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MINISTRY OF NATURAL RESOURCES
GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
NAKURU–THOMSON'S FALLS–LAKE HANNINGTON AREA

DEGREE SHEET No. 35 S.W. QUARTER
AND 43 N.W. QUARTER
(with coloured maps)

by

G. J. H. McCALL, B.Sc., A.R.C.S., Ph.D., D.I.C., F.G.S.
Geologist

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FOREWORD

This report covers nearly 2,500 square miles of the central sector of the Great Rift Valley and its eastern shoulders, an area of great diversity of topography and rock-types in which are to be found many vital clues as to the origin and age of the rift. Dr. McCall's painstaking work in describing and unravelling all the evidence contained in this region therefore makes up a volume which is somewhat larger than the normal reports of the Geological Survey, but will nevertheless be of absorbing interest to geologists and geomorphologists.

The author describes repeated rhythmic successions of lava types erupted at intervals from early Miocene times almost to the present day, and shows that the volcanic activity in the area was accompanied by major episodes of faulting which formed the Rift Valley as it is seen today. From evidence derived mainly from lake sediments intercalated with the volcanic rocks, the later of which sediments contain archaeological remains, Dr. McCall has drawn up a detailed table of the various geological events and their dates.

Particular attention is given to the origin of the welded tuffs and associated rock types which cover many hundreds of square miles of the Rift Valley and its shoulders, and the author's explanation of their origin, which is something of a revolution in geological thinking, will certainly stimulate a good deal of discussion.

The area's only mineral of present economic importance is diatomite, but detailed descriptions of hot springs and steam jets, which are locally abundant, suggest the area may be of interest on account of the possibility of utilizing geothermal energy for the generation of electricity.

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Commissioner of Mines and Geology.

4th August 1966.

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ABSTRACT

The geology of the Nakuru-Thomson's Falls-Lake Hannington area, which lies within the Gregory Rift Valley and on its eastern shoulder, is complicated. From Miocene times to the present day eruptions of lava have taken place at intervals from central and fissure sources. The earliest eruptions were the most extensive, while the recent eruptions were of very small magnitude. Throughout the long history of repeated Cainozoic eruptivity two suites of lava were erupted—a weakly alkaline basic suite with ultrabasic associates, and an alkaline intermediate suite of strongly sodic character. The parent magma bodies of these lavas are never exposed, but the occurrence locally of syenite boulders provides a clue to the nature of the parent magma of the intermediate suite. The total volume of lava is immense; this is one of the world's major volcanic fields. Vulcanicity occurred in episodes of decreasing magnitude—Miocene, Pliocene, Lower Pleistocene, Middle Pleistocene, Upper Pleistocene and Recent—and each volcanic outpouring was succeeded by movement, normal faulting compatible with distension of the crust. Major faulting episodes occurred after the Miocene vulcanicity, in the Pliocene and after the Lower Pleistocene vulcanicity. Minor renewals of movement have occurred later than the middle Pleistocene. The zone of activity—vulcanicity and movement—in the Rift Valley is seen to become progressively narrower.

Sedimentation occurred in lake basins throughout the Cainozoic history of the central Rift Valley from Miocene times onwards, and diatomitic fauna flourished in the soda lakes throughout. Only the diatomite deposits of the Middle Pleistocene soda lake are of economic significance. There are no other mineral deposits of any importance.

The area is characterized by senescent vulcanicity along the Rift Valley floor. The main thermal agent is hot juvenile CO_2, and juvenile steam seems not to be emanating from the underlying magma bodies, now in the last stages of cooling. This suggests that drilling for geothermal steam can never be of any economic value. Nitrogen believed to be of juvenile origin was recognized in fumarole gases, but the search for helium was abortive.

Geophysical and hydrogeological notes support the geological information. The most interesting geophysical features of the area are the minor seismicity and the gravity anomalies suggesting isostatic disequilibrium.

GEOLOGY OF THE NAKURU–THOMSON'S FALLS—LAKE HANNINGTON AREA

I—INTRODUCTION

1. General Information

The Nakuru-Thomson's Falls-Lake Hannington area comprises two quarter-degree sheets, namely Sheet No. 35, south-west quarter (No. 105 of the Directorate of Overseas Surveys) and Sheet No. 43, north-west quarter (No. 119 of the Directorate of Overseas Surveys). The boundaries of the area are delineated by latitudes 0°30′N. and 0°30′S. and by longitudes 36° and 36°30′E.

The area is one of the most diverse in Kenya, extending as it does from high moorlands over 9,000 feet above sea level to the hot lowlands of Baringo at little more than 3,000 feet. The north-western portion of the area is part of the Baringo District, whose District Commissioner's offices are at Kabarnet, outside the area, with District Officer's stations situated at Marigat just outside the extreme north west corner of the area, and at Eldama Ravine to the west of the area. There is an additional administrative post at Kisinana Camp, staffed by an officer of the African Lands Development Organization. This part of Baringo District is rugged and stony in the extreme, and though a limited amount of cultivation is carried out the herding of flocks of cattle and goats form the main occupation of the Tugen people who inhabit all but a small portion of that part of the district lying within the area. A nomadic tribe, the Njemps, inhabit a small area near Ngambo and Logumkum and the northern part of the Ngelesha reserve. This latter reserve, situated on the rugged, dissected and many-tiered Laikipia Escarpment, is not now permanently inhabited, but is open to restricted grazing at certain periods of the year. The higher parts of the area lie within the Nakuru District (administered from the town of that name), the Laikipia District (administered from Thomson's Falls) and the Naivasha District. The greater part of the land within these districts is laid out in farms, but there are extensive areas of forest conserved by the Forest Department.

Nakuru is a thriving centre of the farming area with many industries related to the farming community. Smaller townships are situated at Thomson's Falls, Ol Kalou and Gilgil. There are numerous small trading centres both in the settled area and within the reserves.

2. Climate

As would be expected the climatic conditions match the topographic variety of the area. The high plateaux of Supuko Lereko, Ol Bolossat, North Kinangop, Bahati Forest and Laikipia are inclined to be cold and misty, while Sattima and Kipipiri are usually masked in clouds. The lower lying area around Gilgil and Elmenteita is often hot and humid, especially in the lake basins. The country north of Nakuru becomes hotter and more humid as the land drops to Lake Hannington. This lake lies in a cleft shut off from the prevailing wind and is probably one of the hottest parts of Kenya. The plain to the north of Lake Hannington is a little more clement in climate being less shut in. The Ngelesha reserve is exceedingly hot and lacking in surface water: the prevailing wind is shut off by the rift wall, and the sun beats down with fierce intensity, reflecting off the bare rock surface.

Rainfall is fairly high on the high ground of the Rift Valley shoulders, falling off appreciably in the lake basins and the low country of the Kamasia reserve. Rainfall records are kept at 57 stations in the area (none are kept in the north of the area) and the isohyet diagram (Fig. 1) has been compiled from the records of these stations kept by the East African Meteorological Department.

3. Communications

A tarmacadam road runs between Gilgil and Nakuru, part of the main "Cape-to-Cairo" trunk road. Tarmac branch roads also extend from Nakuru to Njoro, and part of the way from Nakuru to Solai. A good earth road connects Nakuru and Thomson's Falls. There is a network of good roads around Nakuru, Solai, Subukia, Thomson's Falls, Ol Kalou, Gilgil and Elmenteita. A fine earth road connects Nakuru and Marigat, but in the Baringo district to the east roads are frequently primitive, boulder strewn and often difficult to follow. The main line of the old Uganda Railway (now East African Railways and Harbours) passes through the area between Gilgil and Menengai Stations. Branch lines serve Solai and Thomson's Falls.

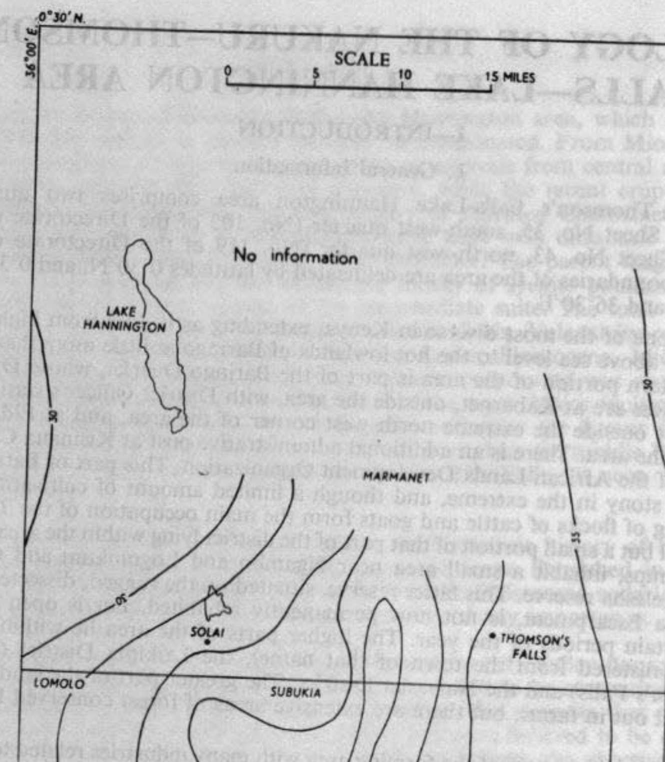


Fig. 1—Isohyet diagram of average rainfall in inches per year.

4. Maps

Geological information was recorded in the field on R.A.F. and Hunting Aero-Surveys Ltd. aerial photographs at a scale of approximately 1:30,000, and transferred to 1:50,000 maps of the Survey of Kenya. The four printed sheets covering the southern part of the area are contoured, but contours in the northern half of the map area were drawn by the author using spot-heights obtained from aneroid barometer readings. Closely spaced traverses were possible in the settled area and in the southern part of the Baringo District where roads are numerous, but in the barren waterless and rocky country of the Ngelesha reserve and along the Laikipia Escarpment difficulty of access necessitated wider spacing of the traverses.

5. Acknowledgements

The writer acknowledges with thanks the assistance of Dr. B. N. Temperley and Mr. C. M. Bristow of the Water Resources Department of the Ministry of Natural Resources and Wildlife, as detailed on p. 4. He is also indebted to the following for assistance and hospitality during the course of the survey:—

The District Commissioners, Baringo District and Laikipia District; Mr. J. Lightbody and Mr. E. Chapman of the Forest Department, Thomson's Falls; Mr. R. Edmondson of A.L.D.E.V., Kisinana Camp; Lt.-Col. S. Reeder of Solai; Lt.-Col. E. R. Bushell of Menenhill Farm, Nakuru; Mr. W. B. Lambert of Chui Farm, Subukia, and the Manager and Staff of Kipipiri Estates. The Survey of Kenya, the Meteorological Department, The Ministry of Works and the East African Railways and Harbours supplied certain material for incorporation in this report. Dr. D. Masson Smith of the Directorate of Overseas Geological Surveys gave invaluable advice in the preparation of gravimetric data.

II—PREVIOUS GEOLOGICAL WORK

Following the pioneer journeys of Joseph Thomson (1885)* through Baringo during the last century, the geologist J. W. Gregory passed through in 1893. He made many observations of a general nature, and his conclusions are contained in two volumes (Gregory, 1896, 1921). Gregory's stratigraphic classification of the volcanic and associated rocks of the Rift Valley zone is given by Shackleton (1945, p. 1). This classification does not stand up to the test of more detailed surveys, and has long since been discarded. Gregory however made observations of the greatest importance and there are numerous references to his work in the subsequent text.

Of the specimens collected by Gregory many were examined by Prior (1903), whose petrographical classification appears somewhat outdated to modern eyes—such terms as phonolitic-quartz-trachyte nowadays raise a smile—but quite different criteria were used in nomenclature at that time and textural variations were given a much greater importance than overall compositional characteristics. Prior defined certain textural varieties in the phonolites—the terms 'Kapiti', 'Losoguta', 'Kenya', 'Kamasia' and 'Intermediate' have been in use for many years, and have been further elaborated in descriptions by Campbell Smith (1931, 1950). They have at times appeared to have been given a stratigraphic significance which is not warranted. The present work would seem to support the idea that in any phonolite group of one age many of these textural types can be seen, and stratigraphic significance of textural types is very limited.

