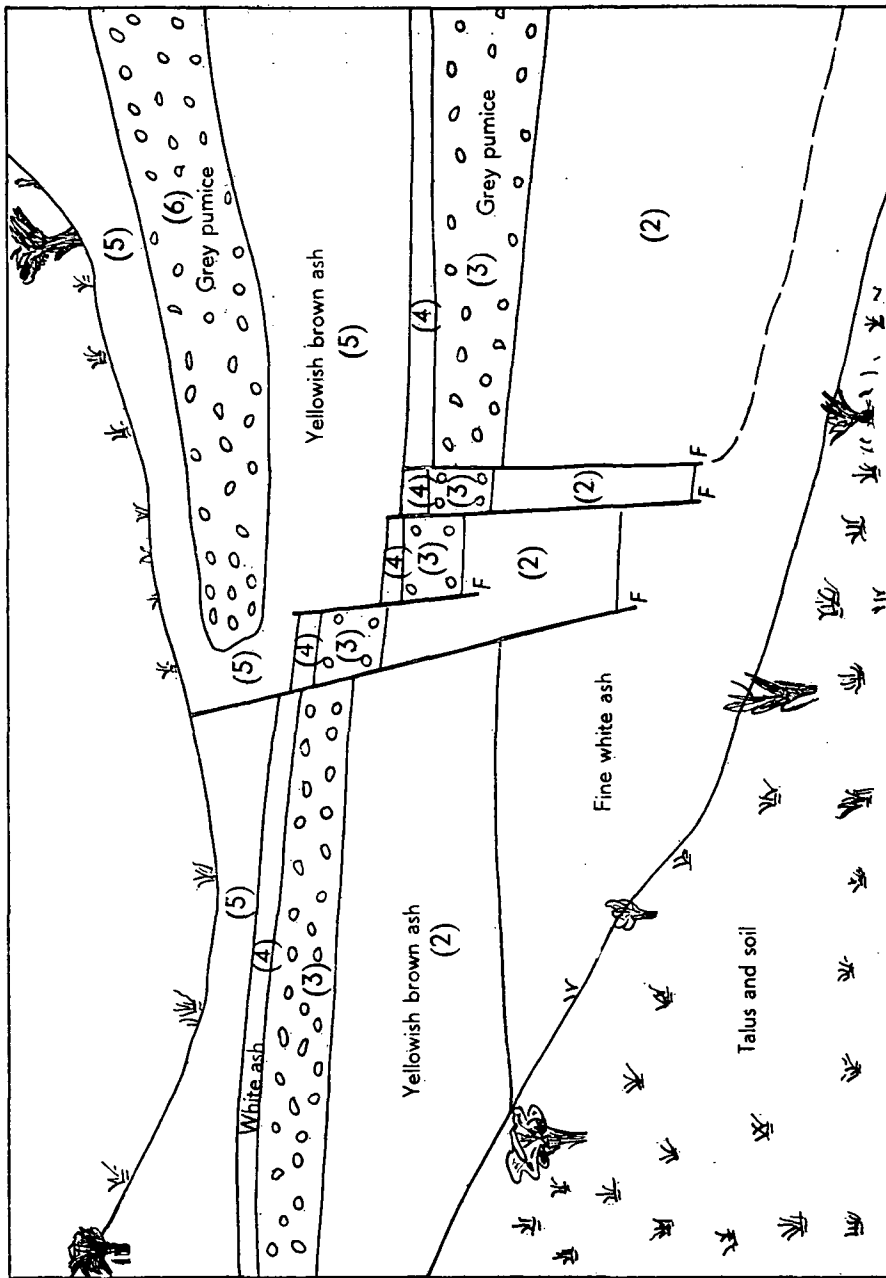


Fig. 6—Faults in pyroclastics, north of Longonot station. The gully face is about 15 feet high.
(Drawn from a colour photograph by A. O. Thompson.)

The following is one of the successions seen in that area:—

	<i>Thickness to nearest 6 inches</i>
	<i>ft. in.</i>
Pumice ash in yellowish soil	1
Drab-coloured soil with pumice fragments	1 6
Coarse light grey pumice	2
Pumice, mainly in powdery form	1 6
Yellow pumice	2
Dark grey pumice	3
Light grey pumice and fine ashes	4 6
Coarsely fragmented grey pumice beds	3
Yellowish ashes with pumice fragments at the base ..	3 6
Light grey pumice	2 6
Orange-coloured ashes	4
Whitish grey pumiceous ash with coarser pumice blocks	9
Band of lava blocks included in pumiceous ash ..	2
Pumiceous ash (base)	

The ashes are usually interbedded with other volcanics, when they form lenses, layers or discontinuous wedge-shaped bands. They are usually fine-grained and powdery although they are often more or less consolidated. In colour they vary from the more common grey and greenish to dark brownish and rarely, brick-red, while some of the ashes of Mount Longonot are buff, or pinkish white. Most of the ashes contain angular pyroclastic fragments, sometimes up to half an inch in diameter. Being particularly prone to erosion, the older ashes are only preserved if covered by more compact volcanic material.

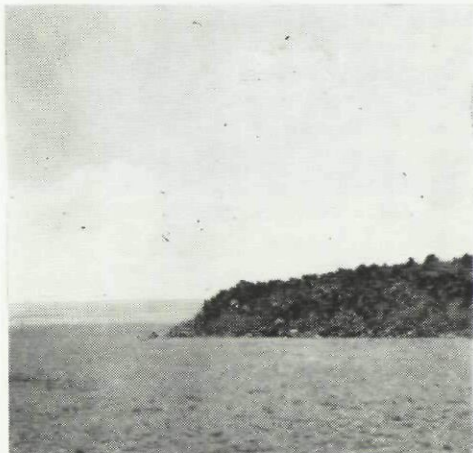
There is a wide variety of agglomeratic rocks in the area. They vary greatly in colour, texture and composition. Typically, the agglomerates consist of angular pyroclastic fragments set in a fine-grained compact matrix. In the Kinangop escarpment the thickest band of agglomerate is a buff-coloured massive rock containing abundant pumice and black scoriaceous fragments, with rarer blocks of lava. A brownish to maroon-coloured agglomerate forms another prominent horizon in the Kinangop volcanics at the base of the upper Karati river gorge, north-east of Naivasha township. In this rock lava fragments and blocks make up the greater proportion of the inclusions. In the Mau escarpment a particularly compact grey agglomerate forms a prominent bluff recognisable from as much as ten miles away. This agglomerate consists of fragments of a coarse-textured probably middle Pleistocene trachyte, black scoriaceous material, and greyish tuff. Medium-sized potash felspar crystals are sparsely distributed through the agglomerate. On the south-western shores of Lake Naivasha, several craters including the crater containing the well-known Crater Lake are composed of compact pale to dark brownish agglomerate containing a wide variety of fragmental inclusions of lavas, including obsidian, pumice and tuff.

One of the most economically important rock types in the Naivasha area is a pale greenish grey tuff, which is extensively used for building purposes. It is fairly compact but can be readily shaped with a mason's chisel and it is possible to cut lines in it with a pocket knife. It is composed of consolidated fine ash with scattered inclusions of darker-coloured tuff and other pyroclastic material. A few rare potash felspar crystals are distributed through the rock. Weathering sometimes reduces the colour to a pale buff and generally softens the rock, but even in weathered form it is used on a limited scale for building purposes.

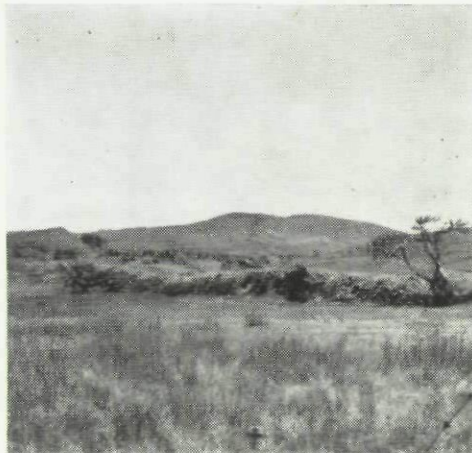
Welded tuffs form important marker horizons in the volcanics of the Kinangop. They exhibit a considerable amount of welding, but do not show the signs of flow

that are commonly associated with the more extreme form of welded tuffs called ignimbrite. In the hand-specimen, the Kinangop welded tuffs are pale greenish to grey in colour and all inclusions are somewhat flattened. They are brittle rocks, a property that forbids their use as building-stone. As they are far more resistant to erosion than any other volcanics except the lavas, they often form prominent benches on the face of the Kinangop escarpment. A generally similar but darker grey welded tuff forms a prominent horizon on the lower slopes of the Mau escarpment. This rock differs from the Kinangop welded tuffs chiefly by its darker colour, finer-grained texture and an unusual pearly lustre on freshly fractured surfaces.

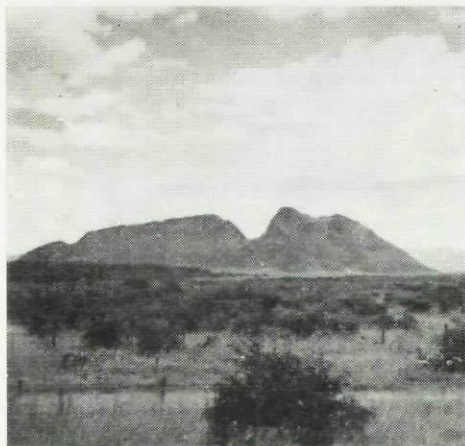
PLATE I



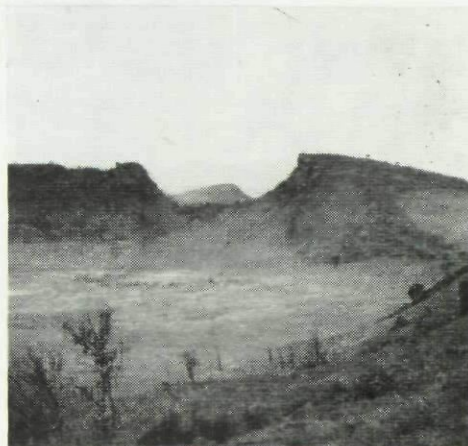
(a)



(b)



(c)

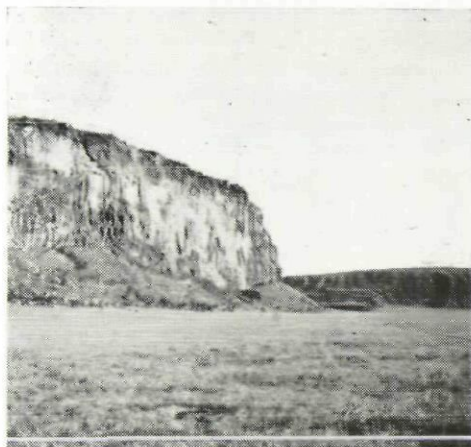


(d)

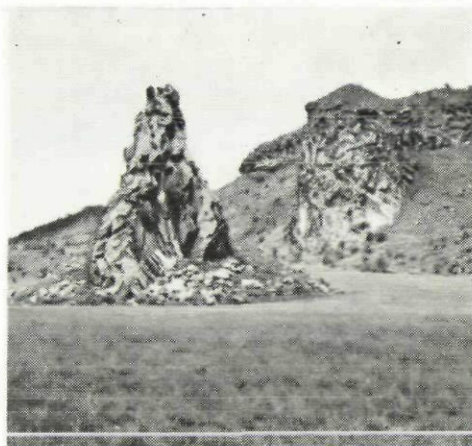
- (a) Recent blocky ("aa" type) trachyte flow on the northern slopes of Longonot.
 (b) Small fault-scarp of comendite near the former Eburru station.
 (c) Fissured cone at the northern edge of the "Badlands". Note the Recent basalt lava flow at the base of the cone on the left-hand side of the photograph.
 (d) View across the fissured cone showing the fissured wall on the southern side.

[Photo by R. G. Dodson]

PLATE II



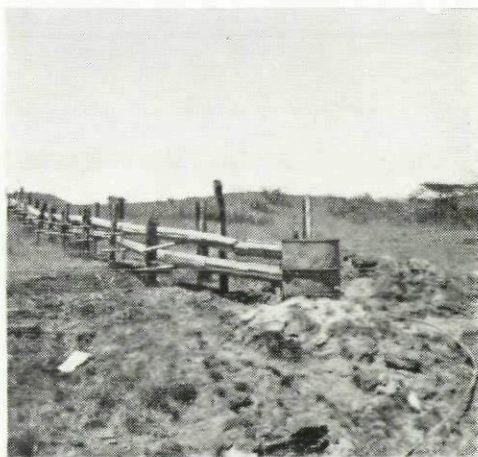
(a)



(b)



(c)



(d)

- (a) Columnar comendite cliffs at the northern end of the Njorowa Gorge.
 (b) Fischer's Tower; plugs of comendite at the northern end of the Njorowa Gorge.
 (c) Steam issuing from a rhyolite plug, north of Orgaria.
 (d) A steam condenser near the former Eburru station.

[Photo by R. G. Dodson]

3. Pleistocene Sediments

The only Pleistocene sediments in the Naivasha area that are of definite known age are the Kanjeran deposits on the Kinangop plateau. From deposits beneath the Kanjeran beds in the Kinangop scarps, L. S. B. Leakey has, however, obtained an artifact which he believes dates them as Kamasian (i.e. lower Middle Pleistocene) in age. Considerably lower in the Kinangop scarps are further sediments associated with pyroclastics, which may be lower Pleistocene in age or even older. For want of evidence, however, these older sediments are considered with the other sediments believed to represent the Kamasian stage.

Thus the Pleistocene sediments of the area can be sub-divided as follows:—

- (3) Upper Pleistocene—Gamblian.
- (2) Upper Middle Pleistocene—Kanjera.
- (1) Lower Middle Pleistocene—Kamasian. (?)

(1) LOWER MIDDLE PLEISTOCENE—KAMASIAN (?)

Gregory (1921, p. 199 *et seq.*) described sediments in the vicinity of Lake Baringo as part of the Nyasan Series of his volcanic succession for Kenya. These sediments he believed were deposited in a lake which he named Lake Kamasia, as the deposits occur in the lower part of the Kamasia hills. He also considered that "the extensive ancient fresh-water deposits" he had seen from the Kedong valley to Baringo were also lacustrine and laid down in his lake Kamasia as well as probably the sediments in the Njorowa Gorge. All these deposits he considered were Miocene in age, on the assumption that they were at the same horizons as the then recently dated Miocene beds of Kanungu. The stage name Kamasian was later adopted (Leakey, 1931, p. 11) but with the connotation that the beds are Middle Pleistocene.

In the Naivasha area there are two groups of sediments of probable Kamasian age in the Kinangop scarps. The lower group of sediments is poorly exposed on the first shelf up the Kinangop farm road above Ol Aragwai, about nine miles north-east of Morendat station. Here about 80 ft. (24.4 m.) of light grey to buff, fine diatomaceous sediments can be seen near the turn-off to the Kingston-Davies farm. Associated with these sediments are intercalated tuffs and consolidated ashes—the whole group underlying a grey compact tuff which is extensively quarried as a building-stone. The tuff is scarcely more than 10 ft. thick. It is in turn overlain by tuffs and the porphyritic trachyte, which is again encountered on the farm road near Bamfylde's house a few miles further north. Dr. Leakey considers that these sediments are equivalent to the Lower Oldawan stage, which probably represents the lowest horizons of the Middle Pleistocene.