Nilsson (1929, 1932, 1935, 1940) investigated Quaternary lake deposits and shore-lines in the Nakuru-Elmenteita, Naivasha and Baringo basins. He elaborated his conclusions in several short later papers, but his 1932 paper provides the basic information as to Quaternary rise and fall of the lakes as far as he measured it by means of recognizable shoreline features.

Leakey (1931), with Solomon, investigated Pleistocene and Recent deposits and shore-line features in the Nakuru basin and published their conclusions. They adopted a classification based on climatic variations, equating certain deposits in the Nakuru Basin with the

*References are quoted on p. 120.

Pleistocene pluvial periods and minor post-Pleistocene wet periods. Using artifacts as a means of dating the sedimentary formations in the Nakuru Basin, they established the following succession:—

Nakuran } ≡Post-Pleistocene wet periods
Makalian }

Gamblian ≡Upper Pleistocene pluvial

Kamasian ≡Middle Pleistocene pluvial

Leakey (1950), later divided the Kamasian into a lower (Kamasian) and an upper (Kanjeran) division. The equation of sediments at Kariandusi with those of the Kamasian type area at Marigat (Baringo) was dropped, and instead the Kariandusi diatomitic sediments were equated with those carrying Middle Pleistocene artifacts at Kanjera on the Kavirondo Gulf, and those of Olorgesaile. Cooke (1957, p.13) questioned the climatic basis for the classification of the Pleistocene sediments of the Nakuru basin, and the extension of the term Kamasian in Kenya and Tanganyika (Olduvai) to include sediments quite unrelated to those of Kamasia. He also demonstrated (pp. 39–41) that the concept of a continuous 'Lake Kamasia' in the Kanjeran epoch was most improbable; Bailey Willis (1930, pp. 79–80) had already suggested the improbability of this concept. 'Lake Kamasia' was suggested by Gregory (though he nowhere suggests that it extended to so late an epoch) and the concept has been extended by a school of archaeologists (Cole 1954, chapter 2) whilst Fuchs, who visited the Baringo district, seems to place the tectonic fragmentation of the Rift Valley basins into their present separate entities as later than Gamblian (Upper Pleistocene). Fuchs has published two papers dealing with the Baringo basin (1934, 1950), his main conclusions being included in his 1950 paper. He attempts to demonstrate the existence of a shore-line at 3,800 feet above Lake Baringo to the west of Marigat and tentatively identifies sediments associated with tuffs at Maji ya Moto (Ndolaita) in the present area as being the southern equivalent of the Kamasian lake deposits. McCall and Walsh (McCall, Baker and Walsh, 1965) have recently re-examined the type sections of the Kamasian described by Fuchs and their revision of this important type area involves considerable modification of Fuchs' ideas. Their suggested revised classification is given on page 72 of this report.

L. C. King (1951, p. 148) mentioned Menengai Caldera in a text-book on land forms.

Shackleton surveyed the country to the east of the area (1945, 1946) and these two geological survey reports provide a basis for much of the succession derived in the present area.

McCall (1957 (*a*)) described Menengai caldera and (1957 (*b*)) gave a brief account on geothermal steam occurrences in the Rift Valley with special reference to Nakuru and Kamasia. In the latter paper he disputed various conclusions published by J. Scott (1953) suggesting the existence of such immense volumes of steam trapped under an impervious cover as occur at Lardarello, Tuscany. McCall (1957 (*c*)) also published a detailed survey of geology and groundwater conditions in the Nakuru area. In both this and the paper on Menengai (1957 (*a*)), the lack of petrographical facilities was a handicap and the more detailed petrographical examinations since carried out and much greater volume of data available, have necessitated some revision of the distribution of the geological formations and dating previously given in those papers.

Thompson and Dodson (1963) surveyed the Naivasha area to the south.

Dr. B. N. Temperley and Mr. C. M. Bristow, geologists of the Water Resources Department of the Ministry of Natural Resources carried out detailed investigations of parts of the area concurrently with the author. Temperley mapped the Kinangop Tuff formation and associated lavas north of Gilgil, and Bristow much of the north-eastern quadrant of the Nakuru sheet. Some of the material incorporated in the present map and report has been derived from discussion and collaboration between the author and the above-named geologists. In addition Bristow carried out geophysical surveys over part of the area, and the sections in this report dealing with magnetometric and resistivity surveys are based on his work. The same geologist also collaborated in the writing of the chapter on structure.

III—PHYSIOGRAPHY

1. Topography

The amazing topography diversity of this area of 2,400 square miles compares strictly with the flat and featureless expanses that abound in eastern Kenya. It owes its diversity entirely to the tectonic and volcanic disturbances of the Rift Valley which have dislocated the peneplained surfaces of the African shield, forming separated ridges and troughs, tending for the most part north-south and piling up great masses of volcanic rock on these structures. The process of dislocation and eruption was complex, many separate periods of activity being represented, and the physiography reflects this complexity. The greater part of the area is in the complex rift zone and characterized by this serrated topography, but a small part of the area near Rumuruti contrasts with this in being a gentle sloping lava plain falling north-eastwards away from the edge of the Rift Valley (Shackleton, 1946, p. 2). Nowhere is the ancient peneplained continental surface of crystalline rock exposed within the area, and since the area is one of internal drainage into the Rift Valley (except for a small portion in the north-east part), nowhere are continent-wide erosion surfaces to be seen.

The area lies partly within the main Rift Valley and partly on the shoulders. In the north it comprises the Laikipia Escarpment which rises from the rift floor at Lake Hannington, situated at an altitude just above 3,000 feet above sea level, the western edge of the Rumuruti plains at an altitude just above 7,000 feet, and the Marmanet Forest (above 8,000 feet).

Lake Hannington is a narrow soda lake lying in the trough formed between a fragmented eastwards sloping lava plateau situated to the west of it and the great fault scarp to the east. Nilsson (1932, p. 68) thinks the lake may be quite deep. This is suggested by the eastwards sloping topography of the lava plateau on the west side of the lake and the direction of throw of the faults to the west of the lake. The lack of any thickness of sediments around the lake suggests that it is a comparatively recent feature of the Rift Valley. It seems unlikely from the lack of influent rivers that the lake itself is heavily silted up except at its north end but it may be infilled with boulder material fallen from the eastern escarpment. To the north, silt brought down by the four great rivers which converge between Hannington and Baringo has divided the once more extensive Lake Baringo joined with Lake Hannington into two parts, and formed the low lying plains of Loboi, Logumkum and Marigat. These plains standing at an altitude of about 3,200 feet are composed of salt-impregnated silts which seem to have a restrictive effect on vegetation and they have a very bare appearance though this may be entirely due to over-grazing.

Lake Hannington is bounded on the north by the alluvial plain dividing it from Lake Baringo, and on the west by a complex plateau of lava broken into horsts and graben, the highest ridge of which forms Kwaibus (5,066 ft.). The Laikipia Escarpment, which is much dissected in the north, is there composed of three or four distinct escarpments. Farther south, to the east of Lake Hannington, only two escarpments bound the Rift, both over 2,000 feet high, whilst to the south-east of Lake Hannington three distinct steps are seen, the Lake Hannington Escarpment, the Solai Escarpment and the Lolderodo-Maryland-Chui Escarpment. These three tiers step up the land surface from Lake Hannington to an altitude of 9,420 ft. at Lolderodo, the highest point in the area, and the summit of the Bahati Forest uplands. The three escarpments are all due to major fault displacements. At the foot of the Solai Escarpment is Lake Solai, now dwindled to a swampy depression. To the east of the Bahati Forest and dying out at Thomson's Falls is a shallow asymmetrical graben: the plain occupying its floor is an extension northwards of the Kinangop Plateau (Shakleton, 1945, p.7). In this trough lies the small fresh-water lake of Ol Bolossat, the highest of all the Rift Valley lakes, which stands over 7,600 feet above sea level, perched on the divide between the Uaso Narok drainage northwards towards the arid flats of the Northern Frontier Province, and the Melawa-Turasha drainage system plunging southwards to Lake Naivasha, an internal drainage system within the Rift Valley. The graben in which Lake Ol Bolossat lies is bounded by weak faulting on the west, developing increasingly to the south, and on the east by the Sattima Escarpment running south from Thomson's Falls, where it takes the place of the Laikipia and Chui-Lolderodo Escarpments as the easternmost scarp of the Rift Valley. This escarpment develops southward into the great three thousand foot feature bounding Sattima on the west. In the south-east corner of the area Kipipiri rises three thousand feet from the Ol Bolossat plain, an isolated volcanic eminence separated from the Sattima massif by the deep cleft of the Wanjohi Valley. Further to the west the land surface is broken by faults forming a complex of shallow horst and graben structures. The Ol Bolossat plain near Ol Kalou is bounded on the west by a series of tilted fault blocks separated by more than a dozen fault scarps which drop the land surface from the Bahati uplands down to the Bahati plain. This flat soil-covered expanse lies to the north of the Lake Nakuru basin and is bounded on the west by the volcanic eminence of Menengai which rises to 7,458 ft. above sea level. A flat swampy clay-filled pan occurs in a depression at the west margin of the area—the Ol Punyata swamp. To the south the volcanic pile of Menengai rises, the country becoming less broken as the caldera is approached and the fault scarps gradually die out. The slopes of Menengai are in general fairly gentle. Deep valleys cut into the soft pumice mantle give a dissected appearance, though this cannot be taken as indicative of any great age. The highest ground is situated to the south and north-west of the caldera—an immense pit thirty-five square miles in extent which is bounded by an almost vertical wall only absent in a few short sectors of the circumference of the caldera. The caldera is filled with a confusion of slaggy bouldery lava flows and cinder cones; these slaggy accumulations are piled up to form a central eminence at 6,858 feet.

South of Menengai is Lake Nakuru (5,776 ft.) lying in a graben between Sirrkon or Lion Hill Volcano (6,881 ft.) and the Mau Escarpment, the west wall of the Rift Valley, the base of which lies within the south-west corner of the area. To the east of Sirrkon is Lake Elmenteita, situated in a complex trough at an altitude of 5,830 ft. This trough is bounded on the north by the southern end of the Bahati Escarpment and on the east by the relatively low Gilgil Escarpment separating it from the northern end of Lake Naivasha basin in which Gilgil township lies. To the east of Gilgil the North Kinangop Escarpment bounds the extreme north end of the Kinangop Plateau which, flanking the Aberdare mountains on the west side, continues the Ol Bolossat plain southwards. The Elmenteita basin is bounded to the south by the volcanic pile of Eburru. Between Eburru and Elmenteita are some basaltic cones and very recent lava flows which form a "pock-marked", rocky wilderness known as the Elmenteita "badlands". The cones stand up as striking features from the plain.

2. Drainage

The greater part of the surface drainage is internal into the Rift Valley. The exception is the Uaso Narok drainage system which takes the water from the Rumuruti plain and the area around Thomson's Falls including the Ol Bolossat lake and swamp, Thomson's Falls swamp and Nakuru swamp (Fig. 2).

(1) Drainage Outside the Rift Valley

The Uaso Narok river is fed by the Ol Bolossat swamp and the Naururu-Equator tributary. The latter is estimated by hydrologists of the Ministry of Works to provide 90 per cent of the flow, the Ol Bolossat swamp providing the remaining 10 per cent. The Naururu stream drains the Thomson's Falls swamp and Naururu swamp, much smaller features than Ol Bolossat swamp. Lake Ol Bolossat has been mentioned by Shackleton (1944, p. 7). He considers the lake to have dwindled from a more extensive lake, and this is certainly supported by the presence of a raised shoreline east of the Lake on Macgregors Farm. It is the opinion of the writer however that the lake was never very extensive. Its position on a saddle excludes great extension and there are no exposures of ancient lacustrine sediments nearby, if minor and localized swamp fillings such as are exposed south-west of Thomson's Falls are excluded. Shackleton attributes the process of dwindling to silting up, and progressive dessication since Upper Pleistocene times (Gamblian pluvial phase). The lake has been plumbed by hydrologists of the Ministry of Works in three places and found to be not more than seven feet deep. It is fed by springs from the water table raised up in the Sattima Escarpment to the west. The water from these springs tends to flow for a limited distance before going down into the talus and feeding the lake as a subsurface source. Recharge from the south and west is negligible. The lake water is brackish.

The Uaso Narok river falls in a sheer drop of over 100 feet over a ledge of the Thomson's Falls phonolite, and collects many tributaries on the way to Rumuruti where it loses its identity in the Uaso Narok swamp. It is a perennial stream throughout its length in the area. The river appears to have captured drainage which formerly fed Ol Bolossat.

The headwaters of the Pesi, Kanyagia and Moridjo streams drain the Supuko Lereko plateau towards the Uaso Ngiro in the north-west. The Supuko Lereko plateau is tilted to the east and the headwaters cut right back to the very edge of the Sattima Escarpment.

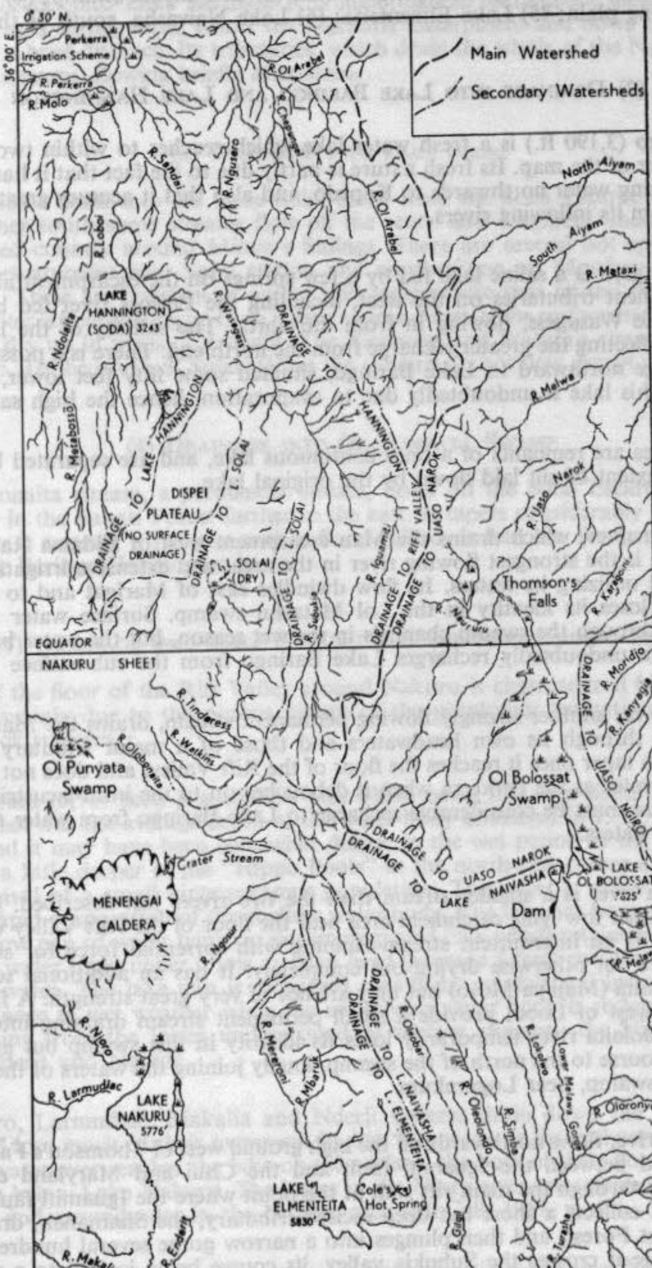


Fig. 2—Map of the drainage systems in the Nakuru-Thomson's Falls-Lake Hannington area.

The systems draining into the Rift Valley discharge into (1) Lake Baringo, north of the map area, and Lake Hannington; (2) Lake Solai; (3) Ol Punyata swamp; (4) Lake Nakuru and surrounding plain; (5) Lake Elmenteita; (6) Lake Naivasha, south of the map area.

(2) Drainage into Lake Baringo and Lake Hannington

Lake Baringo (3,190 ft.) is a fresh water lake which reaches to within two miles of the northern border of the map. Its fresh nature is partly due to the fact that it has a submarine outlet discharging water northwards to Kapedo, and also that it accrues great quantities of fresh water from its inflowing rivers.

Lake Hannington is a saline lake fed by a few springs on the escarpment above it, some small impermanent tributaries on the west, including the Emsoss river fed by strong hot springs, and the Wasagess, flowing in from the north. The salinity of the lake increases to the south, reflecting the greater recharge from the north end. There is a possibility of sub-surface drainage northward to Lake Baringo, situated some fifty feet lower, but most of the loss from this lake is undoubtedly due to evaporation, hence the high salinity.

The two lakes are remnants of a once continuous lake, and are separated by the Loboi plain, a wide extent of silt laid down by the original lake.

The Perkerra river, which drains the Mau escarpment west of Eldama Ravine and the Kamasia Hills, is the strongest flowing river in the area, and extensive irrigation is carried out at Marigat utilizing its waters. Its flow dwindles east of Marigat and to the north of Logumkum it loses its identity in the Lol Matashu swamp. Surface water only reaches Lake Baringo through the swamp channels in the wet season, but the water brought down by the Perkerra undoubtedly recharges Lake Baringo from the sub-surface water-tables.

The Molo river, another strongly flowing permanent stream, drains the Mau near Molo and Elburgon, through its own headwaters and those of a major tributary the Rongai river. It tends to taper once it reaches the floor of the Rift Valley, and does not carry such a great body of water as the Perkerra when it debouches on to the intra-lacustrine silt plain. Once again there must be considerable recharge to Lake Baringo from water tables fed by the Molo river waters.

The Ndolaita river is a smaller stream than the two rivers just described. It obtains its water from a rather low lying catchment area near the floor of the Rift Valley west of Lake Hannington. It is an intermittent stream running with torrential force for short periods after downpours but otherwise drying out completely. It has an additional source in hot springs at Ndolaita (Maji ya Moto) but they are not of very great strength. A further series of hot springs west of Loboi provide a small permanent stream draining into the Loboi swamp. The Ndolaita river temporarily loses its identity in this swamp but again follows a well-defined course to the north of the swamp, finally joining the waters of the Molo river in the Ngarua swamp, near Logumkum.

The Iguamiti river flows northwards off the high ground west of Thomson's Falls following a valley situated between the Iguamiti fault and the Chui and Maryland escarpments. The river breaks through the main rift wall at the point where the Iguamiti fault fades out, and here also it collects a short but deep incised tributary, the Shamanek, draining parts of the Marmanet Forest, and then plunges into a narrow gorge several hundred feet deep. Beyond the gorge it crosses the Subukia valley, its course being incised to a very limited extent, and joins the Subukia river, draining the whole length of the Subukia valley. The united stream, the Wasagess, collects many tributaries from the Laikipia Escarpment and a few from the Bechot plateau to the east. It curves westwards to debouch onto the Baringo plain at Sandai gorge, and finally reaches Lake Hannington a mile south of Loboi. It is the only powerful stream to feed this lake. The Wasagess dries up in years of drought to as high up its course as Murogors Camp.

The Ol Arabel river drains the northern part of the Marmanet Forest and the Ol Arabel Forest, and drains into Lake Baringo. It is impermanent throughout most of its length, though it collects spring water below the Ngelesha Escarpment and flows once again permanently for a brief distance. Its tributaries, which drain the whole of the Ngelesha reserve, are all flood streams, flowing briefly after rains.

(3) Drainage into Lake Solai

Minor streams drain into the Lake Solai basin from the Solai Escarpment and Bahati Forest. Farther south some streams flow off the scarp and disappear underground in the broken faulted country around Milton's Sidings. There are several hot springs along the foot of the escarpment near Solai station and another one on Mowbray Brown's farm to the south. These are constant in output and temperature year in and year out and undoubtedly water is here welling up from a deep source. Most of the surface streams hereabouts are liable to dry up in times of drought. The Tindaress and Watkin's streams are however fairly reliable. To the north of Solai station the streams do not flow except during the rainy season.

(4) Drainage into Ol Punyata Swamp

The Olobonaita stream, a permanent stream, flows off the Solai Escarpment, draining high ground in the Bahati Forest farther to the east. It tapers considerably before reaching the Oi Punyata swamp, a flat pan with a flood spill-over into the Rongai-Molo drainage system of the Baringo-Hannington basin.

(5) Drainage into Lake Nakuru and the Surrounding Plain

In general the floor of the Rift Valley around Nakuru is characterized by very poor run off. This is mainly due to the porous nature of the pumiceous formations which mantle the older rock surfaces.

Lake Nakuru (5,767 feet) is a shallow pan which never fills to a depth of more than a few feet; 5 feet was the average depth of the water body estimated in 1952, but fluctuations are rapid and it may have been somewhat deeper in the wet period at the time of survey. The lake is a little deeper at the "Hippo Pools" at the north-east corner allowing the precarious survival of a small hippopotamus population. The water is saline in the extreme, due to the rapid evaporation of the shallow water body. The lake has been shown to consist of this shallow pan of water lying on salt-impregnated clay which retains in coarser porous sediments a water body under a low artesian head (average 4 feet) completely distinct from the surface water. The lake pan is recharged mainly by rainfall and increments from the surface drainage in wet weather while the underlying water body is recharged by groundwater accruing from the losses underground of surface streams—the Njoro, Larmudiac, Makalia, Nderit and Ngosur.

The Njoro, Larmudiac, Makalia and Nderit systems drain down the Mau into Lake Nakuru. All lose much of their increment by loss in porous or fissured zones, and no great volume of water ever reaches the lake on the surface, the bulk of their flow accruing to the water tables below Lake Nakuru. The losses in the Njoro river are referred to in the report on geology and groundwater in the Nakuru area (McCall, 1957, p. 43).

The Ngosur river, a permanent stream, and several minor streams flow off the Bahati uplands on to the Bahati plain. They run westwards on remarkbly straight courses across the plain before disappearing underground. While some fault control of these straight courses has been suggested by Bristow, it is more probable that their course is simply controlled by the slope of the piedmont-plain bounding the very straight north-west trending Bahati Escarpment. The Ngosur water passes underground to feed the water table under Lake Nakuru.

North of the Ngosur the Crater stream, a permanent water-course, drains westward from Bahati into the north-east corner of Menengai Crater, on Rhodora Farm. Here this stream, the only one to flow into Menengai, disappears abruptly underground in a swampy area at the foot of the caldera wall. There is no surface drainage in the broken, fissured and porous lava-covered expanse of Menengai caldera other than gully run-off down the caldera walls which at once disappears underground in damp patches at the foot of the caldera wall.

(6) Drainage into Lake Elmenteita

Lake Elmenteita (5,827 ft.) is a shallow saline pan similar to Lake Nakuru, floored by rather coarser salt-impregnated sedimentary material than Lake Nakuru. Its surface increment is from the Mereroni, Mbaruk and Kariandusi streams, and like Lake Nakuru it is also fed from the water tables. Evaporation accounts for its high salinity.

The Mereroni, Mbaruk and Kariandusi streams flow southwards off the Bahati Escarpment and feed Lake Elmenteita. Like all the streams in the Nakuru-Elmenteita basin they taper, showing a considerable decrement through loss underground and the amount of water reaching the lake is not very great. There are some hot springs along the foot of the Bahati Escarpment in this locality and the Kariandusi river is largely fed by Cole's hot springs. These springs are quite constant in output over the years, like those at Solai, and like them are probably fed by very deep water bodies.