The upper sediments of probable Kamasian age are intercalated in pyroclastics higher up the Kinangop scarp, occurring beneath the welded tuff which is taken to separate the Kamasian beds from the overlying Kanjera deposits. The sequence in these upper Kamasian (?) sediments exposed on the roadside about 1½ miles north of Bamfylde's house, is tabulated below:—

	<i>Feet</i>
14. Coarse grey and yellow agglomerate	55
13. Coarse pebble and boulder bed	10
12. Coarse black ashy gravel	5
11. Yellowish buff-coloured tuff	3
10. Grey pumice of fine gravel texture in thin bands about 1 in. thick	2
9. Yellow "clayey" ash, probably subaqueously deposited	3
8. Grey pumiceous ashes, probably deposited subaqueously ..	3
7. Fine-grained grey ash	4
6. Yellow clayey ash, probably deposited subaqueously	50
5. Grey agglomerate	5
4. Cream-coloured clayey ash	5
3. White clayey (?) diatomaceous ash	5
2. Buff-coloured clayey ashes	—
1. Grey gravel and sand with scattered pebbles	5
Base of exposure	

A generalized section of the Kamasian rocks is believed to be as follows; the section was compiled from scattered exposures and the thicknesses quoted, it must be stressed, are approximate:—

	<i>Approximate thickness (Feet)</i>
15. Yellow to fawn-coloured coarse scoriaceous massive agglomerate with black scoriae up to one foot across	70
14. Yellowish buff tuffs	25
13. Yellowish buff-coloured ashes and intercalated grey pumiceous ashes, subaqueously deposited	80
12. Grey massive agglomerate	20
11. Grey coarse pumiceous agglomerate	30
10. Trachyte, occasionally highly porphyritic	100
9. Buff tuffs	30
8. Grey building-stone tuff, sometimes greenish-coloured	25
7. Light grey to cream-coloured, sometimes speckled brown to brownish yellow, tuffs and ashes occasionally with intercalated diatomaceous(?) sediments	70
6. Buff and purplish-coloured tuffs of variable hardness	55
5. Purplish or red tuffs, sometimes with hard narrow bands of tuff	60
4. Purplish tuff with thin bands of buff-coloured tuff	40
3. Greenish grey tuff	10
2. Light grey to dirty white ashy tuff that may have been partly subaqueously deposited	15
1. Coarse grey agglomerate with scoriae up to 5 in. across (Kijabe-type basalt)	100
Approximate total thickness ..	730

In the Karati river gorge, about 2 miles north-east of Naivasha township, beneath the grey building-stone tuff that is quarried at the top of the scarp, two hundred feet of the underlying tuffs and agglomerates etc. are to be found. Light-coloured tuffs and sediments of the same group of more tuffaceous character and with little signs of having been deposited under water, further north near Kingston-Davies farm, are not so clearly visible.

This variable nature of the supposed Kamasian rocks is further exemplified by the rocks in the Njorowa Gorge. There are here no rocks or beds that can be correlated with any great degree of certainty with similar rocks or beds in the Kinangop scarps. Likewise with the Kanjeran there is no apparent comparison. The diatomaceous beds of Kariandus are lacking in the gorge, and the marker horizons of the Kamasian beds in the Kinangop scarps such as the building-stone tuff, the intercalated lavas and the characteristic welded tuff that separates the Kamasian from the Kanjeran rocks, are absent. There are, however, horizons that have some similarity with the Kamasian rocks in the Kinangop escarpment viz. the uppermost and lowermost exposures seen in the Njorowa Gorge. These are a yellowish pumiceous agglomerate and a greenish grey coarse agglomerate, which may be respectively correlatable with the yellow coarse scoriaceous agglomerate and the grey building-stone tuff of the Kinangop. If it is accepted that this correlation is correct it is seen that trachyte intercalated in the Kinangop sequence is not present in the Njorowa sequence, but the intervening subaqueous deposits in the gorge, though slightly different in nature, may be of contemporaneous deposition with those exposed in the Kinangop scarps. The thickness of the Njorowa sequence is only slightly greater than the equivalent sequence in the Kinangop if this correlation is accepted, and if the intercalated trachyte of the Kinangop is excluded.

The sequence of the Kamasian deposits and their approximate thicknesses in the Njorowa Gorge are tabulated below:—

	<i>Approximate thickness (Feet)</i>
22. Yellowish pumiceous agglomerate (dirty-white in the upper portions) which forms massive scarps near northern end of the gorge	60
21. Buff to yellow stratified ashy beds with calcareous nodules ..	45
20. Buff to yellow stratified ashy beds with siliceous nodules ..	30
19. Dark yellowish buff massive unjointed agglomeratic tuff ..	25
18. Buff mottled-brown lateritized pebble bed	5
17. White ashes	3
16. Buff-coloured ashy (?) lake-beds	10
15. Drab and greenish, and in places reddish, "felspathic sand" ..	5
14. Buff finely bedded ashy sediments	3
13. Red sandy beds with gypsum crystals	2
12. Variegated pumice sand with irregular lenticular beds of dark grey fine ashy sand	3
11. Variegated ashy sediments with salt efflorescences	2
10. White sediments with light-grey pumice bands	10
9. Drab-coloured sediments with grey pumice lenticles and rare boulders; partial silicification in lower bands	40
8. Light-grey ill-sorted pumice and fine ash bands	25
7. Light-yellow ashes	3
6. Yellow pumice beds of varying thickness	3 to 5
5. Drab slightly massive pumiceous sediments, slightly conglomeratic at base	15
4. Light grey to drab thinly-bedded ashy beds	6
3. Grey ash band	6
2. Dirty-white fine pumice	3
1. Greenish grey coarse agglomerate with fragments of trachyte and comendite	20 ft. only exposed
(Base not exposed)	
Approximate total thickness ..	326

A fault with a vertical throw of about 300 feet (91.5 m.) is believed to re-expose the greenish grey coarse agglomerate at the northern end of the gorge where it has been quarried on a limited scale as a building-stone. It does not appear again in the sequence except near the southern end of the gorge, about one mile north of the bore-hole C. 1524.

Gregory (1921, p. 199) stated that in the Njorowa Gorge the lake deposits "consist of fine-grained regularly bedded clays, layers of sand which contain so much volcanic material that they resemble tuffs, and gravel composed of pebbles of the older lavas." That the deposits sometimes resemble subaerial tuffs has often led to confusion in interpreting the origin and nature of many of the deposits not only in the Njorowa Gorge but practically throughout the whole of the Naivasha area, and it is possible that what have sometimes been referred to as tuffs may in reality be lacustrine sediments and vice versa. Nevertheless the bulk of the material comprising the obvious lacustrine deposits is of pyroclastic origin.

Near the southern end of the Njorowa Gorge, plugs, dykes and sills of comendite can be seen. These intrusions have not displaced the Kamasian beds to any great extent, nor has there been intense baking of the beds. Along the edge of a narrow dyke, about 10 ft. thick, a slight reddening of the adjoining beds has taken place over a width of about a foot, probably as a result of the intrusion.

(2) UPPER MIDDLE PLEISTOCENE—KANJERAN

The Kanjeran stage of the upper Middle Pleistocene is represented in the Naivasha area by a diverse group of sediments. It is also anticipated that Kanjeran deposits of equivalent age to those exposed near Kariandus (*see* p. 17) are present at a shallow depth in the northern parts of the Naivasha area.

A group of clayey sediments, in which Fauresmith and Pseudo-Stillbay artifacts representing the Acheulian Stage 6 have been found, represents deposits of Kanjeran times on the Kinangop.

The succession is:—

	<i>Approximate thickness (Feet)</i>
3 Dirty-white to grey thin bedded clays and silts	60
2. Buff to brown clayey sediments with ferricrete nodules (pauudai deposits (?))	10
1. Yellow to light-brown tuffs (Greenish grey welded tuff often with glassy base, 3 ft.; Kamasian)	10

Leakey (1953, p. 101) has stated that in East Africa the "Fauresmith culture is only found in deposits belonging to the dry period between the Kanjeran and the Gamblian Pluvial" and its "area of distribution is confined to high altitudes around such mountain masses as Mt. Kenya, the Aberdare Range, the Mau Range and Kilimanjaro." Later in the same book (p. 105) he states that in East Africa "there is a curious local culture which is geologically contemporary with the East African Fauresmith and early Levalloisian to which the name of Pseudo-Stillbay has been given."

Cole (1953, p. 161) refers to Fauresmith and Pseudo-Stillbay industries being found in swamp deposits at Weatherall's site on the Kinangop. This site is at the same horizon as the beds listed above, but further south and outside the limits of the Naivasha area. The swamp deposits are typified by the presence of reeds and grasses which have been ferruginized by iron ores.

Shackleton (1955, p. 260) refers to lateritic and tuffaceous beds on the Kinangop which have yielded artifacts of Pseudo-Stillbay, Fauresmith and other late Middle Pleistocene types, resting unconformably on successive beds of trachytic tuffs at Durie's site, a little east of the present area. This unconformity in Kanjeran times is further exemplified by the presence of Kanjeran beds on the first shelf below the Kinangop plateau, near Bamfylde's house where, Dr. L. S. B. Leakey has informed the writers, he has found Pseudo-Stillbay artifacts in light-coloured deposits overlying the porphyritic trachyte believed to be of Kamasian age.

About one mile east of Munyu station where the following Kanjeran beds are exposed, it is believed that they are unconformably overlain by Gamblian sediments, represented by 5 ft. of pumice:—

	<i>Thickness in Feet</i>
3. Brown pumiceous clayey sediments	8
2. Light-grey pumice	3
1. Brown pumiceous compact clayey sediments with some horizons of calcrete nodules	12

Fauresmith artifacts have also been found in the Kanjeran deposits constituting the Mau escarpment. If these artifacts are confined to the interpluvial between the Kanjeran and Gamblian as Leakey suggested, an anomalous position arises because of their occurrence on the Kinangop with Pseudo-Stillbay artifacts. The Kinangop sediments are, however, comparatively thin whereas a great thickness of ashes accumulated at that time in the Mau escarpment. It would therefore appear that pene-contemporaneously with the deposition of the sediments on the Kinangop, ashes were beginning to pile up to the west and with subsequent faulting during late Kanjeran times and during the interpluvial between the Kanjeran and Gamblian pluvials the Mau escarpment began to take form. At the same time the Fauresmith artifacts were distributed on the Mau escarpment in the ashes that were then accumulating, and on the Kinangop as well in conditions where their resting places were not widely separated from Pseudo-Stillbay artifacts which had already been rejected previously. The time-interval is probably represented by thinner deposits on the Kinangop than on the Mau escarpment.

The conditions of deposition during Kanjeran times were not the same on the Kinangop and the Mau and water-laid sediments in the latter were not conclusively determined. A great thickness of tuffs and ashes was observed but it was not established that any of these pyroclastics were deposited subaqueously. It is believed that if any were so deposited it was only locally—probably in depressions caused by faults, for rift faulting was active during late Kanjeran times.

(3) UPPER PLEISTOCENE—GAMBLIAN

Much attention has been paid to the Gamblian deposits both by geologists and archaeologists on account of the numerous artifacts and fossils scattered over and deposited in them. They cover a large surface area but are not thick, and are generally light-coloured. The Gamblian sediments like the older sediments in the Naivasha area include a large proportion of pyroclastic material even in the so-called "clays". Diatomaceous earths are also present but, apart from a few small deposits, have not been commercially exploited to the same extent as the Kanjeran diatomite beds at Kariandus. On Carr's farm, on the south-eastern shores of Lake Naivasha a bed of diatomite about 5 ft. thick has been exposed in a trench. This horizon probably belongs to the upper Gamblian group of sediments.

Solomon (in Leakey, 1931, p. 245 *et seq.*) in his descriptions of the Gamblian sediments at various places in the Naivasha area noted that they consist of gravels and silts with re-deposited tuffaceous material. He also recorded diatomite near the base of the upper Gamblian in the Melawa gorge. The lower Gamblian sediments are, he believed, thicker than the upper Gamblian sediments and consist of silts and impersistent gravels.

Nowhere have the Gamblian sediments been seen greater than 100 ft. in thickness. Solomon (in Leakey, 1931, p. 251) considered that the lower Gamblian has a probable thickness of some 200 ft. and for the upper Gamblian he recorded a thickness of up to 15 ft. He also states that nowhere is the whole series exposed.

Beneath, within and above the Gamblian beds are unconformities. With each drop of level of the Gamblian lakes, the sediments that were exposed were eroded and when the lake level rose again the erosion surfaces were covered by lake sediments. Examples of these unconformities within the Gamblian sediments can be seen along the Melawa river, in the vicinity of the Government Experimental Station (see Fig. 7; also Nilsson, 1940, p. 14). From the sections in the Melawa gorge Solomon (in Leakey, 1931, p. 260) has drawn the conclusions that "conditions of erosion must somewhat have resembled those of today—namely a local cutting of steep-sided channels through the soft lake deposits without much general erosion on the plains." On account of the soft, porous nature of the deposits, rain falling on their surface would drain away rapidly, but under-cutting and erosion by streams and rivers flowing across them would be considerable.

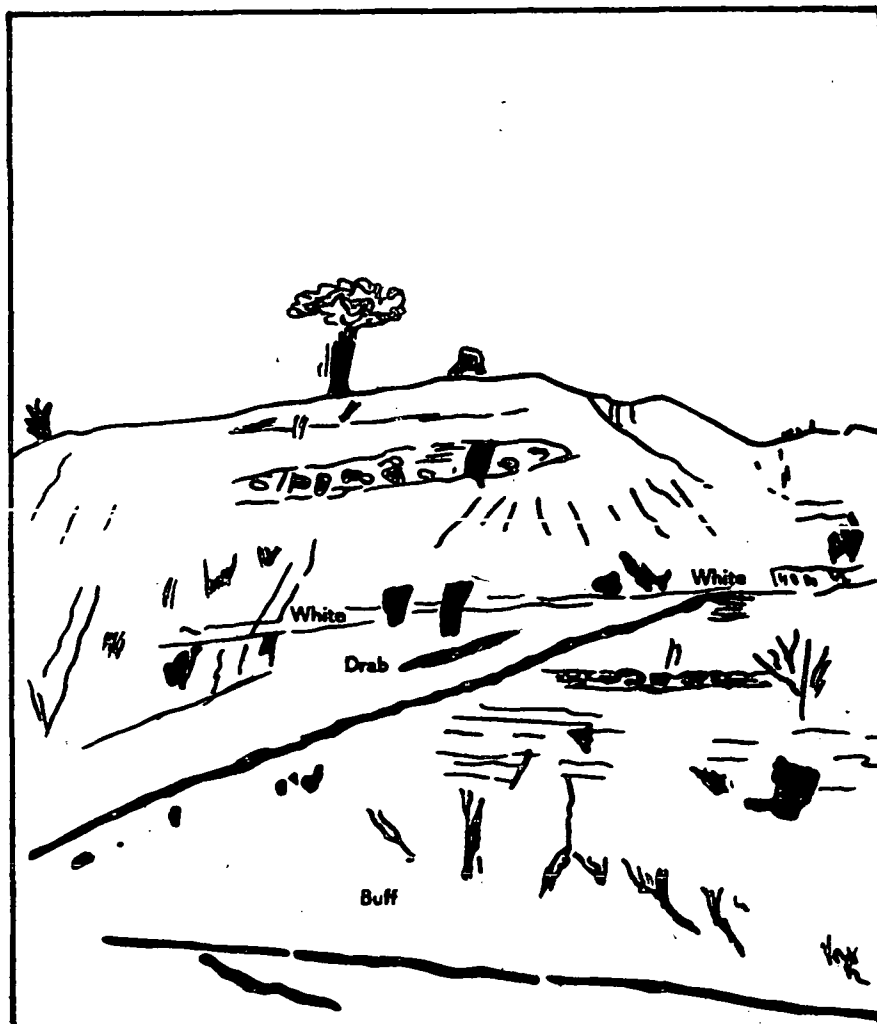


Fig. 7—Unconformity in Gamblian lake-beds, Melawa valley. (Drawn from a colour photograph by A. O. Thompson.)