(7) Drainage into Lake Naivasha

The Melawa river drains off Sattima, its headwaters reaching up into the highest upland valleys. It plunges down the Sattima Escarpment onto the Ol Bolossat plain through a magnificent steep walled gorge, with walls nearly 1,000 feet high, the Melawa Ndogo gorge. The river cuts a deep trench across the Ol Bolossat plain passing very close to the south end of the lake and separated from it by a divide of very low relief, probably not more than 30 feet. The river turns south and cuts another deep gorge, the lower Melawa gorge, along a fault line, to its confluence with the Turasha river just south of the Melawa Water Scheme Intake. The Turasha river, like the Melawa, is a permanent stream. It drains the North Kinangop Plateau and the mountain range to the east of it. It follows a U-shaped course, flowing northwards from the Kinangop Plateau, collecting tributaries from the forested massif of Kipipiri, before curving right round to join the southward flowing Melawa. Like the Melawa it has excavated a deep steep-walled cut several hundred feet deep in the flat-topped tuff plateau, and its tributaries are similarly incised. The deep steep-walled incisions of these river valleys appear to be due to the sudden lowering of base level in the floor of the Rift Valley consequent on the major fault movement of the Pliocene period. The Melawa Ndogo gorge is related to movement on the Sattima fault at the same time. A similar deep incision in equivalent tuffs is seen at Eldama Ravine on the west side of the Rift Valley. The two streams after being united flow southwards to feed Lake Naivasha.

IV—SUMMARY OF GEOLOGY

There are no rocks exposed in the area older than the Tertiary era, and the entire sequence represented in the 2,400 square miles mapped belongs to the Tertiary-Quaternary volcanic suite or the sediments associated with this suite.

The floor of ancient gneisses and schists of the Basement System emerges from under the volcanic rocks of the Rumuruti plain a few miles east of Rumuruti, but although boreholes have been drilled north-west of Rumuruti to nearly a thousand feet these have not encountered the ancient substratum of metamorphic rocks. There is reason to believe that the surface of the Basement System declines gently westwards under the plain towards the edge of the Rift Valley. Under the median area of the Rift Valley in the Lake Hannington sector it must be at least 2,000 feet below the present land surface and may well be more—that is at or below sea level.

The geological history of the area is extremely complicated and a form of tabulation has been used to summarize it (Table I):—

TABLE I

QUATERNARY	RECENT			SUPERFICIAL DEPOSITS SOILS, ALLUVIUM ETC. HOT SPRING DEPOSITS—TRAVERTINE VOLCANIC ROCKS — UPPER MENENGAI VOLCANICS: Trachyte—lava flows —scoria cones (Thickness unknown); ELMENTEITA BASALTS: Olivine basalt—lava flows —scoria cones —Maximum thickness 200′(?) SEDIMENTS : LOBOI SILTS : DELTAIC? MAKALIA SEDIMENTS : ? deltaic ? LOGUMKUM SEDIMENTS : lacustrine (Njemps ndogo) beds (Total thickness never more than 100 feet (?)) — — — Weak unconformity — — — ?Gamblian sediments of Nderit and Makalia sections.
				MINOR FAULTING new fractures and renewals on older fracture lines at: { West of Lake Nakuru; Solai; Marigat (a mile to the north-west of the area)
PLEISTOCENE	UPPER			Tuffs and Sediments (lacustrine) Larmudiac sediments of Nakuru Basin Solai tuffs associated pumiceous sediments Tuffs and fluviatile sediments of: { MUGURIN; NDOLAITA } Kapthurin beds: (Upper part of sedimentary succession in the Kamasia type-area at Marigat: faunal remains of Pleistocene affinity) outcrops in the lower reaches of the Molo River Fluviatile Sediments of: { Lower Arabel Valley: east of Kwaibus } Levallois artifacts of dubious provenance found on surface Pumice showers from Menengai (Pumice mantle) (possibly much older) Total thickness never more than 100 feet
				MINOR FAULTING—new fractures and renewals on older fracture lines in { Nakuru Basin; Elmenteita Basin
	MIDDLE†	UPPER MIDDLE		? older basalts of Elmenteita : Olivine basalt flows at Soysambu. Kariandusi Lake Beds "Kanjeran" Acheulian Artifacts Tuff and Agglomeratic tuff: (Elmenteita cones) . . . ? phreatic (Honeymoon Hill cones) (Total thickness c. 200 feet)
				THIRD MAJOR FAULTING OF RIFT VALLEY: possible date of formation of Menengai Caldera. Very complex grid patterns, dropping Rift Valley floor a further few hundred feet (? c. 1,000′ in Nakuru Basin)*
	LOWER	LOWER MIDDLE		Gilgil Trachyte (Lava flows) Enigma Cove Sediments (Lacustrine) Ronda Sediments (Lacustrine) Ronda Phonolite and Trachyte (lava flows) West Cliff Sediments (Lacustrine) - - - - - - - - - - - - - Mbaruk Basalt (lava flows) Willan's Farm Trachyte (Lava flows) Nakuru Lake Syndicate Phonolite (lava flows) (Total thickness probably never more than 500 feet)
			EROSION	(Late Pumice Tuff, Welded Tuff 'Ignimbrite' and sediments forming uncomformable outliers on the Kinangop and Bahati tuffs).
c. 1,000,000 years				

(Continued over page)

TABLE I—(*Contd.*)

Age	Succession
UPPER TERTIARY — PLIOCENE	**SECOND MAJOR FAULTING OF RIFT VALLEY:** Pattern not as complex or closely spaced as the third; essentially forms a series of tilted blocks dropping the rift valley floor c.3,000 feet vertically in Nakuru sector, 2,000 feet in the Hannington sector.*
	MAU TUFFS { Pumice tuff, 'Ignimbrite', Sediments (lacustrine) } (with intercalated phonolites)
	6. BAHATI TUFFS { Pumice tuff, 'Ignimbrite', Sediments (lacustrine) } 5. Kisinana Sediments (lacustrine) 4. Dispei-Lake Hannington Phonolites 3. (Chemeron sediments intercalated in the phonolites at Marigat just outside the area: the lower part of the sediments in the Kamasia type area) 2. Kwaibus basalt—Thin, very numerous basalt flows, cinder cones. 1. Goitumet basalt—? flows derived from a single central cone in Goitumet.
	5. KINANGOP TUFFS { Pumice tuff, 'Ignimbrite', Sediments (lacustrine) } 4. Fragmental Trachytes of Kariandusi 3. North Kinangop trachytes 2. Turasha Lake Beds 1. Turasha Basalt, Olivine Basalt flow(s)
	(LOWER MENENGAI (VOLCANIC SERIES and SIRRKON (VOLCANIC SERIES
	(Total thickness of Pliocene succession may be locally over 1,000 feet)
?	**FIRST MAJOR FAULTING OF RIFT VALLEY:** Pattern not as complex or closely spaced as those of third faulting episode. Dropping floor of the rift valley c.4,000 feet vertically in Hannington sector: probably much less effect or even negligible effect in Nakuru sector.*
MIOCENE	THOMSON'S FALLS PHONOLITES .. several successive plateau lava flows—possibly interdigitate with Rumuruti phonolites in parts of the area. (c.500′ thick maximum)
	OLORONYI BASALT .. .. .. lava flows of olivine basalt from central cones (?) (called "Laikipia" by Shackleton)
	OL DONYO OLIEP BASALT .. .. lava flows of olivine basalt (? from dyke sources)
	RUMURUTI FOREST BASALT .. lava flows of olivine basalt (? from dyke sources) (Not of any great thickness)
	RUMURUTI PHONOLITES .. .. Phonolite lavas, succession of plateau flows: thickness of individual flows averages 100′ (Subordinate phonolitic trachyte and trachyte)
	SATTIMA LAVAS: Phonolites, Trachytes — flows, intrusive sheets and dykes in Sattima massif (occur only in the extreme south-east corner of the area)
	(Maximum thickness 2,000 feet)
	— — — — — — WARPING OR FAULTING (? and erosion)—UNCONFORMITY — — — — — — (may be localized)
	SAMBURU VOLCANIC SERIES Basalts .. .. Very numerous thin flows and feeder dykes Picrite Basalts .. Picrites (Tuffs and lacustrine sediments intercalated) (No trace of central volcanoes) (Thickness 1,000 feet—(? c.2,000 ft.))
	SIMBARA VOLCANIC SERIES Basalts .. .. Thin flows and feeder dykes Picrite Basalts (Agglomerate and Tuff intercalated) (Central volcanoes in Kipipiri and Sattima (?)) (Thickness 1,000 feet —(? much greater))
	Sub-volcanic Sediments at Kirimun and Palagalagi (Shackleton 1946, p. 27) containing *Deinotherium hobleyi* Andrews *Mastodon* sp.
c.20,000,000 years	FIRST MINOR WARPING OF RIFT VALLEY FORMING BASINS IN WHICH SUBVOLCANIC SEDIMENTS WERE DEPOSITED
EARLY TERTIARY MESOZOIC PALAEOZOIC	INTERVAL OF SEVERAL HUNDRED MILLION YEARS IN WHICH SUCCESSIVE EROSION CYCLES AND EPEIROGENIC MOVEMENTS AFFECTED THE CONTINENTAL SURFACE
PRECAMBRIAN	BASEMENT SYSTEM : (PRECAMBRIAN OROGENIC MOVEMENTS TO SOME EXTENT CONTROL TERTIARY-QUATERNARY STRUCTURES)

The history of the evolution of the Rift Valley is remarkably complex in this central sector. First the continental surface, planed by the erosion cycle which moulded the sub-Miocene erosion surface, was apparently warped down prior to the first eruptions, along a zone roughly corresponding with the present Rift Valley. While direct evidence for this early down warping is absent from this area, the rapid variation in thickness of the Rumuruti phonolites leaves little doubt that they were deposited in an existing valley between the earlier formed volcanic pile of the Samburu basalts, situated roughly in the middle of the depression, and the side of the valley.

The first volcanic eruptions were the Samburu series of thin basalt and picrite lava flows, and subordinate pumice showers. These were in part erupted from swarms of dykes which can be recognized at the present day, and in part from central sources. Some ponding in the Rift Valley at this time resulted in localized deposits of lake beds—well-graded pumice tuffs and diatomite.

This phase of eruption was followed by earth movements in the north of the area, leading to an angular uncomformity between the Samburu volcanics and the overlying plateau phonolites. The exact nature of these movements is obscure but it seems probable that they involved arching.

In the south-east corner of the area an equivalent basaltic volcanic succession, the Simbara basalts, is exposed. These include agglomerates and tuffs, and form two massifs, the Sattima (Aberdare) massif and Kipipiri. The latter is certainly a dissected central volcano, but whether Sattima is not the flank of the same volcano, rather than a separate central volcano left far above Kipipiri by the subsequent faulting, is open to question. Feeder dykes of the Simbara lavas are numerous on Sattima. The Samburu lavas are locally over 1,500 feet thick and the Simbara lavas have at least an equivalent thickness.

The plateau phonolites form an extensive series of thicker flows with no pyroclastic horizons intervening. A continuous succession of more than 2,000 feet of these phonolites is exposed on Ngelesha. They thin out rapidly towards the median line of the rift and away from the shoulder to the east. The youngest members of this eruptive series only just lap over the shoulder, suggesting that the rift floor was dropping at the time of their eruption. No feeders or related eruptive centres are known, but because of their uniformity and great extent (they are known to cover at least 3,000 square miles between Maralal and Bahati) fissure sources are suggested. There is an upper series of plateau phonolite—the Thomson's Falls phonolites—of rather different lithology, which is easily distinguishable to the east of Thomson's Falls but appears to be intercalated within the Rumuruti phonolites elsewhere.

The Sattima lavas described by Shackleton (1945, pp. 2–3) only just extend into the area in the south-east corner. They are trachytes and phonolites with well-exposed dyke feeders on Sattima. It is suggested that the commonly seen pattern of central and fissure eruptions, occurring concurrently, was operative and that these volcanic rocks erupted from dykes congregated around the Sattima-Kipipiri massif at the same time as the plateau phonolites were erupted from fissures along the margin of the rift zone.

The author follows Shackleton (1945, p. 6) in putting the Samburu, Simbara, Rumuruti and Thomson's Falls volcanics in the Miocene, though the upper possible limit of their eruption is not defined and they could be lower Pliocene, though the evidence from land forms is strongly in favour of a Miocene age. The author would also put the Sattima lavas tentatively in the Miocene, thus differing from Shackleton (1945, p. 6). There are some later basalts on the Laikipia plateau which may also be part of the first volcanic series.

This earliest eruptive series was followed by major faulting in the north of the area. The total vertical displacement on these earlier faults, now represented by dissected scarps may have been as much as 4,500 feet in the Lake Hannington sector. Here, in the north of the area, the rift was initiated by this faulting as a fifty-mile-wide complex trough averaging 4,000 feet in depth. In the south of the area this faulting may well have been negligible or absent.

A second series of volcanic eruptions followed this faulting after a long erosional interval. These appear to have been initiated by basalt eruptions, the Turasha, Kwaibus and Goitumet basalts. The basalts in the north-east of the area consist of cinder cones marking old vents and numerous successive thin flows of lava. These basalts were followed by phonolite and trachyte eruptions from centres in Menengai, Sirrkon, near Kariandusi, Kilombe (to the west of the area) and from fissure sources away from the volcanic centres. The eruptives included pumice tuffs, lavas and "ignimbrites"* and all these rock types appear to have been erupted from both central volcanoes and dispersed fissure sources. The "ignimbrites" are apparently principally segregates of a volatile-rich lava in which nucleation and crystallization were impeded, and they merge into normal trachytes. The lavas thought to have been fissure erupted were dominantly of phonolite and form an extensive lava plateau around Lake Hannington.

There was considerable ponding in the earlier-formed depression in the Rift Valley zone —which had the form of a definite rift valley in the north and perhaps only a slightly down-warped valley in the south—and very thick sedimentary successions including diatomite are interspersed with these volcanics. The older part of the Kamasian sediments (Gregory, 1921, pp. 112-114) now called the Chemeron sediments, are intercalated in the plateau phonolites of this eruptive sequence.

These volcanic rocks and the associated sediments are believed to be of Pliocene age, a dating from indirect evidence, and are described as the Pliocene succession. They occupy the whole fifty-mile width of the Rift Valley in the southern part of the area, but in the Lake Hannington section occupy a twenty-mile-wide median zone within the Rift Valley, a zone in which were also restricted the two major faulting movements subsequent to their eruption.

Following these eruptions extensive major faulting, preserved in scarps much less dissected than those of the first major episode, roughed out the Rift Valley as we know it today in the southern part of the area. The floor of the rift was relatively displaced by at least 3,500 feet to the east of Menengai. In the north this second major faulting produced only a single 2,000 foot scarp flanking Lake Hannington on the east. The total displacement of the Basement System floor in the Lake Hannington sector is believed to be about 6,500 feet, and this indicates that it is not higher than 1,000 feet above sea level. This suggests that the apparent lag of the floor behind a continental surface undergoing the two successive up-warpings (easily recognizable in the shape of the erosion surfaces to the east of the Rift Valley) cannot be entirely responsible for the downward displacement of the floor. Some degree of actual downward movement must have occurred.

After these fault movements basaltic lavas succeeded by trachytes and phonolites were erupted in a small area in the Nakuru and Elmenteita basins. These appear to have been fissure erupted, no central sources being visible. They are intercalated with thin successions of lake sediments. As the lavas immediately preceded the deposition of the sediments of Kariandusi, dated by artifacts as Middle Pleistocene, they are described as the Lower/Lower Middle Pleistocene volcanics and sediments. No equivalent formations are seen in the north of the area. They were succeeded by the third major faulting episode which originated closely spaced "grids" in which the numerous faults, preserved in abrupt cliff scarps, have displacements of a few hundred feet, but tend to cancel one another out in horst and graben structure. The total displacement in the faulting was rather small compared with the two previous major episodes. The grid-faulting tends to be concentrated in the basins, and to die out on the volcanic massifs such as Menengai and Eburru. In the Nakuru basin the displacement produced may be as much as 1,000 feet, but this strong development is only local. The caldera of Menengai could be a reflection of this faulting on the circular volcanic pile of Menengai. This grid-faulting renewing movement on an old plane produced a low facet or faced-scarp at the foot of the Bahati Escarpment at Mbaruk and this low facet clearly demonstrates the insignificance of this set of movements compared with the second major episode.

After this last movement there was minor vulcanicity at Elmenteita—basaltic cinder cones, tuff rings (probably phreatic) and lavas—also minor vulcanicity in Menengai—trachyte cinder cones and lava flows erupted subsequent to the widespread pumice mantle of uncertain age which marked the formation of the Krakatoan-type caldera. The last eruptions of lavas in Menengai and at Elmenteita are probably only a few hundred years old.

There are lacustrine sediments, which include thick diatomite, of proved Middle Pleistocene age at Kariandusi and Soysambu in the Elmenteita basin.

**See* para. (*c*), p. 46.

Later lake beds and fluviatile and terrestrial deposits associated with tuffs occur in the Nakuru, Elmenteita and Solai basins, and also to the west of Lake Hannington and at Marigat where they are associated with bouldery torrent-wash and silts, and form the upper part of the Kamasian beds (Gregory, 1921, pp. 112-114). All these deposits are possibly related to pluvial conditions in the Upper Pleistocene, though definite evidence of age is unfortunately very scarce.

The Makalian beds, deltaic or estuarine silts of epi-Pleistocene age, are restricted to the Nakuru basin, but similar formations are seen in the Baringo-Hannington basin in the inter-lacustrine plain.

There are thin layers of welded tuffs and pumice tuffs localized in valleys near Ol Kalou and Ol Joro Orok. These are apparently the result of late fissure (Katmaian) eruptions in the immediate vicinity. Their age is uncertain but is most likely Pleistocene.

The structural pattern is of repeated normal faulting related to distension of the crust. Besides the three major episodes narrow zones of very late (post-Upper Pleistocene?) faulting extend through Nakuru and Solai, and Marigat. These last movements are represented by sheer cliffs devoid of screes or any vegetation. The fault planes are near vertical, and the throws small.

A general pattern is seen:—

Repeated vulcanicity is closely followed by movement. The eruptives in each episode start with basalt. The basalts are calc-magnesian with slight alkaline content, the intermediate lavas are distinctly alkaline, and predominantly sodic. The rock types, basic and intermediate, preserve a remarkable uniformity of composition throughout Tertiary and Quaternary times.

Plateau (fissure) and central eruption have been intimately associated.

The faulting and volcanic pattern shows rapid variations within short distances along the course of the Rift Valley.

The later volcanics are almost entirely restricted to the Rift Valley.

The last faulting and eruptive episodes were of decreasing magnitude compared with the earlier ones, and the Rift Valley seems to have been formed by a succession of eruptive and tectonic episodes occupying successively narrower zones, and getting weaker since the Miocene, though an exception is seen in the south where the Pliocene volcanic sequence is the strongest developed and occupies the whole 50-mile width of Rift Valley. There is a marked tendency for the faults produced in each successive episode of movement to become more numerous and closer spaced, and probably also the hades become steeper.

V—DETAILS OF GEOLOGY

1. Tertiary and Quaternary Volcanic Rocks and Associated Volcanic Sediments

(1) The Older Volcanic Rocks (Miocene)

The oldest volcanic rocks exposed in the area are basalts, characteristically porphyritic in texture, and occurring in flows seldom more than twenty feet in thickness, interspersed with tuffs. Shackleton (1946, p. 29, 31) gave the name "Samburu basalts" to similar rocks which outcrop in the vicinity of Maralal and also, earlier, reported similar basalts in the Aberdare massif, which he named Simbara basalts (1945, p. 2). The Samburu basalts, with associated tuffs and sediments, have now been recognized as far south as Subukia and Solai, only twenty miles from the Aberdare occurrences, and the correlation proposed by Shackleton (1945, p. 6) is thus strongly supported by the extension of mapping carried out during this survey. The two names are however retained.

(a) *Samburu Basalts*

The Samburu lavas are believed to be well over a thousand feet thick, though like all the volcanic formations of the Rift Valley they thicken and thin out rapidly. The basaltic rocks of this group underlie the Rumuruti phonolites in the escarpment at Moera in the extreme north of the area, in the escarpment below Lelumwa, and in the escarpment between Kaon and the Ngusero river. Southwards from that point they can be traced for many miles along the foot of the Laikipia and Marmanet escarpments, the southernmost outcrops on this line of escarpments being seen at Dalgleish's Farm, Subukia. Further outcrops of basalt of similar type underlie Rumuruti phonolites at various points along the Solai Escarpment which branches to the south-west from the Laikipia Escarpment. The most southerly exposures of all occur on this escarpment on the pass between Solai and Subukia. The basalts are here felspar-phyric types finer in texture than those further north and probably represent a thickening of the top part of the Samburu succession. They are associated with whitish tuffs and diatomites identical with those seen at the top of the Samburu succession further north. A feature of the Samburu basalts is the high angle of dip commonly seen. Dips of 25° to 35° to the east are not uncommon near Lelumwa and to the west of the Ngusero river. East of the Ngusero river however the dips are gentle, not more than 5°, still to the east. Further south dips of up to 12° are seen near Murogors Camp, and dips up to 15° are seen below the Bechot plateau, on the escarpment east of Lake Hannington. Appreciable dips are again seen in the escarpment section two miles north of Solai station. The dips are almost invariable eastwards, that is away from the median line of the Rift Valley. Less regularity in direction of dip is seen in light coloured stratified tuffs which occur at the top of the succession and intercalated in the basalts. A dip of 70° was seen in these tuffs on A. J. Williamson's farm at Subukia: this high dip is, however, exceptional and was noted in a locality of extreme structural complexity at the foot of the Laikipia Escarpment. The dips of the superincumbent phonolite flows of the Rumuruti group are also uniformly eastwards but are gentler, 7° being the maximum observed. This fact and the indication of considerable irregularity in the upper surface of the underlying basalt formation near White Rocks leads to the conclusion that an angular unconformity must be present, and it is probable that considerable erosion took place between the eruption of these two volcanic formations. Shackleton (1946, p. 31) seems to have suspected an unconformity between the Samburu and Rumuruti groups. He noticed a similar discordance of dip to that seen in the present area, though the dip of the basalts was here westerly. He ruled out an unconformity when, near Maralal, he detected an alternation and lack of discordance at the contact (Shackleton 1946, p. 31). This would certainly seem to rule out unconformity at that locality but further south the writer has found the contact between the two groups to form a marked break without alternations. Phonolite occasionally outcrops in small patches within the basalt exposures but these appear to be in the nature of outliers. Repetitions in the succession seen in sections of the Marmanet and Laikipia escarpments appear to be due to faulting, though on the Laikipia Escarpment, two miles south-east of Murogor's Camp, a body of porphyritic orbicular phonolite of unusual type appears to be intercalated in the basalt formation. It could, however, be explained as an intrusive dyke feeding the overlying lavas. The writer is of the opinion that there is a widespread unconformity throughout the area, fading out towards the east. The Samburu basalts are predominantly lavas. Agglomerates are absent as far as is known, Tuffs, light in colour, well stratified and pumiceous, and occasionally with diatomite, are found at the top of the series and intercalated in the lavas.

The lavas of the Samburu group are predominantly basaltic but ultrabasic variants are not uncommon. The main rock-types are:—

(i) Felspar-phyric basalts
(ii) Augite- and olivine-phyric basalts
(iii) Picrite-basalts
(iv) Picrites
(v) Limburgites
(vi) Aphyric basalts
(vii) Brecciated basalts
(viii) Dyke rocks

A closely allied suite is seen in the volcanic island of Mauritius (Walker and Nicolaysen, 1954) and the authors of that detailed petrological study considered that such variants of a basaltic suite are quite compatible with a derivation by means of processes of crystal differentiation in a common basic parent magma. The oceanitic (olivine-phyric) picrite-basalts, present in Mauritius, are not however seen in the Samburu lavas.