The classic example of the unconformities within the Gamblian sediments, and between them and the subsequent Makalian sediments is at the Nderit drift, on the road between Elmentaita and Mau Narok (Nilsson, 1932, p. 54; 1940, p. 20; Solomon, in Leakey, 1931, p. 248). At this locality a ferruginized gravel about 2 ft. thick and containing rolled Lower Kenya Capsian tools, rests unconformably on the Gamblian I sediments, separating them from the overlying drab Gamblian II beds, which in turn are unconformably overlain by white or light grey Gamblian III sediments. Resting unconformably on the Gamblian III beds are drab Makalian deposits of Holocene age. The beds of different age are seldom more than 20 ft. thick.

The first basaltic flow in the Badlands area was covered by a thin deposit of sediment. From its whitish appearance it is believed that this deposit was laid down in late Gamblian III times rather than in Makalian times as the upper Gamblian sediments are light-coloured and diatomaceous, in contrast with the drab-coloured

silts of the Makalian epoch. The lake levels during both Gamblian III and Makalian times were at the same height in the Nakuru basin, namely 375 ft. above the modern Lake Nakuru (5,776 ft.).

The Gamblian sediments have yielded a large fauna and many artifacts of the Stillbay and Capsian (Kenya Aurignacian) culture (*vide* Nilsson, 1932; Leakey 1931). Fossils from occupational levels in Gamble's Cave have been identified by various authorities. The sediments containing the fossils were deposited when the lake had reached its second maximum in the Gamblian times and thereafter. Fossil mollusca found in the beach sands on the floor of the cave were identified by M. Connolly (*see* Appendix D in Leakey's 1931, p. 276 *et. seq.*) as follows:—

Lymnaea elementeitisensis ? Smith.
Bulinus sp.
Melanoides tuberculata (Müll.).
Corbicula africana (Krs.).

Sediments deposited as the Gamblian II lake waned ("fourth occupational level", Gamble's Cave (Leakey, 1931)) contain the following fossils which have also been identified by Connolly (*op. cit.*).

Planorbis nairobiensis Dautz
Segmentina planodiscus ? (M. & P.).
Bulinus sp.
Bulinus syngenes ? (Preston)
Melanoides tuberculata (Müll.)
Mutela bourguignati Ancy.
Aspatharia sp.
Halolimnohelix bukobae (Mts.).
Cerastus lagariensis (Smith).
Homorus sp. indet.
Homorus sp.
Subuliniscus adjacens ? Conn.
Opeas aphantum Conn.
Opeas psephenum Conn.
Opeas tangaense d'Ailly.
Subulina sp.

A. T. Hopwood identified (*see* Leakey, 1931, Appendix C, pp. 271, *et seq.*) the following mammals from this occupation level:—

Thos adustus (Sundevall).
Lycaon pictus (Temminck).
Lutra maculicollis Lichtenstein.
Aonyx capensis hindei Thomas.
Atilax paludinosus Geoffroy and Cuvier.
Felis sp.
Tachyoryctes sp.
Pedetes sp.
Hystrix galeatus.
Thryonomys swinderianus (Temminck).
Choeromys sp.
Lepus sp.
Orycteropus aethiopicus Sundevall.
Two or three monkeys indet.
Choiropotamus choiropotamus (Desmoulins).
Hylochoerus meinertzhageni Thomas.
Phacochoerus africanus Linné.

Hippopotamus amphibius Linné.

Antelopes.

Redunca sp.

Procavia sp.

From Quaternary lake beds near the Melawa river, probably those deposited by the Gamblian II lake, Lönnberg (1933) described a fossil water buffalo, *Bubalus nilssoni* sp. nov. Additional figures and descriptions of this buffalo were given by Nilsson (1945).

From a site described as about 10 km. south-south-east of Lake Naivasha and 1-2 km. from the road to Nairobi, in what are believed to be late Pleistocene lake beds Lönnberg (1937) described the following fossils:—

Felis leo bleyenberghi Lönnb.

Bathyleptodon aberrans gen. et. sp. nov.

Proconsuloides naivashensis gen. et. sp. nov.

Also from lacustrine deposits of Gamblian age along the Melawa river Hopwood (Appendix C in Leakey, 1931) described the following fossils:—

Hippopotamus amphibius Linné.

Diceros bicornis (Linné).

Bovines (two species).

Aurignacian* artifacts belong to this period were described by Leakey (1931). In Gamble's Cave he found backed blades, scrapers, burins, fabricators, sinew frayers, hammer-stones, cores, awls, beads and fragments of pottery belonging to this culture. From a beach about 200 ft. (61 m.) above the level of Lake Naivasha township, Leakey (1942, p. 172) obtained a fossil human skeleton and skull, which he dated as belonging to the declining second maximum of the Gamblian Pluvial. Rolled tools of Levalloisian type that somewhat resembles those of the upper "Kenya Aurignacian" phase C were also found on this beach. These discoveries were made in silts.

At the Gilgil river crossing on the Naivasha-Gilgil road, cream-coloured diatomaceous earths and tuffaceous silts with a dip of about 2° to the north-east are exposed to a depth of about 15 feet by gully erosion along the flanks of the river. At this site a rich assemblage of artifacts belonging to the Stillbay and upper Kenya Capsian cultures have been found. Neolithic pottery has also been found on the eroded surface of these Gamblian sediments.

The Gamblian pluvial, with its three maxima, has been equated with the Würm glaciation and may have lasted from about 70,000 to 10,000 B.C. (Cole, 1954, p. 51). De Geer (1934, pp. 75-96) suggested that deposits in the Melawa river which probably represent the lake corresponding with the last maximum (Gamblian III) were laid down about 12,700 years ago (Cole, 1954, p. 52). This dating was done by counting the brown (dry season) and grey (wet season) varves in the sediments and by teleconnection with already-dated Swedish varves.

The extent of the first and largest Gamblian lake—Gamblian I—has been plotted by Nilsson (1932, p. 43) (see Fig. 4). He believed that the Nakuru and Naivasha basins were joined together at the Gamblian I maximum and separated at the subsequent maxima. He also considered that the basins were tilted at various times during the Gamblian stage. He believed they were tilted northwards and southwards from a point about Gilgil, with decreasing amounts of tilt as the younger lakes developed and in general shrank in size. The Eburru ridge appeared to be the pivot away from which the relics of the lakes were tilted, that is about this ridge the

* It should be noted that it was recommended by Leakey (1947, p. 205) that "Kenya Aurignacian" should be replaced by "Kenya Capsian" and that the latter name was used at the Pan-African Congress of Prehistory in Algiers in 1952.

beaches of each lake level occur at their highest recorded level. If it is correct that the two lake basins were joined during the first maximum, as the writers believe, then an anomalous situation arises with regard to the heights of the various terraces, beaches and barriers frequently quoted in print. Either the recorded levels of the terraces above the respective lakes or of the lakes are incorrect if no tilting has taken place. An examination of the published Gamblian I lake-levels reveals the anomaly. Cole (1954, p. 45) quoted the maximum heights above present-day lake level for the Gamblian lakes in the Nakuru basin as—Gamblian I, 720 ft.; Gamblian II, 510 ft.; Gamblian III, 375. Approximately the same figures were given by J. D. Solomon (in Leakey, 1931, p. 247 *et seq.*). Nilsson (1932, p. 46) also observed a terrace 120 metres (394 ft.) above Lake Naivasha and Solomon (*op. cit.*, p. 259) recorded the height of the highest Gamblian lake level as about 380 feet above the level of the same lake. The lake levels at the time of the measurements were 5,776 ft. above sea level for lake Nakuru and 6,203 ft. for Lake Naivasha. These heights together with the heights of the Gamblian I terraces above the lakes in the two basins, if there has been no tilting, should give a similar figure for the Gamblian I lake level, but this is not the case. The figures are tabulated below:—

Lake	Lake-level	Height of Terrace above Lake-level	Height of Terrace + Lake-level = Gamblian I Lake-level above present Sea-level
Nakuru ..	5,776	720	6,696
Naivasha ..	6,203	380	6,583

This reveals a discrepancy of nearly 100 ft.

During the course of the present survey, the maximum extent of the Gamblian I lakes was found to be approximately at the 6,550 foot contour throughout the area, both in the Naivasha and Nakuru basins. Nilson (1932, p. 41 *et. seq.*) was probably the first to draw attention to the possibility of tilting of the lake sediments in this part of the Rift Valley. He recorded (*op. cit.* pp. 50-51) differential uplift of the order of 110 metres for the Naivasha-Nakuru basin, between the maximum height of the Gamblian I lake and the Gamblian II lake, when there took place a rather uniform tilting of the whole (Naivasha-Nakuru) basin towards the north. Between the levels of the Gamblian II and III lakes this difference had practically disappeared owing to a tilting in the opposite direction, while tilting affected the Nakuru more than the Naivasha basin. The next stage was one in which the Nakuru basin was tilted towards the north, and the Naivasha basin towards the south about an axis running between Gilgil and the Eburru ridge. The subsequent movements within each basin were independent of one another and of less magnitude than before. Nilsson recognized six stages in the development of these basins to their present form. Solomon (in Leakey, 1931, p. 258) recorded a southerly tilt of approximately 1.6 ft. per mile for the Gamblian I lake in the Naivasha basin only. He also stated that the lower terraces of the upper Gamblian show similar tilting both in direction and magnitude. Shackleton (1955, p. 261) stated that "there was not much tectonic activity during most of the upper Pleistocene, for the high beaches of the Gamblian pluvial . . . are not faulted although they are slightly tilted; the maximum dip is about $0^{\circ} 17'$." This is of the order of 26 ft. per mile.

4. Holocene Sediments

The oldest Holocene sediments were deposited in the Makalian, the middle in the Nakuran, and the youngest in the Recent climatic stage. The time interval of

these stages is slight in comparison with other geological time divisions, in fact the last two mentioned stages and the upper part of the Makalian come within historical times.

Deposits of these different stages are of local extent and are not thick.

(1) MAKALIAN DEPOSITS

Unfossiliferous beds up to 20 ft. in thickness in the Njorowa Gorge, composed largely of fine white ashes, are believed to be Makalian in age. In part they have been re-worked, and probably include a proportion of re-worked Kamasian sediments.

Where streams from the Mau escarpment and the Kinangop disgorged themselves in Makalian times, boulder beds and gravels were deposited as piedmont fans. Relics of the boulder beds are visible near Gamble's Cave, along the Nderit river at the base of the Mau escarpment.

Drab-coloured silts and sands constitute the lacustrine representatives of the Makalian wet phase. Solomon (in Leakey, 1931, p. 252) recorded the presence of well-bedded diatomaceous silts, and fine, poorly stratified ash up to 10 ft. thick, overlying diatomaceous silts with gravel at the base, in the Makalia river just beyond the limits of the present area.

From silts and sands at the Nderit river drift A. T. Hopwood (Appendix C, in Leakey, 1931) identified the following mammalian fossils:—

Hippopotamus amphibius Linné.

Antelope sens. lat.

Elephas (?).

M. Connolly identified the following mollusca from the same locality:—

Helicarion ugandensis ? Thiele.

Cerastus lagariensis (Smith).

Limicolaria martensiana (Smith).

Homorus margaretae ? Conn.

From the "upper occupational level" in Gamble's Cave Leakey (1931, p. 116) obtained elements of the Elmentaitan culture together with pottery and many animal bones, but no human remains. Regular two-edged and backed blades, scrapers, *lames écaillées* and cores were amongst the artifacts found.

The Makalian wet phase had two peaks, when terraces in the Nakuru basin 375 and 325 ft. above Lake Nakuru were cut. It was separated from the Gamblian by an arid period and was followed by a further period of desiccation. In the Naivasha basin, the level of Lake Naivasha was 120 ft. (36.6 m.) higher in the Makalian than in modern times.

(2) NAKURAN DEPOSITS

The Nakuran wet phase is thought to have begun in Mesolithic times and to have continued well into Neolithic times. The Nakuru site, which represents the maximum of the phase, is dated at about 850 B.C. (Cole, 1954, p. 232) and the phase extended to the end of the pre-Christian era. It continued almost to Kenyan historical times and probably would have been included with modern times by archaeologists, had a culture existed that had developed handwriting and recorded it in something permanent.

Deposits laid down during the phase are of local extent. Artifacts of the Gumban and Wilton cultures are preserved in the deposits largely in rock shelters and caves as well as along river banks, for example along the Gilgil and Nderit rivers. Human skulls found at Willey's kopje on the northern slopes of Eburru are believed to belong to this phase (Leakey, 1931, p. 200). The silts flanking and cut by the present-day Nderit river represent deposits laid down during this phase. The silts are drab to brown in colour and are probably not more than 10 ft. thick.

In the Njorowa Gorge vigorous erosion of the white "Makalian" ashes has taken place since their deposition. Channels cut in the ashes have been filled with black soil, large boulders and pebbles, which it is believed represent deposits belonging to the Nakuran phase.

(3) RECENT DEPOSITS

So close was the Nakuran wet phase to the present day that it is difficult to distinguish between the deposits formed in the two periods. Sediments that were laid down since the wet phase were deposited within historic times and include deposits that are probably being added to at the present time. The silts and clays being deposited along the north-eastern and northern shores of Lake Naivasha are representative. Re-worked and re-deposited sands, gravels, pebble, and boulder beds in the lower reaches of the Njorowa Gorge probably also represent deposits of Recent age. The boulder beds often include large irregular and often unrounded lumps of pumice up to 2 or 3 ft. across. Numerous boulders of comendite are also to be found in them.

5. Syenite

Blocks and fragments of syenitic rock, torn off a deep-seated source underlying the surface lavas of the Rift Valley and extruded during the more explosive volcanic phase, are occasionally found lying about on the surface, embedded in layers of pyroclastics, or on the slopes of the volcanic cones. There is a distinct possibility of a relationship between the parent magmas of the syenite, a plutonic equivalent of trachyte, and the local trachytes. There is no indication as to the extent of the syenite body and to date no bore-hole has penetrated rock other than the volcanics exposed on the surface and in the sides of the Rift Valley in the Naivasha area.