(i) *Felspar-phyric basalts*

These are much less conspicuous in the Samburu basalts than in the Simbara series. They are characterized by platy phenocrysts of andesine or labradorite of good crystal form and up to a centimetre in length, which typically show a sub-parallel alignment, set in a compact base. In a typical thin section, specimen 35/1297* from Kabuswa, the felspar phenocrysts of the composition of andesine (An_{34}) show polysynthetic twinning. Less numerous and smaller titan-augite and olivine phenocrysts are also present. The base is composed of augite granules, altered olivine, plagioclase laths and magnetite grains. There is much secondary serpentine and iddingsite, and apatite is an accessory. A visual estimation of proportions of component minerals by volume is as follows:—

Plagioclase	50%
Augite	20%
Olivine and alteration products ..	15%
Magnetite	14%
Apatite (less than)	1%

Other slides examined revealed a great variation in the felspar present, and in one case (35/707 from Bechot) labradorite (An_{68}) was recognized. Vesicular textures are not uncommon, being especially well seen in the lavas from the section on the Solai Escarpment to the north of Solai station. Here several flows, separated by red bole layers, show rounded vesicles infilled with yellow and white zeolites. Olivine is in general the more common phenocryst mineral than augite. It is occasionally seen included in augite phenocrysts (35/1287 from Kabuswa), a feature also of the Simbara basalts. Augite is usually the more abundant of the two minerals in the microgranular base. Resorption of phenocrysts is a common feature of the felspar-phyric basalts. There are often present in the base fragments of untwinned or strain-twinned plagioclase, suggesting an earlier generation now almost completely resorbed. Analcite was doubtfully identified in the base of a specimen from near Murogor's Camp (35/1411) and nepheline altered to cancrinite was doubtfully identified in a specimen from Williamson's farm (35/1549). The felspar-phyric basalts, like all the rocks in the Samburu group, are usually holocrystalline and show either aligned textures or decussate textures. However glassy lavas, which may be the tops of flows, have occasionally been recognized, such as specimen 35/707 from Bechot and specimen 35/1538 from Lelumwa.

In general the basalts in the Samburu group exposed to the south of White Rocks are comparatively rich in felspar and show finer textures than the basalts of the outcrops along the Laikipia Escarpment.

(ii) *Augite- and olivine-phyric basalts*

These are the most common rock types in the basalt outcrops on the Laikipia Escarpment. In a typical specimen (35/1241) from Dalgleish's Farm, Subukia, titan-augite phenocrysts predominate, olivine phenocrysts being small and much altered to serpentine and iddingsite. Felspar is restricted to numerous small automorphic laths in the granular base, associated with granules of augite and magnetite. The rock is vesicular, small rounded vesicles and larger irregular vesicles being infilled with a variety of fibrous and near-opaque secondary minerals.

Some felspar phenocrysts (andesine) are seen in the rock from Kabuswa (35/1296), but titan-augite phenocrysts and augite in the base make up about 60% of the volume. There are automorphic felspar laths in the base, and the felspar content seems too high for the rock to be classified as a picrite-basalt.

*Numbers prefixed 35/ and 43/ refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

Other specimens show augite, olivine and felspar phenocrysts in about equal proportion. Labradorite was identified in one such rock (35/1242 from Dalgleish's farm), and oligoclase-andesine in a similar lava from Bechot. In specimen 35/1327 from near Murogor's Camp augite phenocrysts show a peculiar stellate aggregation, a very characteristic feature of the augite-phyric basalts in the Samburu group. Analcite was identified in the base of many specimens, for example 35/1327, which also contains a bluish serpentine replacing olivine. The augite phenocrysts in these basalts are usually a pink-tinted titaniferous variety, often with an inner zone neutral in colour.

A cellular texture is sometimes seen in certain lavas of this group, which contain so much vesicular material that it predominates over the primary minerals. An example of this is seen in 35/1563 from Bechot. Olivine and altered felspar can be recognized in this section but the base is fine and near opaque, either vitreous or extremely micro-granular. Vitreous lavas are otherwise unknown in the augite-phyric basalts, textures being holo-crystalline and frequently with an intergranular arrangement, but only rarely with directed textures.

(iii) *Picrite basalts* (*ankaramites*)

Lavas of picrite-basalt composition and ankaramite type are not uncommon in the Samburu lavas on the Laikipia Escarpment. A typical specimen (35/1383) shows stellate clusters of titan-augite phenocrysts together with sparse smaller phenocrysts of altered olivine. The base contains small automorphic plagioclase laths set in a granular aggregate of augite granules, magnetite and serpentine minerals, together with a little analcite.

The composition by volume was visually estimated as:—

Augite	60%
Olivine	5%
Magnetite	15%
Felspar	15%
Alteration products of olivine and analcite	5%

In another specimen from Bechot (35/712) the felspar (andesine) does not amount to more than 10% of the composition. This rock is vesicular, the vesicle infilling being of zeolite and carbonate. Olivine is nearly as abundant as augite in a specimen from west of Tikamur manyattas (35/1526). In this rock felspar (andesine) accounts for about 15 per cent of the rock by volume, and again a little analcite is present. Biotite flakes were noted in 35/679 from Samburumburu.

(iv) *Picrites*

The ultrabasic members of the Samburu group show no recognizable felspar. Whether these are separate flows is uncertain. They may be segregations in basalt flows: support is given to this idea by the fact that at Bechot a felspar-phyric and an ultrabasic sample were both taken from the limits of a small exposure about five yards across.

A typical specimen (35/1145) from the Marmanet Escarpment is rough in texture and black in colour, speckled with orange coloured altered olivine phenocrysts. In thin section the olivine is seen to have a large 2V and to be optically positive. Iddingsite and serpentine minerals are aggregated around the olivine, the former in the form of haloes. The base is composed of serpentine, magnetite and augite. The rock differs texturally from the type picrite of Silesia (Johannsen, 1938, Vol. IV, p. 433), and further it lacks hornblende, a constituent of that rock. Small rounded vesicles infilled with zeolite support the identification of this rock as a lava. A chemical analysis of this rock is included in Table II (A).

TABLE II

CHEMICAL ANALYSES

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
SiO_2 ..	43·96	48·19	45·98	47·30	50·27	54·73	55·32	56·58	57·29	56·16	61·58	61·58	59·17	63·40	42·58
Al_2O_3 ..	7·20	18·32	15·34	20·01	16·27	18·86	16·44	17·20	17·36	18·67	14·13	17·02	17·19	12·06	11·43
Fe_2O_3 ..	3·78	8·01	6·11	7·79	3·28	2·35	5·90	4·72	3·61	4·77	5·11	1·97	5·51	3·50	4·98
FeO ..	7·93	3·88	8·39	2·56	7·84	2·87	2·97	3·53	3·16	1·97	3·75	3·12	1·02	5·70	7·86
MgO ..	20·03	2·40	3·98	2·55	4·89	1·22	0·51	0·47	0·77	0·75	0·44	0·78	0·87	0·31	7·05
CaO ..	10·65	7·82	7·74	9·74	8·66	2·12	1·88	2·05	1·82	1·41	1·09	1·63	2·39	0·99	13·26
Na_2O ..	1·65	4·25	3·35	3·50	3·85	6·15	7·18	6·00	6·62	6·85	7·10	6·95	6·60	7·95	3·12
K_2O ..	0·54	1·50	1·75	0·90	1·75	6·00	4·95	5·00	5·70	5·00	4·95	5·55	3·70	4·55	0·75
H_2O+ ..	1·74	0·80	1·47	0·83	0·53	3·66	2·17	2·89	2·23	2·18	0·41	0·38	0·45	0·24	2·03
H_2O- ..	0·36	1·08	0·52	1·75	0·48	1·38	1·60	1·16	0·60	1·82	0·62	0·08	1·03	0·03	0·72
TiO_2 ..	1·80	2·98	3·80	2·32	1·90	0·62	0·42	0·32	0·73	0·58	0·65	0·68	1·47	0·73	3·33
P_2O_5 ..	0·35	0·65	1·46	0·88	0·42	0·09	0·14	0·05	0·17	0·06	0·11	0·25	0·46	0·10	0·51
MnO ..	0·17	0·19	0·24	0·16	0·24	0·33	0·43	0·29	0·31	0·28	0·39	0·22	0·12	0·40	0·24
CO_2 ..	0·32														2·30
Total ..	100·48	100·07	100·13	100·29	100·38	100·38	99·91	100·26	100·37	100·50	100·33	100·21	99·98	99·96	100·16

TABLE II
CHEMICAL ANALYSES—(*Contd.*)
NORMS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	—	0·90	0·89	2·68	—	—	—	—	—	—	0·33	—	2·06	7·45	—
or	3·19	8·89	10·34	5·32	10·34	35·46	29·92	29·56	33·68	29·89	29·28	32·85	21·90	26·72	4·45
ab	13·96	36·16	28·34	29·61	32·58	31·36	39·90	47·49	41·26	40·16	45·05	50·04	55·90	37·23	21·98
an	10·65	26·41	21·65	36·25	21·95	6·12	—	5·26	0·83	5·26	—	—	6·30	—	14·97
ne	—	—	—	—	—	11·19	9·26	1·77	7·99	7·47	—	3·58	—	—	2·42
ac	—	—	—	—	—	—	3·28	—	—	—	13·22	1·85	—	10·17*	—
di	29·49	6·05	5·83	4·93	14·97	3·16	5·76	1·91	5·89	1·04	4·04	5·19	1·85	3·66	26·33
wo	—	—	—	—	—	—	3·28	—	—	—	—	—	—	—	—
hy	1·67	3·20	11·62	4·06	0·31	—	—	—	—	—	5·08	—	1·31	8·79	—
ol	24·20	—	—	—	9·89	3·25	—	2·23	0·88	0·97	—	2·42	—	—	7·35
mt	7·52	4·41	8·86	2·05	4·76	3·40	6·92	6·83	5·23	5·58	0·79	1·85	—	—	7·22
he	—	4·96	—	6·38	—	—	—	—	—	0·92	—	—	5·51	—	—
il	3·42	5·62	7·22	4·41	3·61	1·18	0·80	0·61	1·39	1·10	1·23	1·26	2·41	1·37	6·32
ap	0·83	1·68	3·46	2·08	0·99	0·20	0·30	0·10	0·40	0·14	0·27	0·67	1·10	0·23	1·21
cc	0·73	—	—	—	—	—	—	—	—	—	—	—	—	—	5·23
C.I.P.W. INDEX ..	IV 12321	II 1524	II 1534	I 1514	II 1534	I 1623	II 1524	I 1514	II 1514	I 1514	I 1514	II 1514	I 1524	II 1513	III 1544

*4·46 excess Na metasilicate.

Anal. A—J. Furst, Mines and Geological Department, Nairobi.
B to O—Min. Res. Div., Overseas Geological Survey.

A 35/1145 Picrite, Marmanet Escarpment. Miocene?
B 43/1325 Vitrophyric olivine basalt (Kijabe type), Melawa Ndogo gorge. Miocene?
C 43/1068 Olivine basalt, Oloronyi. Pliocene?
D 43/1181 Olivine basalt, Mbaruk. Lr. Pleistocene?
E 43/1267 Olivine basalt, Elmenteita. M. Pleistocene to Recent.
F 35/1201 Rumuruti phonolite (Uaso Narok flows), Marmanet Forest. Miocene?
G 35/589 Rumuruti phonolite (Jorokokwa flows), Tarabunyan. Miocene?
H 35/1102 Rumuruti phonolite (Kenya type in Iguamiti flows), Chui Peak. Miocene?
I 43/962 Thomson's Falls phonolite, Moridjo Forest. Miocene?
J 43/693 Dispei-Lake Hannington phonolite (Kenya type), Ol Punyata. Pliocene?
K 43/1193 Lr. Menengai trachyte, Lion's Head. Pliocene?
L 43/1274 Syenite, Menenhill Farm. Pliocene?
M 43/1146 Quartz trachyte, Turasha Valley, N. Kinangop. Pliocene?
N 43/1192 Pantellerite trachyte, Menengai caldera floor. Recent.
O 35/1148 Limburgite, Marmanet Escarpment. Miocene?