In the hand-specimen the syenite is a speckled, greyish rock composed of dull whitish feldspars contrasting with dark-coloured ferromagnesian minerals. In the thin section of specimen 43/329, found in ashes south-east of Naivasha township, the rock was found to be coarse textured and composed of stout, interlocking cloudy potash feldspar, brown hornblende, euhedral greenish diopsidic pyroxene, deep green aegirine, magnetite, analcite, secondary epidote and accessory apatite.

VI—STRUCTURES

The tectonics of the Rift Valleys have interested large numbers of investigators and much has been written to account for the gigantic trough-like structure known as the Gregory Rift Valley. Theories put forward to explain the rifting invoke tension, compression, volcanism and finally, the advance and retreat of polar ice-caps.

J. Scott (1953A), who put forward the last-named theory considered rifting to be due to a squeezing effect towards the equator, caused by the weight of fully developed polar ice-caps during periodic ice ages. He considered that cracks so formed were longitudinal and oblique to the earth's surface, so that in time collapse of a suitable wedge-shaped block could give rise to the floor to the Rift Valley. This theory must be considered untenable as it is not consistent with geological fact. As opposed to the more popular theories invoking tension and compression, S. J. Shand (1936, p. 311) visualized the Gregory Rift Valley as caused by a trench-like subsidence in a fissure volcano, much as cauldron subsidence takes place in volcanoes. He pointed out that the Rift Valley is deepest, although the floor elevation is greatest, where the volcanic sequence was thickest, and that, as the volcanic rocks thin to the north and south, the valleys flatten out. The most obvious objection to this hypothesis is that the Gregory Rift Valley is only a small part of an enormous rift system extending from Palestine through East Africa, possibly as far as South-West Africa (Brock, 1953, p. 226). Furthermore, vast stretches of the rift valleys are free of volcanics.

The compression hypothesis explains the mechanism of rifting by two opposing ramps, downthrusting a central block. E. C. Bullard (1936) sought to prove that negative gravity anomalies in the Rift Valley indicate downward thrust, but F. A.

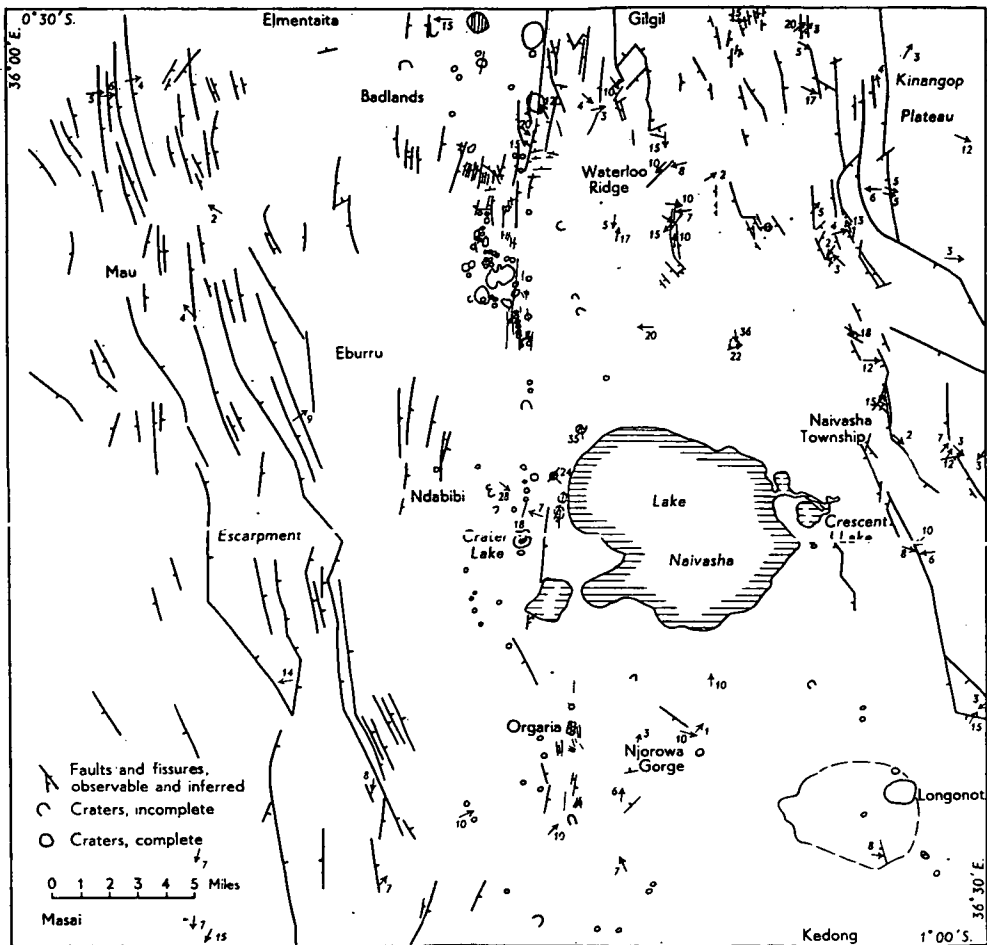


Fig. 8—Structural map of the Naivasha area.

Vening Meinesz (as quoted by B. G. Escher, 1951, p. 751) disproved Bullard's findings, observing that it is possible to interpret a negative anomaly in a tension-faulted trough covered by light sediments. B. Willis (1936, pp. 72-97) presented a hypothesis in which he visualized initial uplift caused by an expanding subterranean mass of molten rock which he called an "asthenolith." If the "asthenolith" is depleted of lava either by intrusion into the country rock or extrusion at the surface, the overhanging wall is likely to collapse to form a basin or a trough. If the trough is delimited by faults it would constitute a rift valley. Gregory originated the tension or keystone hypothesis. He visualized the formation of the Rift Valley as the dropping of a central trough between two parallel faults after the wide-based arching-up of East Africa. According to B. B. Brock the chief objection to this theory is the mechanical difficulty of explaining an appreciable tension as a result of arching, or alternatively, regional compression followed by regional tension, both manifesting themselves along the same axis. The fact remains, however, that in certain parts of the rift valley systems, the opposing sides are raised to gently inclined ramp-like walls on both sides of the valleys. The most likely explanation of this fact would be Gregory's hypothesis invoking arching on a continental scale which might incidentally include localized compressive forces during the earliest phase, but which

would finally result in the tension responsible for the collapse of the trough-like rift valley. There is no doubt, however, that the Rift Valley axis did undergo a number of tectonic phases and it is possible there may have been mild compression. It has been suggested, and the writers accept the probability, that rifting took place along ancient tectonic lines in certain parts of the rift valley system. If the rift valleys do occupy older structural lines, it is most likely that most subsequent regional stresses would be manifested along them. As to the cause of the original movements initiating rifting, the answer must be sought on a trans-continental scale. Movements caused by crustal adjustment or, in the opinion of the writers, possibly continental drift might be considered, the latter being considered the less acceptable possibility.

In the Naivasha area there is evidence of near-vertical step-faulting. These fault-scarps are often well preserved and marker horizons can be progressively traced on lower steps. It is notable that the greater portion of the fault-blocks plunge southwards.

The age of the faulting as a whole presents a problem. Shackleton (1955, p. 262) considered the main faulting took place just before the lower Pleistocene while Kent (1944, p. 24) suggested that the earliest rifting of the Gregory Rift Valley took place in the Upper Miocene. McCall (1955, p. 21) considered that the main rifting took place during the Miocene, and either the Pliocene or Pleistocene. Baker (1958, p. 61) too found evidence of pre-Pleistocene faulting in the Magadi area. In the present area evidence of pre-Pleistocene rifting is lacking, as there are no pre-Pleistocene rocks and as the nature of the subvolcanic floor is unknown. The bulk of the faulting apparently took place in late Middle Pleistocene times, either in late Kamasian times or possibly as late as the Kanjeran stage, possibly along older fault lines. Kamasian beds in the Kinangop escarpment can be seen to have been cut by the faulting. The Kanjeran sediments capping the Kinangop, best exposed at the stone-age horizon known as Cartwright's site, have also been severed as they re-appear on the lower down-faulted shelf. There has been a great deal of slumping in this part of the area, however, and the lower occurrence is obscured by much overburden, so there is no definite proof of fault displacement as to set against the suggestion by Shackleton (1955, p. 261) that these beds were deposited over the fault-scarps. It should be noted, however, that if faulting did take place towards the close of the Kanjeran stage, the damp sediments might tend to slump rather than fracture cleanly along the fault-lines, which could account for the disparity of dip-slopes quoted by Shackleton. The faulting that took place in Middle Pleistocene times is also believed to be largely responsible for the intense disruption of the valley floor lavas.

The youngest phase of faulting is at least of late or post-Gamblian (Upper Pleistocene) age as it cuts through Gamblian sediments at the faulted ash craters in the Badlands area, and again in a single instance on the Ndabibi plains south of Eburru. This faulting is essentially tensional, the result being fissures of various dimensions. There is no indication of whether the Orgaria fissures, in which abundant steam-jets occur, are of the same age but their general appearance and condition of erosion suggests that they were contemporaneous with the Eburru faults. The two main sets of faulting are quite distinctive, the rift faulting being aligned in a north-north-west to south-south-easterly direction while the younger faults follow an approximate north-south alignment (Fig. 8).

There is little evidence of folding in the area. Scott (1953A, p. 7) described anticlinal arching of "Kamasian" beds in the valley floor as a whole on a north-south axis. The only exposures of what are believed to be middle Pleistocene sediments of Kamasian age in the Rift floor are in the Njorowa Gorge. The writers did not find direct evidence of the folding Scott describes, but there is slight arch on an approximate east-west axis, the dip of the limbs being of the order of $\frac{1}{2}^\circ$. The bands of rock at the two extremities of the gorge dip gently to the north and south respectively.

Nilsson's ideas on the slight tilting of the upper Pleistocene Gamblian lake beds, as a result of arching along an axis passing through Eburru, have already been discussed (p. 46). While the writers accept the evidence for this north and south tilting, the limits of the area mapped are too confined to allow an accurate assessment of the movement. McCall's (1955) geological map records "flexures" in some of the lavas. The writers are of the opinion that curving or arching of congealed lava flows does not necessarily indicate flexing, but is mainly due to the behaviour of viscous lava closely following the lines of an undulating surface over which it flowed. It is likely that a certain amount of bulging took place when moving viscous lava encountered obstacles.

VII—MINERAL DEPOSITS AND OCCURRENCES

1. Steam-jets

(1) HISTORY

The earliest description of steam-jets in the Naivasha area was recorded by G. A. Fischer in 1885. Traversing the Njorowa Gorge he discovered a large steam-jet and collected a sample of condensed steam for analysis. While the presence of the steam-jets was undoubtedly known to a number of early travellers, settlers and administrative officials, they aroused little comment until Gregory's (1921, p. 169) brief account. For many years farmers in the Naivasha area have harnessed the steam to various types of condensers, to collect water for domestic supplies and stock-watering (Plate II (d)). P. C. Spink (1945) visited the steam-jets, and described their situation and general characteristics. In 1953 Scott wrote a paper on the possibility of the occurrence of geothermal steam in the area (Scott, 1953A) and later in an article in the *Kenya Weekly News* (Scott (1953B)) he described the steam-jets, offering a theory to account for their origin and recommending exploitation of the steam as a source of power.

(2) DISTRIBUTION AND DESCRIPTION

The steam-jets are mainly concentrated in two foci of activity, one north of Lake Naivasha on the eastern and northern slopes of Eburru and the other in the Orgaria-Njorowa Gorge area, south of the lake (see Fig. 9). A few minor jets issue from Longonot crater and McCall (1955, p. 14) has described steam-jets north of the present area in the Menengai crater near Nakuru.

While the steam-jets (see Plate II (c)) vary in dimensions, form and output, they usually possess certain common characteristics. Typically, they occur along fracture lines, often close to recent lava bodies. In exceptional cases, where steam issues from lava free of obvious fractures, it is probable that it is escaping through the fractures up which the lava originally flowed, and makes its way to the surface along the joints or through the spongy vesicular texture of the lava. The youngest jets, which are often the more powerful, emerge from slightly altered rock, the older and extinct fissures being characterized by a broad zone of oxidized products stained reddish-brown by iron oxide. The vents from which the steam issues vary from small narrow fissures to large holes up to two feet in diameter. Some of the larger steam-jets such as the one situated roughly in the middle of the Njorowa Gorge, the jets on Maiella estate about one mile west of the gorge, the jets on a hill due east of Orgaria and some of the jets on Eburru are released under low pressures and are characterized by a hissing noise, audible in some cases up to about fifty yards away. Experiment showed that pressure from the most powerful jet in the area, the large one on Maiella estate just west of Njorowa Gorge, was sufficient to throw out lava pebbles up to an inch in diameter, when they were dropped into the vent.

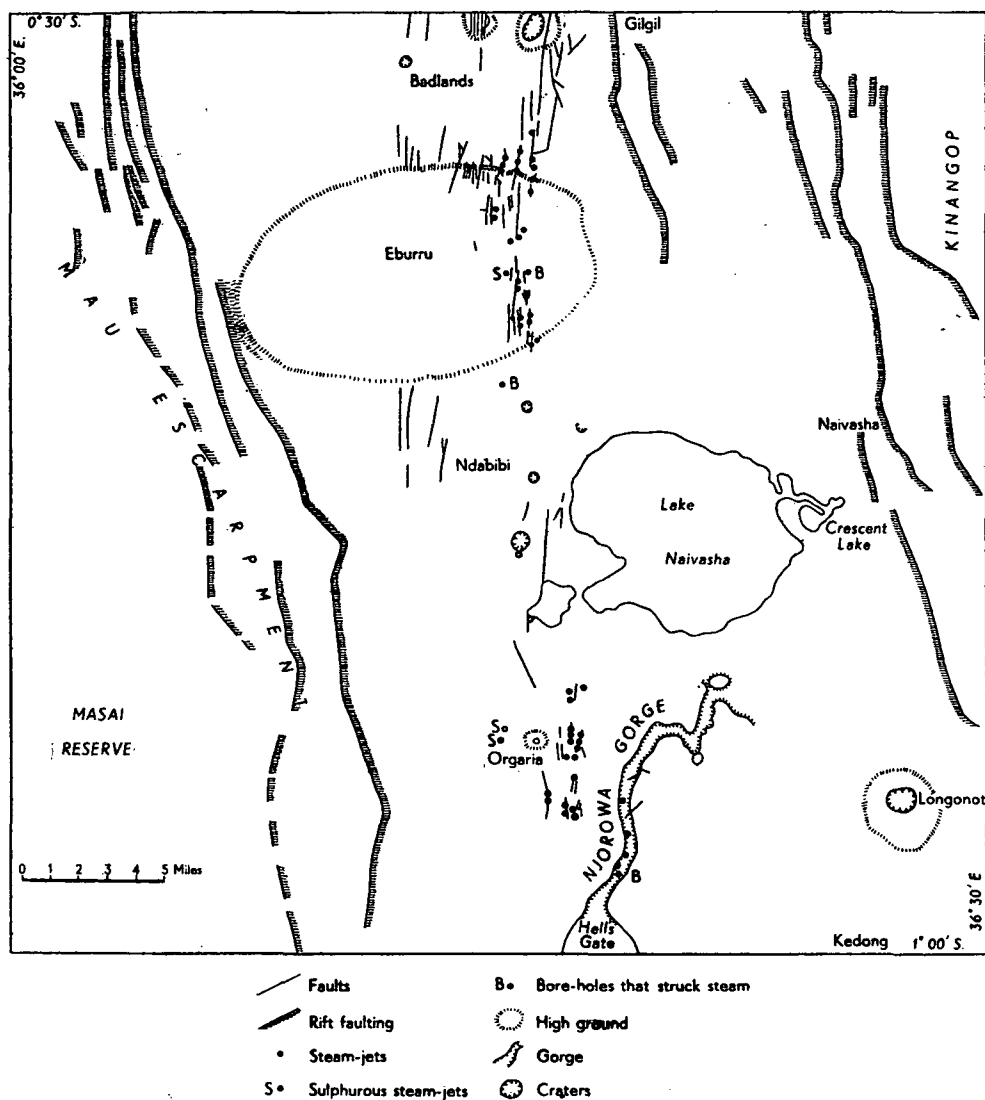


Fig. 9—Distribution of steam-jets in the Naivasha area.

(3) COMPOSITION OF THE STEAM

Most of the steam is remarkably free from impurities. Local farmers make extensive use of water condensed from it for drinking and other domestic purposes. Certain exceptional steam-jets contain detectable amounts of hydrogen sulphide and possibly sulphur dioxide, and at two sulphurous steam-jet sites near Orgaria a small amount of native sulphur has been deposited around the vents. Some of the steam-jets near the eastern summit of Eburru are slightly sulphurous. As yet few analyses

of the steam have been carried out, the following being the only ones available at present (figures expressed as parts per 100,000):—

	1	2	3	4
Alkali as CaCO_3 ..	nil	nil	nil	nil
Alkali as Na_2CO_3 ..	0.4	1.2	0.5	—
Alkali as NaHCO_3 ..	—	—	—	3.5
Chlorides ..	0.1	nil	0.1	0.4
Sulphates ..	trace	trace	trace	trace
Fe ..	0.3	trace	trace	0.14
Total hardness ..	—	1.0	0.5	1.0
pH (before removal of CO_2) ..	5.4	5.8	5.9	6.9
pH (after removal of CO_2) ..	5.8	6.8	6.6	7.4

1 and 2—Steam-jets on Wolseley-Lewis farm, on eastern slopes of Eburru.

3—Steam-jets on Alfrey's farm, on eastern slopes of Eburru.

4—Steam-jet in 500 ft. bore-hole (Ministry of Works No. C 704).

Analyst—Government Chemist, Nairobi.

In No. 4 the percentage of uncondensable gases in the steam varied from 0.34 per cent to 0.4 per cent. The analysis of these gases was as follows:—

	A per cent	B per cent
Carbon dioxide (CO_2) ..	77.8	71.2
Oxygen (O_2) ..	2.0	3.8
Hydrogen (H_2) ..	4.2	3.0
Methane (CH_4) ..	8.6	7.6
Inert gases (by difference)	7.4	4.4

Sample A was calculated to have a calorific value of 74 B Th. U/Cu. ft. The flow of gas from the bore-hole was measured as 173 cu. ft./hour.

No other analyses of gases from the steam-jets in the area are available, but in view of the presence of easily detectable sulphides in some of the steam-jets, it is obvious that the above figures do not represent a typical composition of uncondensable gases in the steam throughout the area.

Chemical analyses for sulphate and boron in samples of condensed steam revealed the following results:—

	1 per cent	2 per cent	3 per cent
SO_4 ..	0.0008 grms/litre	0.0011 grms/litre	0.004 grms/litre
B ..	<1 p.p.m.	<1 p.p.m.	<1 p.p.m.

1—From tank near house on Hornsby-Wright's farm.

2—From tank near former Eburru station.

3—From tank on Maiella estate.

Analyst—W. P. Horne and Mrs. Inamdar.
(16-7-56)

By comparison with the steam, ground-water from bore-holes and seepages near Lake Naivasha shows considerably higher proportions of soluble salts. The following analyses comprise samples from the Lake Naivasha area, with a few from scattered localities nearby, including lakes Elmenteita and Nakuru:—

TABLE III
ANALYSES OF WATERS FROM THE NAIVASHA AREA AND SURROUNDING COUNTRY
(Parts per 100,000 except the fluorine figures which are parts per million)

	1	2	3	4	5	6	7	8	9	10
ALKALINITY										
Carbonate	1.1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2.4
Bicarbonate	30.2	10.6	3.73	83.9	85.5	112.1	25.9	112.6	43.5	46.4
AMMONIA										
Saline	0.001	0.004	tr	tr	0.004	n.d.	0.003	tr	0.022	tr
Albuminoid	0.024	0.002	0.012	0.002	0.009	0.004	0.014	0.021	0.013	0.015
Chlorides	1.2	1.2	2.6	8.2	10.7	6.1	3.1	5.0	1.6	1.6
Sulphates	1.2	tr	3.6	2.5	1.5	1.5	3.6	tr	tr	tr
Nitrites	Nil	Present	Nil	Nil	Nil	Nil	tr	Nil	Nil	Present
Nitrates	tr	tr	Nil	Nil	Nil	Nil	Present	Nil	Nil	Present
Calcium	2.65	n.d.	n.d.	n.d.	6.5	n.d.	n.d.	n.d.	4.5	n.d.
Magnesium	0.44	n.d.	n.d.	n.d.	1.8	n.d.	n.d.	n.d.	3.5	n.d.
Iron (as Fe)	0.065	0.025	tr	0.07	0.07	tr	0.04	0.07	0.03	0.07
Silica (as SiO ₂)	n.d.	n.d.	4.6	1.3	1.4	1.9	2.0	1.4	4.8	2.0
Total hardness	8.4	n.d.	5.0	4.0	23.6	8.0	4.0	6.0	25.6	8.0
Total solids	n.d.	n.d.	52.5	117.0	121.0	140.0	45.8	139.0	64.0	61.0
Fluorine	n.d.	3.0	8.4	8.1	6.8	14.1	6.3	17.4	6.0	5.2
pH	7.7	6.8	7.8	8.2	7.7	7.9	8.3	7.9	6.9	8.3

Tr = trace n.d. = not determined

TABLE III—(Contd.)

	11	12	13	14	15	16	17	18	19
ALKALINITY									
Carbonate	Nil	Nil	Nil	15.2	n.d.	150.0	Nil	Nil	2.1
Bicarbonate	32.8	113.2	88.1	12.6	n.d.	138.0	34.0	38.0	32.0
AMMONIA									
Saline	0.004	0.062	0.004	0.006	0.006	0.016	tr	0.006	n.d.
Albuminoid	0.006	0.012	0.009	0.04	n.d.	0.024	tr	0.007	n.d.
Chlorides	1.9	18.0	8.2	1.9	10.0	22.5	2.8	3.85	4.1
Sulphates	tr	5.2	2.0	2.8	7.0	tr	1.5	3.2	tr
Nitrites	tr	Present	tr	Nil	Nil	Nil	Nil	Present	n.d.
Nitrates	tr	Nil	tr	Present	Nil	Nil	Present	Nil	n.d.
Calcium	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.28
Magnesium	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.5
Iron (as Fe)	0.29	0.07	0.05	0.6	n.d.	0.08	n.d.	n.d.	n.d.
Silica (as SiO ₂)	5.2	0.3	1.8	3.9	n.d.	1.4	8.8	4.5	n.d.
Total hardness	3.0	9.0	13.0	1.0	11.5	2.0	3.0	5.5	8.0
Total solids	50.0	201.0	119.5	68.0	97.2	410.00	57.5	61.2	66.88
Fluorine	7.3	14.7	7.3	6.2	n.d.	64.0	n.d.	n.d.	n.d.
pH	7.5	7.3	8.1	9.8	7.35	8.8	7.7	8.2	n.d.

Tr=trace n.d.=not determined

EXPLANATION OF TABLE III

1. Bore-hole C733, about 3 miles south of Gilgil township.
2. Bore-hole C468, Kenya Co-operative Creameries, Naivasha.
3. Naivasha township Supply—believed taken from tap.
4. Bore-hole C2220, General Manager's house, Kenya Co-operative Creameries, Naivasha.
5. Bore-hole C2224, L/O 396/9, S. H. Miller, Naivasha.
6. Bore-hole C2223, L/O 6203, W. Z. Bilous, Naivasha.
7. Bore-hole C2246, Veterinary Station, Naivasha.
8. Bore-hole C2119, Mrs. Bunbury, Naivasha.
9. Bore-hole C2304, L. R. No. 4141, Korongo Farm, Naivasha.
10. Bore-hole C2304 S. A. L. Roberts, Korongo Farm, Western shores of Lake Naivasha (*Note:* Nos. 9 and 10 were taken from same bore-hole, one sample submitted by the owner and the other by the drilling contractor).
11. Bore-hole C2347, H. C. Ferguson.
12. Bore-hole C2430, G. Alcock (eastern shores of Lake Naivasha).
13. Bore-hole C2221, Mr. Davis's house, Kenya Co-operative Creameries.
14. Bore-hole C1395, Oldobeye Estate, Elmentaita.
15. Bore-hole C231, Naivasha township water-supply.
16. Water from Crater Lake; collected by Mr. J. W. Etherington, South Kinangop.
17. Bore-hole C531, Naivasha township supply.
18. Bore-hole C458, A. F. W. Gossage.
19. Lake Naivasha (main lake).

It must, however, be remembered that the steam analyses, few as they are, represent steam in a limited locality and cannot be considered as typical of the steam throughout the area as a whole. Although the present area is not a typical hot-spring area it is of interest to note that Barth (1950, p. 41) concluded that chlorides are practically absent in the early evolutionary stages of hot-springs in general, but are always present in the later stages.

In the Iceland hot-springs and geyser areas Barth reported extensive fumarole concentrations of gypsum, sulphur, siliceous sinter, pyrite, opal and limonite. In the present area most of the steam-jets are surrounded by reddish to greyish crusts which consist mainly of kaolin and a small quantity of salts and hydrothermally deposited material. Samples collected from the Orgaria sulphurous steam-jets showed the following qualitative results:—

Sample	CO ₂	SO ₄	Cl	Borates	Fe	Al	Ca	S	Cu	Na	K
1	nil	some	trace	?	some	some	nil	some	no	large	nil
2	nil	little	trace	nil	slight	some	nil	some	no	some	nil
3	nil	large	trace	nil	slight	some	nil	doubtful	strong trace	slight	nil

Analysts—W. P. Horne; I. R. Inamdar.

When sample 3 was collected, care was taken not to include visible sulphur which occurs as cavity infillings and as crusts fairly extensively throughout the deposits.

A partial analysis of the Perigny fumarole deposits, carried out by W. P. Horne confirmed that the clay-like material there is composed almost entirely of silica and alumina. The deposits are free of boron.

(4) ORIGIN OF THE STEAM-JETS

Two theories have been offered by investigators to explain the presence of steam in the Naivasha area. Scott (1953A) stated his belief that the steam of the jets originated as juvenile water associated with an underlying magma. As has been mentioned (*see* p. 49) Scott envisaged the Rift Valley as the product of fracturing due to the opposing weights of polar ice-caps during the maxima of ice ages. He considered that juvenile steam was entrapped in the magma against what he believed to be the collapsed hanging-wall of the rift-fractures, and also beneath arched Kamasian beds in the Rift Valley floor. The writers were unable to recognize any features in support of this hypothesis. Furthermore, the sealing quality of a succession composed almost entirely of pumice, ashes and other pyroclastics must be considered doubtful.

McCall (1956, p. 405) considered the steam as juvenile and stated "the evidence suggests a widespread source of steam coinciding with a lava reservoir underlying the Rift Valley zone." There is little doubt that a certain amount of the steam is juvenile, but the writers consider that steam from this source constitutes a small percentage of the total steam released in the Naivasha area.

Since recent attention has been primarily directed towards the possibility of harnessing the steam-jets for the production of electricity as is being done at the famous Larderello power stations in Italy, it is as well to consider the salient features of the Italian occurrence for comparative purposes. Mazzoni (1954A, p. 19) described the Larderello steam-jets as a mixture of steam and gases issuing more or less violently and noisily from the ground and characterized by a smell of hydrogen sulphide. Some of the jets had temperatures of more than 450° F. and when shut in pressures are known to build up to between 70 to 430 p.s.i.* Crusts of borates, calcium sulphate, iron sulphate, calcium carbonate, and crystalline sulphur occur around the *soffioni*, as they are locally known, and the borate radicle occurs in the waters associated with the steam and in the saline crusts. The area in which the steam-jets occur is occupied mainly by sediments of Eocene to Miocene age, a relatively small part consisting of serpentine of similar age. The area is well dissected by faults of Miocene age, which are related to the steam-jet distribution. There is no sign of recent volcanism in the immediate vicinity, although it has been suggested that the steam might be connected with a magma responsible for trachytic extrusions about seventeen miles from Larderello. The more widely accepted theory is that the steam originates from a deep-seated magmatic body, the existence of which is suggested by Miocene granite rocks outcropping as islands in the Tyrrhenian Sea to the west. Experiments with laboratory melts indicate that a granitic magma is able to absorb between 7 and 9 per cent of its volume as water, which during cooling would be released as steam. Mazzoni considered the existence of an impervious covering of sediments essential for the build-up of steam pressures, a condition well provided for by shaly horizons in sediments at Larderello. Keller and Valduga (1946, p. 334) considered the Larderello steam to be magmatic for many reasons, the chief being the superheating of the steam, high pressure of the jets, the fact that the volume of steam is not appreciably affected by extensive drilling and finally, the abundance of boric acid and other chemicals in the emanations.

The comparison between the Naivasha steam-jets and those at Larderello made by Scott (1953B, p. 25) was perhaps unfortunate as the two areas have little in common. At all steam-jets examined during the present survey, the steam issues at local surface boiling point, or within a few degrees of it. Pressures of the jets are either negligible or slight and according to several local farmers, two of whom had taken accurate measurements of the water output by condensation, volume is limited i.e. the overall water condensation does not increase noticeably when more bore-holes are sunk in one locality. P. C. Spink (1945, p. 199) stated, however, that in

* p.s.i. = pounds per square inch.

the Naivasha area, the yield of water from a steam-jet can be readily supplemented by trapping another source of supply in the same fissure, and he considered this condition to be suggestive of a considerable supply of plutonic steam. During the course of field-work no confirmation of this statement was obtained, but in view of the limited experimental work of that nature carried out, it is possible that in certain areas the rule may apply. While steam issues from some of the vents under low pressures, experimental restriction carried out by the East African Industrial Research Organization failed to cause build-up of pressure on the 500-foot bore-hole in which steam was struck on Mardon's farm, Eburru. Similar negative results were obtained when a steam bore-hole was restricted by the drilling contractors on the Akira ranch at the southern end of the Njorowa Gorge. Finally, the steam-jets are remarkably free of chemicals, as is shown by the analyses and also by the fact that the steam is extensively condensed for human and animal consumption. No abnormal corrosion of metal pipes could be detected and in nearly all cases the water is free of unusual taste or odour. Exceptional steam-jets, such as those in the vicinity of Orgaria and a few towards the summit of Eburru, contain detectable amounts of hydrogen sulphide.