(v) *Limburgites*

A specimen from nearby (35/1148) shows titan-augite phenocrysts predominating over olivine. Felspar is completely absent. Vesicles with beautiful concentric infillings of secondary minerals are present. The rock is considered to be a limburgite though lacking the glassy character of the type rock.

Specimen 35/1263 from Dalgleish's Farm (Subukia) shows titan-augite in stellate clusters. Olivine is again subordinate and no felspar was recognized.

A rock from south east of Murogor's Camp shows prismatic crystals of titan-augite and a little serpentinized olivine in a very finely granular base. The latter is difficult to resolve, but no felspar would seem to be present, the only other recognizable mineral being magnetite. In 35/1330 from nearby pink titan-augite phenocrysts and subordinate olivine phenocrysts are set in a granular base composed of augite, magnetite, serpentine and possibly analcite. Augite makes up 50% of the rock. Over 75% augite was the estimated content of another ultrabasic lava (35/1349) from near Murogor's Camp. The base is very fine but thought to be microgranular rather than glassy. No felspar could be identified. Other picrite lavas examined include 35/1407 also from near Murogor's Camp, which shows annular growths of titan-augite around olivine. Some clear isotropic granules (? analcite) are present in the base.

(vi) *Aphyric basalts*

The bulk of the lavas in the Samburu series are porphyritic, but fine-textured aphyric basalts are occasionally encountered. Specimen 35/1385 from three miles north-east of Murogor's Camp is an example of an aphyric basalt. Olivine, much altered, augite granules and automorphic plagioclase laths together with iron ore are the components of the finely granular assemblage. There is a considerable amount of an isotropic mineral of low refractive index (? analcite). A concordant layer of fine textured basalt from the Lelumwa Escarpment (35/1529) also shows aphyric texture. Felspar (andesine) make up at least 30% of the slide in a mosaic of large crystals with rather irregular outlines forming a base in which are set smaller titan-augite, olivine and iron ore crystals.

(vii) *Brecciated basalts*

A specimen of brecciated melanocratic basalt from 3 miles north of Murogor's Camp (35/1384) shows a texture indicative of cataclasis. Phenocrysts of olivine and titan-augite and a few of andesine are fragmented, and the finely granular base is distorted and strained, showing dark streaks which appear almost isotropic under crossed nicols. Similar rocks were noted at the foot of the Laikipia Escarpment in the main fault zone and they appear to be very coarse porphyritic flows which have endured cataclasis in a fault zone.

Another basalt from the foot of the Moera pass (35/1482), somewhat richer in felspar, shows an extremely streaky appearance and in thin section the originally crystallized texture appears to have suffered cataclastic deformation. There is an unusual amount of zeolite and green serpentinous and chloritic minerals present suggesting extensive secondary crystallization.

(viii) *Dyke rocks*

Like the basalt of the Simbara series (Shackleton, 1945, p. 2) the basalts of the Samburu series are cut by numerous dykes of similar basaltic rock types. Both coarsely porphyritic and fine aphyric types are represented, the former being far more common. The dykes strike at diverse angles, but the most common orientation is parallel to the boundary of the Rift Valley, that is north-north-westerly. Most of the dykes are vertical but some north-westerly trending dykes hade at about 70° to the south-west. A thin section of one of these dykes (35/1408) shows a coarsely porphyritic basalt containing phenocrysts of titan-augite, olivine much altered to deep red-brown secondary aggregates andesine and magnetite. The felspars have a distinct sub-parallel alignment suggestive of flow orientation. The base is fine and in part opaque. Another dyke rock (35/1530) from the Lelumwa Escarpment is very fine textured, composed of augite, iron ore granules, and pools of zeolite. It is ultrabasic in composition and augite accounts for over 70 per cent of the rock. It appears to be closely related to augitite. Specimen 35/537 from lower down the Lelumwa Escarpment contains very large olivine and titan-augite phenocrysts. Felspar (andesine) is present as small automorphic laths in the base, but does not account for more than 10% of the rock, which is intermediate between oceanite and ankaramite.

The Samburu basalts are devoid of agglomerates but intercalated tuff horizons suggest that central eruptions were occurring during the eruption of the lavas. It seems likely that these lavas may have been erupted from numerous dykes, around such central volcanoes, and along the margin of the rift zone. A similarity to the lavas of the Kisingiri series (McCall 1958, p. 54), apparently erupted from dykes around the central vent of Kisingiri (Rangwa), is suggested. Indeed the lavas of the Samburu series show a considerable resemblance to the Kisingiri melanephelinite suite, especially in mode of occurrence. The melanocratic minerals are very similar but the Kisingiri lavas are strongly undersaturated while the Samburu lavas are marked only by traces of analcite and appear to be in the main saturated lavas, and alkaline tendencies are only weakly developed.

(ix) *Tuffs associated with Samburu lavas*

In the north of the area light coloured pumice tuffs showing well developed stratification occur as a marked horizon near the top of the Samburu succession, and also as intercalations within the lava succession. The junction of the Samburu series and the overlying Rumuruti phonolites is seen in section in a chain of outliers west of the Ngusero river and in exposures south east of Murogor's Camp. The succession in both localities is:—

3. Rumuruti phonolite
2. Stratified tuffs
1. Samburu basalt

Further outcrops of these tuffs are seen north of Bechot summit and Kaptonai, where they show regular stratification in thin beds. On A. J. Williamson's farm, to the north of the farmhouse, they are associated with diatomite. The presence of diatoms, identified in thin section 35/552, leaves no doubt that sub-aqueous deposition played a part in the derivation of these beds. Farther south, at White Rocks, soft fissile diatomaceous sediments are exposed, associated with fairly coarse stratified tuffs. These tuffs are again seen farther west, on Nicholson's farm, where they directly underlie phonolites of the Lake Hannington group, and there are numerous outcrops of these tuffs on the Solai Escarpment. In all these exposures the tuffs are associated with felspar-phyric olivine basalts of the Samburu group. Although field relations are often difficult to discern in this expanse of eroded horsts and grabens, the tuff is never seen above phonolite, and thus has been accepted as an underlying formation. The irregular distribution of the outcrops and discordant dips suggest an angular unconformity between the Samburu tuffs and Rumuruti phonolites.

Though the most striking occurrence of these tuffs is at the top of the Samburu succession there are also many intercalations within the lava succession. Such intercalations are clearly seen on Lelumwa Hill, in the country to the west of Samburumburu, and in the section revealed by the borehole recently drilled on Vale Estate, Subukia (C 2939).

The tuffs show a close lithological resemblance to the Kinangop tuffs—stratified waterlain tuff intercalations and thin diatomites are present in both sequences—and the rocks of both sequences are pumiceous, and show little evidence of rounding of grains indicating transport.

Microscope slides are not rewarding, the whole rock being intensely kaolinized. Thin sections (35/181,219,245,602) reveal textures more typical of a tuff than a sediment, comprising angular fragments of lava (trachyte or phonolite and basalt) together with pumice set in a dense kaolinized matrix, which appears to be composed of pyroclastic fragments, in part welded together. Rapid deposition of air-borne pyroclastic material on a topography characterized by numerous shallow bodies of water seems a reasonable estimate of their mode of derivation.

A specimen (35/336) from south-east of Murogor's Camp shows an unusual cellular texture, being composed of globules of streaky, more or less clear, glass, isotropic in thin section and set in a turbid brownish matrix. It is well stratified, but appears to be derived from a shower of incandescent particles which have welded themselves together, rather than by sedimentation.

The tuffs become more prominent in exposures nearer to the centre of the rift, as would be expected if a trough had already been formed along the line of the Rift Valley at the time of these eruptions.

(*b*) *Simbara Basalts*

The Simbara basalts have been described by Shackleton (1945, pp. 9-16). In the present area their outcrop is limited to a small stretch of country along the Sattima scarp from Cowen's farm southwards to the Melawa Ndogo gorge. There is continuous exposure along the fault scarp in this sector, and the field relations are clearly seen in a section several hundred feet deep within the Melawa Ndogo gorge.

Shackleton considers that these basalts were erupted from a volcanic centre in Simbara, where he recognized numerous dykes of similar basaltic material, aligned radially or parallel to the main line of faulting. He considered that these dykes may have been feeders of the lava flows, but could find no trace of a central crater or vent in Simbara or in Kipipiri. Recent air-photos of Kipipiri do however show a well marked circular pattern in the ridges of this dissected peak, which might be a reflection of a crater now obliterated by erosion. Their dissected state suggests that these volcanic centres are comparatively old, and Shackleton's attribution of the Simbara series to the Miocene is followed by the writer, though an even greater age is conceivable.

At Cowen's farm the Simbara basalts underlie Thomson's Falls phonolites, which are in turn overlain by tuffs of the Kinangop succession. The basalts form a series of flows varying from 20 feet to 60 feet in thickness, and separated by boles of red brick-like material which appears to be either a thin basaltic tuff intercalation or very weathered surface material of the lava flows. The most common type of lava is the Kijabe-type basalt (Shand, 1937, p. 265–7) with large platy plagioclase phenocrysts, but olivine- and augite-phyric basalts and finer aphyric basalts also occur in this lava series. The suite shows only weak alkaline tendencies indicated by andesine and rare orthoclase, biotite and analcite. This is borne out by analysis B, Table 2. Agglomerates have been recognised in the lower part of the section in the Melawa Ndogo gorge. Beneath the agglomerates the lowest lavas exposed are flows of fissile basalt apparently conformable with the overlying basalt. Two distinct flows were recognised in the river section, the lowest being underlain by a red old land surface, and the two flows being separated by a rubble layer composed of angular fragments of lava with a matrix of smaller crushed fragments of the same material.

(i) *Felspar-phyric basalts*

The most common rock type within the Simbara series is the Kijabe-type felspar-phyric basalt, which shows platy felspar phenocrysts up to four inches in length, with a decussate or sub-parallel arrangement, in a dark grey and fine textured matrix. In thin section the felspars are seen to be labradorite, which is the most common felspar in the Simbara basalts, though bytownite has been recognised and andesine is characteristic of some of the finer basaltic lavas. The felspar phenocrysts are of good crystal form though frequently broken. This is not surprising since the idea of a lava carrying such large phenocrysts flowing at all is somewhat difficult to entertain. Olivine and titan-augite phenocrysts are sometimes present, smaller and subordinate to the felspar, the olivine frequently showing bright red-brown haloes of alteration products. The groundmass is finely granular to moderately coarsely granular, and intergranular textures composed of small automorphic felspar laths and granules of augite, magnetite and a little olivine are typical. Orthoclase may be present, and a little analcite and other zeolite, and chlorite have been recognised. The Kijabe-type basalts like all the Simbara basalts are typically vesicular, showing small rounded empty cavities.

(ii) *Olivine- and augite-phyric basalts*

Olivine- and augite-phyric basalts closely resembling similar lavas in the Samburu series are subordinate in the Simbara series and chiefly occur near the bottom of the succession. In a typical specimen (43/984a) from Peterson's farm large titan-augite and medium-sized olivine phenocrysts, together with even smaller felspar phenocrysts, are set in a finely granular base. Another specimen, 43/998 from the Melawa Ndogo gorge, is olivine-phyric, no other phenocrysts being present. Picrite basalts are not common. A specimen of ankaramite (43/973) from Cowen's farm shows titan-augite and smaller and less numerous olivine phenocrysts. Felspar is seen only in the finely granular base, and forms less than ten per cent of the rock by volume. A little isotropic material (analcite?) is present in the base.