The thermal areas of New Zealand differ considerably from Larderello. At Waikakai, the largest of the steam-producing areas, the geological succession described by W. M. Hamilton (1955, pp. 36-44) consists of an uppermost layer of loose pumice and gravel, followed by cemented rhyolite tuff which locally includes rhyolite flows, and finally a layer of ignimbrite. On the basis of geophysical information it is believed that greywackés forms a foundation at about 8,000 ft. below the surface. It has been suggested (Hamilton, *op. cit.*) that the steam originates from a deep-seated magma rising through fissures in the greywackés into the overlying permeable volcanics. At present steam is extracted from the surface layer of permeable volcanics, mostly as "flash steam." Bore-holes have been sunk to various depths, usually less than about 2,000 ft., but there is as yet no clear relationship between the depth of a bore-hole and its productivity. When a thermal water-table is penetrated, steam or a mixture of steam and water forcefully discharges at the surface. Use is made of super heated water by leading it into cooling tanks where it forms steam under pressure which can be used as a source of power.

The Icelandic hot-springs area is far more similar to the Naivasha area. Barth (1950, p. 16) states . . . "hot-springs are circulating groundwater of surface origin augmented by steam originally in a superheated state rising from an underlying magma. . . ." In Iceland he considers hot-springs are controlled by the high rainfall and the porosity of local rocks, which are lavas and pyroclastics, ensuring little run-off and high absorption of meteoric water into the water-table. The Yellowstone Park area in America also shows features similar to those of the Naivasha occurrences.

Hague (1910) has shown that the volatiles of lavas are composed of about 95 per cent water, vapour and two per cent carbon dioxide, with chlorides, fluorides, sulphur and traces of other elements as the remaining constituents. Analyses of steam from Larderello, quoted by Mazzoni (1954A), show a similar ratio of water vapour to uncondensable gases—95.55 per cent water vapour, 4.265 per cent carbon dioxide etc. The steam from the 500-foot bore-hole on Mardon's farm on the eastern slopes of Eburru contains between 0.24 and 0.31 per cent carbon dioxide, or roughly, one eighth of the amount indicated by Hague as present in the volatiles of lavas. The writers believe, therefore, that the steam-jets in the Naivasha area are composed mainly of meteoric water, mixed with a certain amount of magmatic steam. The proportion of juvenile steam may be in the order of 10 per cent of the total. Lake Naivasha represents a "hydrographic window" or an outcrop of the water-table in an area of internal drainage and only slight run-off. Free underground movement of meteoric waters is allowed by the porosity of pumiceous, scoriaceous or ashy beds and other pyroclastics, which constitute about eighty per cent of the known volcanics in the area. The lava flows too are usually well-jointed and often

vesicular, allowing free movement to meteoric water. The absorptivity of the Naivasha area is well known—within a few hours after rain, most surface water has disappeared. It is believed that super-heated juvenile steam locally mixes with groundwater, heating it to surface boiling point, the resultant steam being discharged at the surface. Upward movement follows the path of least resistance created by the cracks and fissures.

This explanation of the origin of the steam explains the distribution of the main steam-jets and also such apparent exceptions as the crater of Longonot. The drainage of the crater is completely internal and the extensive jointing and porosity of most of the rocks will permit freedom of movement to meteoric water in the cone. The sulphurous steam-jets of the Orgaria and Eburru areas contain a higher proportion of juvenile material and it is possible that the sulphur is derived from solfataras. There is no evidence to suggest that this sulphur is derived from earlier deposits as has been the case with Silician and Japanese sulphur deposits. Since the steam in the Naivasha area is considered to be composed of partly juvenile material, mixed with heated groundwater there is every likelihood that the Orgaria sulphur is derived from the normal sulphurous gases associated with lava bodies. Nowadays little steam issues from the sulphurous Orgaria jets but extensive crusts of oxidized material and small deposits of salts and native sulphur indicate far greater activity in the past.

In explaining the distribution of the steam-jets the writers consider the following to be controlling factors in the Eburru and Orgaria area. The first is the availability of an adequate water-supply, the heavy rainfall of the Mau Summit area and Eburru itself supplying the northern jets, while the probable southward movement of Lake Naivasha waters would provide the Orgaria area with an adequate water-supply. Secondly thermal zones at these two foci of activity are probably closer to the surface than at any other point in the Rift Valley. In other parts of the Rift Valley, it appears that thermal zones are either non-existent or are so deep that steam does not form and the water is absorbed by upper layers of volcanics or sediments, or in some cases is discharged at the surface as hot-springs such as occur in the Magadi area and other parts of the Rift Valley. Finally, the steam issues from vents aligned along a young north-south completely tensional fault system which produced little horizontal displacement but opened intricate fissure systems, some over a mile long, a hundred feet wide and up to about fifty or more feet deep.

(5) ECONOMIC POSSIBILITIES

Scott suggested investigation with a view to harnessing the steam as a source of power in a manner similar to the Larderello scheme in Italy. The writers believe this to be impractical in the Naivasha area, as there appears to be little chance of encountering steam at sufficiently high temperatures or at pressures of an order suitable for running productive turbines. Mapping of the area proved that the geological succession consists predominantly of vast thicknesses of porous ashes, tuffs, pumice-beds, and intercalated lava flows. The lavas, however, are characteristically well-jointed and frequently vesicular. In addition, the areas in which the steam occurs are characterized by complex fracture systems. The characteristic porosity of local rock types and the extensive fracturing allows sufficiently free movement of steam to prevent pressure build-up in a restricted steam-jet. This is shown by the results of experimental restriction of two bore-holes in which steam was encountered at depth.

In certain circumstances usable steam at high pressures and temperatures can be extracted from deep-lying porous and permeable water-bearing formations. The conditions governing production of the "flash-steam" are as follows: provided the temperature of water contained in porous rock at depth is sufficiently high, that is, closely approaching the boiling point under the pressure at which it occurs, a release of this pressure by drilling into the formation will either lower the critical boiling

point, allowing the water to boil, or alternatively, if the water is allowed to reach the surface it will be converted to steam when either the temperature or pressure is lowered beyond critical levels. If the surrounding rock is permeable there will be an inflow of water at a temperature similar to the water already removed, forming a reservoir of hot water which can be converted to steam. In the Naivasha area, known facts concerning the water-table are not favourable to the belief that "flash-steam" might be obtained by drilling. The known water-table (see Fig. 10) is characteristically composed of cold water and there is no reason to believe that a suitable hot water-bearing formation underlies it. The steam in the Naivasha area is believed to be derived by small quantities of juvenile steam, locally heating small quantities of groundwater to boiling point.

The writers conclude, however, that steam for some purposes could be obtained by drilling in most localities in the two main foci of activity within the north-south fault-zone. For many years farmers have condensed the naturally-escaping steam and steam from bore-holes in different types of condensers, with varied results. Efficient condensers would undoubtedly increase the water-supplies, providing a valuable supplement in areas devoid of regular supplies, such as around Orgaria. These remarks would become particularly applicable if more intensive farming or farming of smaller holdings is attempted in that area. Use has also been made of the steam by circulating it to dry pyrethrum flower crops, and it is possible that further uses might be found for it in ways comparable with those employed in Iceland.

(6) DRILLING OPERATIONS BY POWER SECURITIES CORPORATION LIMITED

In 1954 Power Securities Corporation Limited, secured an exclusive prospecting licence from J. Scott, over an area of some 11,600 square miles, later amended to 6,060 square miles in the Rift Valley *. The area includes all natural steam occurrences in the Rift Valley between the Tanganyika border in the south and the Baringo area in the north.

* The area first licenced was defined as contained by a boundary starting where the Great North Road intersects the interterritorial boundary at Namanga and continuing:—

thence approximately 88 miles along the interterritorial boundary westwards to where that boundary cuts the Loliondo-Narok road;

thence northwards along that road a distance of approximately 70 miles to Narok Township;

thence northwards along the Narok-Marioshoni-Elburgon road, a distance of approximately 60 miles, to the point where that road joins the main Nakuru-Eldoret road at Elburgon Station;

thence northwards along the main Nakuru-Eldoret-Kitale road approximately 110 miles to Hoey's Bridge;

thence up the Nzoia River and the Moiben River to the most southerly point of the Moiben River;

thence approximately $2\frac{1}{2}$ miles due east to the top of Chapman's Peak;

thence in a straight line east by north approximately 75 miles to the top of Losiolo (8,104 ft.), the highest point of the Karissia Range near Maralal;

thence south-easterly for approximately 9 miles to Maralal Township;

thence generally south by this road and other main roads through Maralal, Rumuruti then along the Rumuruti-Nyeri road to where that road crosses the boundary of the Central Province;

thence along the western boundary of the Central Province to where that boundary crosses the Athi River-Kajiado road about one mile south of Athi River Station;

thence following the Athi River-Kajiado-Namanga road to the point of commencement at Namanga but excluding all areas within these boundaries where the metamorphic rocks or their weathered products form the land surface.

The area covered by the licence was reduced to 10,100 in 1956 and again reduced in 1957, when it was defined as: commencing at a point on the Kenya-Tanganyika interterritorial boundary due south of and approximately $44\frac{1}{2}$ miles distant from Lorgasailik trigonometrical beacon;

(Continued on page 62)

Following a survey of the Eburru and Orgaria thermal areas by Mr. D. Marriott, engineer-geologist, it was decided to sink an unspecified number of deep bore-holes in the hope of striking steam at sufficiently high pressures or temperatures so that the steam could be harnessed to turbines for the production of electricity, as has been done in Italy and New Zealand. The first bore-hole was attempted at a site one and a quarter miles north-east of Orgaria (bore-hole X 1). Drilling operations were greatly impeded by the high proportion of tuffs, ashes and pumiceous layers in the succession. The pyroclastic material proved particularly unsuitable for percussion drilling methods. Drilling on this site was suspended and a new site near the Oserian steam-jet was chosen (bore-hole X 2). The depth reached by the 3rd July, 1958 was approximately 3,090 ft.

According to a statement provided by the Power Securities Corporation Limited:— In this second bore-hole low pressure steam was encountered down to 680 ft. approximately and was cased off. The highest temperature logged was 220° F. at 675 ft. The drill then encountered a dry impermeable zone in which temperatures at the bottom of the hole fluctuated from 150° F. to 195° F. At 2,322 ft. the temperature suddenly increased to 290° F. but this could not be further investigated owing to a drilling mishap and a new, diverted hole had to be drilled. This latter did not yield any abnormal increase in temperature when it passed through the 2,320 ft. level.

Subsequently, a sudden increase of temperature to 350° F. was encountered at 3069 ft. when the drill-pipe became stuck. Efforts to free the pipe and investigate this second increase of temperature are continuing but the suddenness of the temperature increases at 2,322 ft. and 3,069 ft. are considered to be consistent with close approach to, or actual intersection of, a fissure bearing high-temperature juvenile steam.

(Continued from page 61)

thence along the interterritorial boundary on a bearing of approximately 300° for a distance of approximately 37 miles;

thence in a straight line due north for a distance of approximately 16 miles to Escarpment trigonometrical beacon;

thence in a straight line bearing approximately 8° 30' for a distance of approximately 63½ miles to Melili trigonometrical beacon;

thence in a straight line bearing approximately 347° 30' for a distance of approximately 42½ miles to Njoro trigonometrical beacon;

thence in a straight line bearing approximately 355° for a distance of approximately 35 miles to Cobat trigonometrical beacon;

thence in a straight line bearing approximately 30° 30' for a distance of approximately 10½ miles to Kwaibus trigonometrical beacon;

thence in a straight line bearing approximately 60° 30' for a distance of approximately 22 miles to Ngelesha South trigonometrical beacon;

thence in a straight line bearing approximately 165° for a distance of approximately 29½ miles to Thomson's Falls Station;

thence in a straight line bearing approximately 159° 30' for a distance of approximately 34 miles to Kipipiri trigonometrical beacon;

thence in a straight line bearing approximately 177° 30' for a distance of approximately 29½ miles to Kijabe trigonometrical beacon;

thence in a straight line due south for a distance of approximately 4½ miles to intersect the Central provincial boundary;

thence following along the western boundary of that province in a southerly and then easterly direction to a point due north of and approximately 7½ miles from Lamwia trigonometrical beacon;

thence in a straight line due south for a distance of approximately 7½ miles to Lamwia trigonometrical beacon;

thence in a straight line bearing approximately 219° 30' for a distance of approximately 25½ miles to Lorgasailik trigonometrical beacon;

thence in a straight line due south for a distance of approximately 44½ miles to the point of commencement.

The following are the geological successions encountered during drilling operations in the two bore-holes. In both cases they comprise Recent and Pleistocene volcanics and most of the lavas encountered at depth show considerable alteration.

BORE-HOLE NO. X 1

Temperature Range (Fahrenheit)	Depth (feet)	Rock Type
	0- 34	Pumice breccia.
	34- 215	Comendite with intercalated bands of obsidian and, in the lower part, tuff.
	215- 252	Comendite.
120°-160° ..	252- 534	Tuff, mainly soft, but with a compact horizon at 413-507 ft.
157°-178° ..	534- 617	Variable tuffs, the lower section including a fine-grained type with clayey matrix.
156°-178° ..	617- 630	Compact tuff.
128°-204° ..	630- 850	Comendite, with a bed of clayey tuff at 658-660 ft.
202° ..	850- 927	Compact, coarse-textured tuff.
202° ..	927- 953	Tuff with clayey matrix.
202° ..	953- 958	Brown clay.
202°-246° ..	958-1,235	Multi-coloured tuffs with variable matrices.

BORE-HOLE NO. X 2

Temperature Range (Fahrenheit)	Depth (feet)	Rock Type
	0- 37	Overburden.
	37- 97	Volcanic sands and gravels in soil, probably lake beds.
148°-185° ..	97- 176	Tuffs.
185°-190° ..	176- 197	Coarse to medium tuffs.
190°-192° ..	197- 202	Fine tuffs.
188°-200° ..	202- 452	Slightly bentonitic clays alternating with layers of tuffs 5 ft.-20 ft. thick.
198° ..	452- 462	Lava
198°-202° ..	462- 567	Tuffs.
200°-204° ..	567- 577	Lava, probably comendite.
201°-202° ..	577- 637	Tuffs.
202° ..	637- 647	Lava.
202°-220° ..	647- 680	Tuffs.
217°-150° ..	680- 724	Comendite.
150°-155° ..	724- 757	Rhyolite.
155° ..	757- 797	Comendite with intercalations of ash or tuff between 755 ft and 795 ft.
140°-152° ..	797- 930	Rhyolite with tuffs between 862 ft.-872 ft., and 925 ft.-930 ft.
155°-176° ..	930-1,115	Tuff and agglomerate.

BORE-HOLE NO. X 2 (Continued)

Temperature Range (Fahrenheit)	Depth (feet)	Rock Type
152°-164° ..	1,115-1,425	Comendite
164°-184° ..	1,425-1,585	A series of quartz trachyte flows with intercalated tuffs and agglomerates.
184°-196° ..	1,585-1,750	Tuffs.
178°-196° ..	1,750-2,160	Tuff with compact bands, possibly lava, at 1,740 ft., 1,765 ft., 1,820 ft., 1,840 ft., 2,030 ft., 2,040 ft. and 2,150 ft.
178°-290° ..	2,160-2,230	Lava with intercalated tuffs.
	2,230-2,265	Tuffs.
	2,265-2,322	Lava with thin layers of tuffs at 2,305 ft. and 2,320 ft.
Not determined	2,322-2,495	Tuff and agglomerate.
	2,495-2,510	Lava, probably trachyte.
	2,510-2,730	Tuff and agglomerate layers.
	2,730-2,764	Trachyte.
	2,764-3,025	Porphyritic trachyte with bands of compact agglomerate.
	3,025-3,055	Lava, probably trachyte, with associated tuffs.
At 3,069 ft. temp. 350°	3,055-3,080	Tuffs with fragments of quartz and pyrite.
	3,080-3,090	(Not known).
400° ..	3,090-3,096	Somewhat altered trachyte.

2. Sulphur

For some time small sulphur deposits in the Naivasha district have been known. Spink (1945, p. 202) described sulphur in the Orgaria area, pointing out the limited nature of the deposits, and in 1943 B. N. Temperely had investigated the same deposits, concluding that in all there was not more than about five tons of sulphur available (unpublished report). As previously mentioned, some of the steam-jets in the vicinity of Orgaria, and a few at Eburru, are sulphurous although the only obvious accumulations of sulphur occur in the Orgaria area. The sulphurous steam-jets at Orgaria are nearly extinct, but it is apparent that there has been considerable activity in the past.

The sites consist of broad patches of much-altered whitish to grey material rich in kaolin, with a less-altered reddish margin separating them from the surrounding volcanics. The sulphur occurs both as finely disseminated grains in the crusts of altered material, colouring it pale greenish yellow, or as incrustations of bright yellow sulphur usually coating cavities just below the surface of the ground. The deposits are strictly limited in extent and with the possible exception of limited local use, the sulphur cannot be regarded as economic. Pyrite and copiapite (?) were recognized by Dr. W. Pulfrey in specimens collected by steam-jets in the Orgaria area. He also identified alum in specimens from deposits around the large steam-jet in the Njorowa Gorge.

3. Kaolin

In a Mines and Geological Department report on the kaolin deposits of Kenya, written in 1942, C. S. Hitchens described the kaolin deposits at Eburru. He suggested that the kaolin might prove of value as a source of alumina or for blending with other kaolin

clays for pottery manufacture. A number of samples of this kaolin have been examined at various times and in 1953 J. M. Miller carried out a detailed survey and described the kaolin and brick-earth deposits in an unpublished departmental paper. He concluded that the reserves of white clay present on Mardon's farm, Eburru, exceed 69,000 tons. The following are analyses of the Eburru clays together with comparative analyses of aluminosilicate minerals:—

	1	2	A	B
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
SiO ₂	64.73	59.72	46.5	63.4
Al ₂ O ₃	25.99	29.28	39.5	23.9
Fe ₂ O ₃	0.19	1.12	—	—
MgO	0.51	n.d.	—	—
CaO	0.13	n.d.	—	—
H ₂ O—	0.16	2.10	—	—
Loss on Ignition ..	9.15	9.02	14.0	12.7
TiO ₂	nil	n.d.	—	—
	100.86	101.24	100.0	100.0

1. Eburru clay; Analyst—East African Industrial Research Organization.
2. Eburru "kaolinite". Analyst—Government Chemist.
- A. Kaolinite, theoretical.
- B. Cimolite (Anauxite) theoretical.

If these clays are kaolinite, the analyses of samples 1 and 2 would correspond with the following calculated mineral compositions:—

	1a	2a
	<i>per cent</i>	<i>per cent</i>
Kaolinite	65.79	74.13
Quartz	34.10	25.25
Fe ₂ O ₃ , CaO, MgO ..	0.83	1.12
Moisture	0.16	2.10
	100.88	102.60
H ₂ O deficiency ..	0.02	1.36

In the samples examined by Dr. W. Pulfrey in 1947 and other specimens examined by the writers, free quartz was found to be rare. The optical properties of the Eburru clay indicate that at least the bulk of the material is cimolite.

These deposits have been worked for a number of years and in 1956 the total extraction of kaolin amounted to 1,499.1 tons. During the recent war the clay was used for the manufacture of pottery by the Industrial Management Board. North-westward, on the Wolsley-Lewis farm, similar occurrences of kaolin are being exploited.

Mapping of the area has proved the existence of other less extensive kaolin deposits both in the immediate vicinity of the main Eburru sites and in a small area about five miles south-west of Lake Naivasha, near Orgaria. All the Eburru kaolin occurs within a zone aligned in an approximately north-south direction extending across the eastern slopes of Eburru. The more southerly occurrences are situated about one mile west-north-west of Orgaria hill. In present circumstances there is little chance of exploiting the southern occurrences; the reserves are not great, the quality unproved, and the distance from the nearest railhead, Naivasha, over 30 miles.

The white clay was formed by the action of steam on acid lavas, converting the potash feldspars to kaolin. It is interesting to note that the best development of kaolin occurs at the sulphurous steam-jets, which it is believed contain a greater proportion of

juvenile steam. Steam-jets are seldom constant; in most cases thermal activity gradually lessens until the vents become extinct while new jets commence, or in rarer cases, rejuvenation of the older jets takes place. It is, therefore, obvious that the best kaolin will occur on the sites of formerly large, extinct steam-jets. In the early stages of rock decay, before cracking, the altered lavas assume a brick-red colour due to the oxidation of ferromagnesian constituents.

4. Pumice and Pumicite

Pumiceous material occurs extensively both as terrestrially laid bands and as lacustrine beds. Whatever their form of deposition, the pumice layers are usually free of foreign rock. While pumice is found in nearly all parts of the area, the best deposits occur north-east of Longonot station, south-west of Gilgil township (deposits which are at present being exploited), as bands near Nagum and in the Waterloo ridge succession, as valley infilling in the Njorowa Gorge and near Gamble's Cave. Pumicite occurs in bulk in one locality only, a flat open plain believed to be the site of a former lake, about three miles south-south-west of Orgaria.

Pumice is a frothy-looking volcanic glass foam, sufficiently porous to make it buoyant in water. The pore space usually accounts for about two thirds of the total volume. The local pumice varies from greyish to pure white and often has a pearly lustre. It occurs as small rounded pebbles with an average diameter of about one inch, as larger irregular lumps and finally, as larger blocks up to 3 ft. long. Some of the beds are over 40 ft. thick. *Pumicite* is a fine white powdery material chemically similar to pumice. The distinction between the two is merely one of size, the powdery pumicite often being finer than 200-mesh. The local pumicite is pure white and nearly free of visible impurities.

Pumice is used mainly in the production of concrete blocks, when such properties as lightness and insulation against heat, cold and sound, resulting from the high porosity, are desirable. To a lesser extent in crushed form it is used as an abrasive and fairly recently other important uses have been discovered. For instance, crushed pumice is included in plaster for acoustic purposes and it is also mixed with Portland cement to produce a hydraulic cement, better able to resist disintegration by water. Other less important uses that might suit the pumicite are as an insecticide carrier, for insulation purposes, for paint fillers and as an absorbant. To date, the pumice quarried in the Naivasha-Gilgil area has been almost entirely used in the manufacture of concrete blocks. Apart from other possible uses described above, a certain amount of suitable pumice might be sold for toilet purposes. Some African tribes in particular favour the use of pumice stone when bathing.

5. Obsidian and Perlite

Obsidian (volcanic glass) is abundant in the central part of the area where it occurs intercalated with pumice and acid lavas. The best exposed and most extensive flows occur around the northern and eastern slopes of Eburru, near the south-western shores of Lake Naivasha, and in the Njorowa Gorge area. In 1943 B. N. Temperley carried out a search for obsidian in the Naivasha area for use as *pozzuolana*. Later that year, E. Parsons reported on the occurrences following an investigation of material suitable for lining sulphuric acid chambers, and in the extraction of sulphur from pyrite. Parsons described obsidian in the Eburru area only, and considered the material on Marden's farm to be the most suitable for the purpose. In addition to its use as a chemical chamber lining, obsidian has also been used for the manufacture of artificial pumice. S. W. Mudd (1949, p. 45) described a process in which obsidian heated to 900° C. is dropped down a shaft furnace against a rising draught of hot gases. The obsidian swells to porous particles and is then consolidated with lime or cement to a form resembling pumice with an apparent specific gravity less than natural pumice.

Perlite in the geological sense is a variety of obsidian with curving perlitic cracks. The commercial definition is somewhat different, perlite being the pearl-like exfoliation product obtained when certain suitable glassy lavas are expanded by heating. The expansion of such fragments varies between 400 and 2,000 per cent. Some of the devitrified or porous obsidian flows and perhaps a few of the more compact types of pumice might be of use in producing perlite. Heat expansion experiments carried out by W. P. Horne, Chemist of the Mines and Geological Department, on various qualities of obsidian from the Naivasha area, proved disappointing as the maximum expansions at temperatures of about 1,100°C. were in the order of about 400 per cent.

The chief uses for "perlite" are as follows: (1) as an additive to drilling muds, (2) insulation in concrete and block walls, (3) as insulation for steam-pipes, (4) to insulate refrigerators, etc., (5) as a filler and extender in rubber, soaps, paints, plastics, resins, (6) as a filter-aid.

6. Diatomite

Diatomite occurs as discontinuous horizons intercalated with the Gamblian lake beds around Lake Naivasha. With the exception of a few lava flows which extend to the lake shore, most of the present-day shore-line is composed of Gamblian sediments in which the diatomite occurs. The diatomite crops out sporadically, the best exposures being in the south-western shores of the lake.

The diatomite varies from poor quality to reasonably good material, the quality often varying within a given horizon. The chief impurities are clay, grit and pumice. The bulk density of this diatomite is usually of an order of between 12 and 15 lb. per square foot as against about 4 to 7 lb. for the bulk density of high quality material. A sample of diatomite from Willsdale on the southern shores of Lake Naivasha gave the following result on chemical analysis:—

					<i>per cent</i>
SiO ₂	..	..	..	..	73·18
Al ₂ O ₃	..	..	..	..	5·92
Fe ₂ O ₃	..	..	..	..	3·32
MgO	..	..	..	..	0·21
CaO	..	..	..	..	0·65
Moisture (110°C.)	..	..	..	..	9·86
Loss on ignition (1,000°C.)	..	..	..	..	4·08
TiO ₂	..	..	..	..	0·37
Cl ..	..	..	..	..	0·09
SO ₃	..	..	..	..	0·24
Not determined	..	..	..	..	2·08
					<hr/> 100·00 <hr/>

Analyst—M. G. Edwards,
E.A. Industrial Research Organization.

It is apparent from the analysis that there is little chance of extensive exploitation of the diatomite around Lake Naivasha.

7. Building-stones

A number of volcanic rock types in the Naivasha area have been used for building purposes with varied success. By far the most commonly exploited suitable rock is the grey tuff locally referred to as building-stone tuff. It is sufficiently soft to be easily quarried and shaped, while it is tough enough for most building requirements. Weathered it is buff-coloured and while not as compact as the fresh material it can

still be used for less exacting purposes. The grey tuff outcrops as distinctive horizons in the Kinangop volcanics and is also exposed in the valley floor below the eastern scarp. Attempts at using welded tuffs have not met much success. Such rocks are highly brittle, making quarrying operations difficult and shaping unsure in the hands of semi-skilled artisans. Other successful building-stones are the agglomerates and basaltic ashes which form craters on the south-western and western banks of Lake Naivasha. The agglomerates are fairly compact and can be readily shaped into building blocks. While they are probably not sufficiently tough for large buildings they have proved suitable for some houses and farm buildings. The lavas are of little value for building purposes although lava boulders have been used on a limited scale for the building of roofless stock-pens.

8. Road-metals

Most of the lavas occurring in the Naivasha-Gilgil districts can be used as road-metal, railway-line ballast and as aggregate in concrete. The trachytes are probably the most suitable of the lavas as they are usually compact, medium-grained rocks. The phonolites are usually fine-grained and are sometimes considered excessively hard and brittle. The banding, typical of most of the comendites, tends to give them undesirable cleavage, while the basalts such as the Badlands lavas are too hard and their highly vesicular nature detracts from their value as road metal.

Several quarries are being worked in the vicinity of Gilgil township and should the demand arise there are a number of outcrops of medium-grained trachyte suitable for quarrying near Naivasha and Morendat station.

9. Radio-active Minerals

During the past few years there have been reports of radio-activity in some parts of the Naivasha area. H. Vogt recorded slight radio-activity by an air-borne scintillation counter and other prospectors have measured slight radio-activity by means of portable ratemeters.

A specimen of alleged radio-active lava from the Masai Gorge area was examined by the writers and recognized as comendite. It was concluded that the slight radio-activity is caused by the relatively high potassium content of the acid and intermediate lavas abundant in the Naivasha area. Potassium normally contains small amounts of radio-active isotopes. The possibility of the discovery of exploitable radio-active mineral occurrences in the Naivasha area must be considered as exceedingly remote.

10. Other Minerals

For some years there have been local rumours of the presence of valuable minerals, particularly gold and diamonds, in the Naivasha area. It is said, for example, a minor gold rush took place following the reputed discovery of gold on the southern shores of Lake Naivasha. A prospector has also stated that he discovered cassiterite in the area. As the area is occupied almost entirely by fairly young volcanics, and sediments derived from them, of types not normally associated with mineralization of value, the presence of such minerals is considered as exceedingly unlikely.

11. Water

Despite the fair distribution of rainfall in the Naivasha area, water is no mean problem. The long periods in which little or no rain falls has necessitated intensive exploitation of underground water. The only permanent rivers in the area are the Little Gilgil and Melawa which flows into Lake Naivasha at its northern and north-eastern shores. The Karati river near Naivasha is intermittent and largely carries flood water after heavy rains only. However, on account of the very porous nature of many

of the rocks—particularly the lacustrine sediments and the pyroclastics—extensive water-tables exist in the area, one about Lake Naivasha, the lake itself forming a hydrographic window, and another about Lake Elmenteita which is to the north and beyond the limits of the present area. Perched water-tables exist on the flanks of the Rift Valley, and sometimes issue as spring on the down-stepped fault blocks. These springs are not, on the whole, very large but generally sufficient as domestic supplies. One of the larger springs occurs in the Masai reserve south-west of the Maiella house, and it is probable that this perched water-table is also tapped by the tunnel dug by Mr. H. A. Murray several years ago into the Mau escarpment on the Manunga (Maiella) estate, as it was called at that time.

(1) BORE-HOLES

Up to the beginning of 1956, the records of 99 bore-holes in the Naivasha area (see Fig. 10) were available at the Hydraulic branch of the Ministry of Works, Nairobi (see Table IV). For the sake of convenience these bore-holes are here grouped arbitrarily into those drilled in the Rift floor, on the Mau and on the Kinangop. Those drilled in the Rift floor are further divided into two groups viz. those belonging to the drainage system of the Naivasha basin and those of the Elmenteita basin. There is also a further group, classified as "others", drilled in the Rift floor which do not belong to either of these groups in so far as they were not drilled in the Gamblian sediments. The bore-holes under the headings Mau and Kinangop include those drilled on the down-faulted blocks on the flanks of the escarpments. An analysis of the results from the bore-holes is given below:—

	RIFT FLOOR			KINANGOP	MAU
	Naivasha basin	Elmenteita basin	Others		
Number of bore-holes drilled	62	15	11	7	4
Number of unsuccessful bore-holes	2	2	9	1	3
Percentage of success ..	97	87	18	86	75
Aggregate tested yield of bore-holes (gallons)	3,027,660	422,090	78,800	163,200	120,960
Average yield of successful bore-holes (gallons per day)	50,461	32,468	39,400	27,200	40,000

It would be rash to generalize about the bore-holes in the Naivasha area at this stage, but it is considered that neither rock type nor locality influence the yields to any large extent. The reason for the average yield of the bore-holes in the Naivasha basin being higher than elsewhere may be on account of the shallower depth of the water-table, the shallower depth from which water is pumped, the more efficient pumps used during the tests, for example, air-lift pumps, as well as other factors. If the two Naivasha township bore-hole figures (viz. 112,320 and 240,000 g.p.d.) are omitted the average yield drops to about 144,000 g.p.d. If these bore-holes and the other township bore-hole, together with those drilled at Munyu station and Korongo are omitted, the average yield drops to about 40,000 gallons per day per bore-hole.

slightly higher in the bore-holes near Naivasha and on the western side of the lake, which includes most of the bore-holes drilled on the Ndabibi estate. In the Rift floor beyond the area covered by the Gamblian I lake, apart from a few anomalous areas, the water-table appears to plummet to unknown depths south of Lake Naivasha. At the southern end of the Njorowa Gorge, in bore-hole C1525 for instance, water had not been encountered at the depth of approximately 4,650 ft. above sea-level. Steam, however, was struck in the two bore-holes C1524 and C1402, which were drilled to approximately the 4,950-ft. level.

The bore-holes drilled to the north-east and north-north-east of Lake Naivasha, namely C1483, C295, C457 and C465, although sunk within the area covered by the Gamblian lakes, have probably encountered perched water-tables connected with the fault-blocks on the west of the Kinangop. Another anomalous bore-hole is C733, about 3 miles south of Gilgil township lying between Waterloo Ridge and the Gilgil river, where the water-table is probably related to the Lake Elmenteita basin.

Thus it would appear that the underground water-table controlled by Lake Naivasha drops sharply on the southern side beyond the limits of the Gamblian deposits and, if there is a connexion between it and Lake Elmenteita, does likewise on the northern side. It also appears that subsurface recharge of the Lake Naivasha basin takes place from the Kinangop and Mau escarpments in the central region of the lake.

(ii) *Elmenteita Basin*

In general it appears that the water-table in the Elmenteita basin is perched. It appears to be about 200 ft. (61 m.) above the level of either Lake Elmenteita or Lake Nakuru. Recharge of this basin probably comes from the Mau escarpment, with practically none from the Eburru massif—there is a slight suggestion that the water-table drops the closer one approaches Eburru. Unfortunately without more bore-holes in the basin, more cannot be deduced.

It is possible that the various levels of the water-table in this basin are not directly related, being controlled by the different positions of the aquifers in a faulted area and revealed by some bore-holes piercing a few or separate perched water-tables. Bore-hole C965 in the southern part of the Cole estates suggests such a state. This bore-hole, although drilled to a depth of 602 ft. had not encountered water at this altitude of about 5,950 ft., whereas bore-hole C733, about $3\frac{1}{2}$ miles further north-east, struck water at 5,966 ft. above sea-level. It is possible that drilling in the first hole was stopped too soon. The lowest level of the water-table in the Elmenteita basin, that of C429, is approximately at the 5,815-foot level, and if water is at all present in the vicinity of bore-hole C965 it is possible a further drilling of about 135 ft. would have encountered water at the same level.

(iii) *Other Bore-holes Drilled in the Rift Floor*

Of the 11 bore-holes drilled in the Rift floor beyond the limits of the Gamblian I lake level only two were successful, namely C458 and C465 on the trachyte ridge north-north-west of Naivasha. Four (C704 to C707) were also drilled on Eburru and encountered steam—two of them being taken to shallow depths of 130 ft. and 150 ft. (39.6 and 45.7 m.). The deepest of the four bore-holes, namely C704, drilled to a depth of 500 ft. (152 m.), only encountered steam in sufficient quantities for condensing for domestic and agricultural purposes. Approximately 2,000 gallons of water a day are stated to be condensed from this bore-hole. Bore-hole C1524 at the southern end of the Njorowa Gorge also struck steam, but this has not been harnessed for any useful purposes. Bore-hole 101 was probably drilled to too shallow a depth to have encountered water, and probably on the upthrown fault-blocks forming Waterloo Ridge. Its exact position is unknown as it was drilled nearly 20 years ago.

The two successful bore-holes in this group, although drilled in the Rift floor in or near the area covered by the Gamblian lake at its maximum extension, probably encountered perched water-tables in rocks that form part of down-faulted blocks of the Kinangop.

(b) BORE-HOLES OF THE KINANGOP AND MAU ESCARPMENTS

Of the six bore-holes drilled on the flanks of the Kinangop all were successful, but one bore-hole, C1970, on the eastern side of the Mau was unsuccessful, according to the standards adopted by the Hydraulic branch of the Ministry of Works. Only 960 gallons per day were pumped from this hole.

In all the successful bore-holes drilled in these areas, presumably perched water-tables were encountered, as the rest-levels in the different holes vary. It also appears that the average yield of the bore-holes on the Mau escarpment is greater than for those on the Kinangop escarpment and its down-faulted blocks.

(2) RIVERS AND STREAMS

Apart from the water drawn off from the ground-water tables by means of bore-holes in the Naivasha area, riparian owners along the banks of the rivers, chiefly the Melawa, Gilgil and Marmonet, draw off quantities of water for various purposes. The Nakuru municipality is entitled to draw off a piped quantity of one cusec or approximately 538,000 gallons per day from the Melawa river for consumption in the town, and is also permitted to draw off up to 4 cusecs a day provided provision is made for storing the extra water.

The construction of earth dams has on the whole proved fairly successful in the area; some natural shallow ponds are even known to exist on the southern slopes of Mount Longonot in the pumiceous ashes which abound in that region. On the Kinangop there are numerous dams but in all cases a successful impervious layer of clayey materials must be found which will effectively seal the porous and often pumiceous soils that commonly occur where dams are most needed.

It is reported that a concrete wall for a dam constructed on the south-western slopes of Eburru on Ndabibi estate was wrecked by an earthquake several years ago (1928?), but it is unknown if earth dams have been similarly affected.

TABLE IV
BORE-HOLES IN THE NAIVASHA AREA

Bore-hole Number	Name of Owner or Farm (at time of drilling)	Total Depth (feet)	Approximate Contour Height of Bore-hole (feet)	Approximate Contour Height of Water Rest-level (feet)	Yield (galls. per day)
C. 54	Sir J. Ramsden ..	105	6,250	6,200	64,800
C. 61	Sir J. Ramsden ..	520	Position unknown	?	Nil
C. 137	Comtess de Perigny ..	?	6,220	?	10,000
C. 210	Artillery Range Camp ..	220	6,250	6,200	86,400
C. 231	Naivasha Township ..	150	6,250	6,221	112,320
C. 295	B. O. Leas ..	282	6,500	6,377	6,480
C. 457	J. G. Hewett ..	250	6,400	6,312	40,400
C. 465	Foster and Empson ..	325	6,700	6,564	28,800
C. 466	Ndabibi Estate ..	258	6,400	6,236	43,200
C. 467	Sir J. Ramsden ..	313	6,400	6,128	48,000
C. 468	Kenya Co-operative Creameries	152	6,250	6,195	>48,000
C. 531	Naivasha Township ..	200	6,300	6,248	96,000
C. 562	A. L. Block ..	185	6,200	6,125	48,000
C. 563	G. W. A. Tailby ..	103	6,200	6,176	33,200
C. 567	A. L. Block ..	335	6,300	6,116	32,400
C. 578	A. G. de Villiers ..	107	6,250	6,185	42,720
C. 579	J. W. Milligan ..	140	6,200	6,127	36,000
C. 580	E. C. V. Bunbury ..	220	6,300	6,150	36,000
C. 581	G. Colville ..	100	6,250	6,174	38,400
C. 582	B. A. Brannstrom ..	184	6,200	6,155	43,200
C. 594	M. McCrindle ..	112	6,250	6,198	42,320
C. 628	R. B. Wills ..	150	6,250	6,140	43,200
C. 629	N. Anderson ..	199	6,200	6,157	43,200
C. 630-D	G. Colville ..	415	6,450	6,123	11,520
C. 631	M. Rocco ..	150	6,300	6,123	28,800
C. 632	F. G. Taylor ..	108	6,200	6,210	43,200
C. 667	R. B. Wills ..	120	6,250	6,164	42,240
C. 729	A. L. Block ..	600	6,750	6,178	43,200
C. 733	Sir J. Ramsden ..	790	6,600	6,225	20,460
C. 947	F. B. Childe ..	162	6,250	5,966	19,200
C. 1068	G. Hutton ..	250	6,300	6,170	24,000
				6,152	62,400

RIGHT FLOOR—(Contd.)
Naivasha Basin

Bore-hole Number	Name of Owner or Farm (at time of drilling)	Total Depth (feet)	Approximate Contour Height of Bore-hole (feet)	Approximate Contour Height of Water Rest-level (feet)	Yield (galls. per day)
C. 1279 ..	A. L. Block ..	600	6,470	6,070	37,000
C. 1281 ..	A. L. Block ..	104	6,200	6,122	40,800
C. 1356 ..	Berkley-Matthews ..	101	6,200	6,160	57,600
C. 1359 ..	C. T. Todd ..	110	6,200	6,159	48,600
C. 1404 ..	G. Colville ..	345	6,400	6,208	> 72,000
C. 1464 ..	Korongo Farm ..	102	6,250	6,225	67,200
C. 1481 ..	B. O. Leas ..	100	6,200	6,145	36,000
C. 1482 ..	Mr. Hodgkiss ..	119	6,200	6,163	11,200
C. 1483 ..	B. O. Leas ..	150	6,500	6,396	9,600
C. 1486 ..	E.A.R. & H.—Munyu Station	500	6,450	6,120	108,000
C. 1487 ..	E.A.R. & H.—Munyu Station	510	6,450	6,150	155,520
C. 1652 ..	M. Beazley ..	200	6,200	6,175	48,000
C. 1926 ..	Block Estate ..	410	6,500	6,203	36,000
C. 1927 ..	Block Estate ..	137	6,250	6,190	24,000
C. 1947 ..	Naivasha Township	220	6,300	6,248	240,000
C. 2015 ..	W. C. Cooper ..	106	6,250	6,212	> 48,000
C. 2017 ..	R. S. Bunny ..	75	6,200	6,149	16,800
C. 2058 ..	B. O. Leas ..	153	6,200	6,150	33,600
C. 2069 ..	G. Colville ..	259	6,350	6,200	> 21,600
C. 2071 ..	B. L. Turner ..	62	6,250	6,212	21,600
C. 2117 ..	Mrs. Howard ..	86	6,200	6,160	43,200
C. 2119 ..	V. Bunbury ..	91	6,200	6,163	24,000
C. 2220 ..	Kenya Co-operative Creameries	190	6,250	6,150	48,000
C. 2221 ..	G. Davies ..	120	6,200	6,160	48,000
C. 2222 ..	E. C. V. Kelsall ..	160	6,200	6,150	> 48,000
C. 2223 ..	W. Z. Bilous ..	100	6,200	6,159	> 48,000
C. 2224 ..	S. H. Miller ..	150	6,200	6,150	48,000
C. 2241 ..	G. Colville ..	485	6,500	6,099	48,000
C. 2246 ..	Veterinary Department	125	6,250	6,205	26,400
C. 2300 ..	G. Colville ..	371	6,550	6,220	> 50,400
C. 2304 ..	Korongo Farm ..	138	6,250	6,235	264,000

TABLE IV—(Contd.)

RIFT FLOOR
Elmenteita Basin

Bore-hole Number	Name of Owner or Farm (at time of drilling)	Total Depth (feet)	Approximate Contour Height of Bore-hole (feet)	Approximate Contour Height of Water Rest-level (feet)	Yield (galls. per day)
C. 59 ..	Oldobeye Estate ..	460	6,400	6,060	33,600
C. 79 ..	Oldobeye Estate ..	388	6,350	6,029	36,000
C. 266 ..	A. L. Block ..	500	6,300	5,952	33,000
C. 429 ..	Delamere Estates ..	336	6,050	5,815	41,400
C. 431 ..	A. L. Block ..	720	6,450	5,920	24,000
C. 533 ..	A. L. Block ..	725	6,550	5,875	>25,000
C. 845 ..	M. Robinson ..	725	6,400	5,980	28,050
C. 965 ..	Cole Estates ..	602½	6,550	—	Nil
C. 1395 ..	Oldobeye Estate ..	606	6,350	6,050	36,000
C. 1798 ..	A. L. Block ..	622	6,350	5,910	42,240
C. 1877 ..	A. L. Block ..	637	6,500	5,983	36,000
C. 1941 ..	McCall and Aitkenhead ..	567	6,400	5,935	28,800
C. 1990 ..	Delamere Estate ..	340	6,100	5,894	40,000
C. 2059 ..	M. S. Elliot ..	388	6,100	6,033	18,000
C. 2288 ..	Cresswell Ltd. ..	910	6,600	—	Nil

RIFT FLOOR
Others

101 ..	Sir J. Ramsden ..	320	6,500?	—	Nil
C. 57 ..	Sir J. Ramsden ..	308	6,800	—	Nil
C. 458 ..	A. F. W. Gossage ..	336	6,400	6,312	>50,000 (Mineralized)
C. 704 ..	V. R. Mardon ..	500	8,200	—	2,000± (Condensed from steam)
C. 705 ..	V. R. Mardon ..	150	8,200	—	—

TABLE IV—(Contd.)

 RIFT FLOOR—(Contd.)
 Others

Bore-hole Number	Name of Owner or Farm (at time of drilling)	Total Depth (feet)	Approximate Contour Height of Bore-hole (feet)	Approximate Contour Height of Water Rest-level (feet)	Yield (galls. per day)
C. 706 ..	V. R. Mardon ..	130	8,200	—	—
C. 707 ..	V. R. Mardon ..	337	8,200	—	—
C. 1402 ..	E. C. Meyers ..	760	5,700	—	steam
C. 1524 ..	Akira ranch ..	800	5,700	—	steam
C. 1525 ..	Akira ranch ..	711	5,350	—	Nil
C. 1843 ..	Akira ranch ..	840	6,800	—	Nil

KINANGOP

C. 92 ..	Sir J. Ramsden ..	520	7,000	—	Nil
C. 572 ..	M. R. Armstrong ..	520	7,150	6,459	718,000
C. 814 ..	J. Benn ..	370	7,100	6,740	24,000
C. 939 ..	Cedar Mount Dairy ..	491	7,000	6,585	28,800
C. 1488 ..	Maj. Krause ..	300	6,800	6,550	12,000
C. 1892 ..	C. J. Miller ..	841	7,200	6,433	20,400
C. 1898 ..	B. O. Leas ..	336	6,750	?	60,000

MAU

C. 261 ..	W. W. Cresswell ..	500	7,000	6,764	33,600
C. 785 ..	H. M. Harries ..	650	7,200	6,786	> 48,000
C. 1970 ..	Manunga Estate ..	750	8,300	7,875	960
C. 2289 ..	Cresswell Ltd. ..	464	6,950	6,660	> 38,400

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