(iii) *Aphyric and finely-porphyritic basalts*

Aphyric basalts closely resembling similar rock types in the Samburu series are interspersed with the porphyritic flows, grading into finely-porphyritic types. In all these lavas felspar accounts for a considerable proportion of the rock. Olivine is the most common microphenocryst, while augite predominates in the base which is usually intergranular, and composed of small automorphic felspars, pyroxene, olivine and magnetite. The olivine is always altered to red-brown secondary minerals (iddingsite?). A grey fine-textured lava (43/991) from the Melawa gorge, near the base of the succession on the north side, resembles a trachyte in appearance. It is seen to be a mugearitic basalt, with felspar dominant over olivine, augite and iron ores, and some orthoclase is present besides the plagioclase, which is a sodic andesine. Biotite is present in small ragged flakes. The texture is holocrystalline, the matrix material being set in a mosaic of felspars, many of which are rounded and granular in appearance.

(iv) *Aphanitic basalts*

Fissile compact black lavas (43/326, 7), closely resembling trachytes, appear at the bottom of the section in the Melawa gorge. They are aphyric or contain sparse felspar phenocrysts. The textures are unusual, the felspar being granoblastic, untwinned, and often parallel aligned, plagioclase making up the greater part of the rock. In thin section 43/1322 a large plagioclase phenocryst is present. The melanocratic minerals are the same as in the Samburu basalts. There is no doubt these are flows since locally red bole surfaces separate individual flows, which are conformable with the overlying Simbara basalts though separated from them by agglomerates.

A section of the bole (43/979) at the top of a flow on Peterson's farm shows a spongy dark opaque glass with augite and plagioclase phenocrysts. Like the Samburu basalts the Simbara series are typically holocrystalline, glass being only seen at the top of flows. These red layers at the tops of flows appear to be weathered surface layers of the actual flows.

(v) *Agglomerates*

Agglomerates are seen only in the Melawa Ndogo section where they separate the upper basalts from the underlying fissile basalts. They are composed of a coarse orange-brown or yellow tuff matrix, carrying many crystals of olivine together with angular or partly rounded blocks of basalt identical with the overlying Simbara basalts.

(c) *Rumuruti Phonolites*

The Rumuruti phonolites of the Laikipia plateau have been described by Shackleton (1946, pp. 31-33). He also described Kapiti-type phonolites and the Losiolo (Kenya-type) phonolites closely associated with the predominant Losuguta-type. In both this phonolite group and the younger Dispei-Lake Hannington group Kapiti-, Kenya- and Losuguta-types may be found and, in the present area, these terms have lost any sense of stratigraphic notation they may once have had. The phonolites of the Rumuruti group are seen in deep sections in many localities. They form a succession of numerous lava flows, individual flows being much thicker than the flows of the Samburu group, averaging 50 to 100 feet. The flows are separated by weathered zones but there is little or no tuffaceous material associated with this group, as there is in the area to the west (Walsh, at the press). Boreholes to the north-west of Rumuruti show an unbroken lava section, continuous to depths of nearly 1,000 feet. The greatest thickness of this formation is seen on the Ngelesha Escarpment where a thickness of over two thousand feet has been estimated, taking into account possible apparent thickening due to repetition by faults.

The Rumuruti phonolites show a remarkable change in thickness from east to west. They thin out rapidly into the Rift Valley and the Samburu basalts emerge from beneath them, overlain only by isolated outliers of thin phonolite. Again a few miles east of Rumuruti rocks of the Basement System emerge from under these lavas which have there thinned out to nothing. In the zone of greatest thickness the lowest phonolites exposed—at the base of the Ngelesha Escarpment and the Marmanet Escarpment (immediately to the north of the Iguamiti gorge) and again on the road section down the Lolderodo Escarpment—are divided by joints into sheets dipping very steeply westwards towards the Rift Valley. These sheeted zones may represent the actual zones of eruption. No other probable source is known for these lavas, but from their distribution, great extent and lack of any intermingled pyroclasts, a derivation by a process of welling out from fissures, in a zone running along the margin of the Rift Valley is suggested. The diagrammatic section of the plateau phonolites (shown in Fig. 14) suggests deposition in an early down-warped trough coincident with the present Rift Valley. The phonolite wedged out against basalt in the middle of this trough and against its gentle outer slopes. To the north of Rumuruti phonolites conformably overlie sediments containing *Deinotherium* (Shackleton, 1946, p. 28) and a Miocene age has been assumed. There is no reason in the light of the present survey to doubt the validity of this dating.

The petrography of these phonolites is very varied within the great expanse of lava flows exposed in this area, but it is a textural variation in the main, since analyses are very uniform (Table 2), though the group also includes trachytes. There is no consistent succession throughout the area but a distinct separation into sets of flows can be made (Fig. 3), though individual sets thicken to several hundred feet or thin out to nothing with great rapidity. The sub-divisions made and their relations to one another are as follows:—

	Subukia-Solai Escarpment	Murogor's Camp northwards	Laikipia plateau	Ngelesha	Jorokokwa
	Iguamiti flows	Iguamiti flows	Iguamiti flows		
Inter-digitated	Sipili Trachytes		Sipili Trachytes	(Ol Arabel flows?)	
Inter-digitated	Wasagess flows	Wasagess flows (=Ol Arabel flows)	Marmanet flows	Marmanet flows	Jorokokwa flows
	Uaso Narok Flows				
	Ngelesha and Ndurumo flows			Ngelesha and Ndurumo flows	

(i) *Ngelesha phonolite flows*

The lowest lavas in the Rumuruti phonolite are exposed at the foot of the Ngelesha Escarpment and on the Laikipia Escarpment near Murogor's Camp where they directly overlie the Samburu basalts, and a further occurrence is seen immediately north of the mouth of the Iguamiti gorge at the foot of the Marmanet Escarpment. These phonolites are dark greenish black, compact and fine-textured lavas showing only sparse felspar phenocrysts. They are characteristically vesicular, rounded or elongate vesicles being very frequently seen infilled with white zeolite. They are also characterized by spheroidal weathering producing a "boxworks" structure, individual spheroids being up to a foot in diameter. In the two best exposures, on Ngelesha and at the Iguamiti section, they are cut by the very steep joint planes already referred to dipping in towards the Rift Valley.

A typical specimen of the Ngelesha type phonolites is 35/1199 from the foot of the Marmanet Escarpment north of the Iguamiti river. The most striking feature of this thin section is the presence of numerous well formed nepheline crystals, uniformly stippling the slide. This texture is typical of nephelinites, but in this slide the nephelines are surrounded by a decussate network of minute attenuated felspar laths. Aegirine-diopside phenocrysts are present, aggregated with magnetite, and a deep reddish brown biotite.

In another example, (35/1468) from the foot of the Ngelesha Escarpment, small Carlsbad-twinned phenocrysts of orthoclase are set in a fine base composed of felspar laths, cossyrite, kataphorite, riebeckite fringing aegirine-diopside, barkevikite, nepheline and analcite.

(ii) *Ndurumo phonolite flows*

Phonolites characterized by very prominent and numerous anorthoclase and nepheline phenocrysts occur interspersed with the lavas described above at Ngelesha. Their most striking outcrops are on the surface of the Rumuruti plain on Ndurumo and Lariak estates, and in the Ol Bolossat Forest. They also occur along the Marmanet Escarpment near the base of the succession.

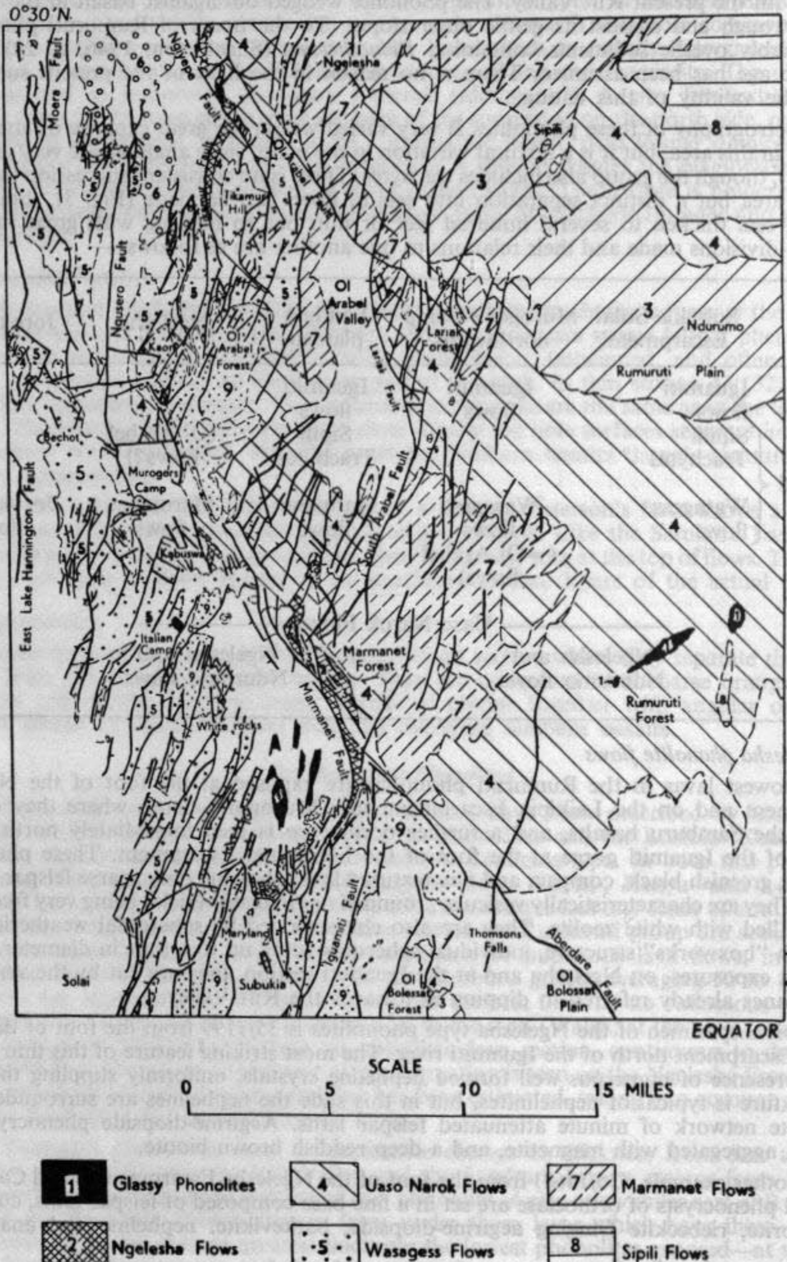


Fig. 3—Subdivision of the Rumuruti phonolites.

These lavas bear a closer resemblance to the Kapiti-type phonolites than to Kenya- or Losuguta-types. In thin section they show glassy phenocrysts of anorthoclase, often rather cracked as if transported some distance in the cooling magma, and some nepheline phenocrysts. The matrix is dense, porcellanous in appearance and dark green in colour.

A typical thin section, 35/1424 from Lariak Estate, shows stout partly resorbed anorthoclase phenocrysts, and narrow elongate soda-orthoclase phenocrysts set in a fine intergranular base composed of aegirine-diopside, riebeckite, cossyrite, and a light brown amphibole, together with nepheline and analcite, all these minerals occupying the interstices between laths of felspar. In this slide there are some partly resorbed phenocrysts which appear to be olivine, and some iron oxides are present.

Another porphyritic lava, (35/1143) from the base of the escarpment below Marmanet, shows phenocrysts of anorthoclase, soda-orthoclase, nepheline, aegirine-diopside and a pale reddish brown amphibole (barkevikite?). Aggregates of magnetite are prominent and the base is composed of cossyrite, kataphorite and riebeckite, felspar laths and analcite. Apatite is an accessory. There are a few ragged relict fragments of an early generation of biotite now almost completely resorbed.

A third example of the Ndurumo type of lava was taken from the coarsely porphyritic flows intercalated in the fine Ngelesha flows at the base of the Ngelesha Escarpment. In thin section (35/1470) numerous large felspar and nepheline phenocrysts, to some extent resorbed, are crowded into a very fine base. The nepheline phenocrysts are altered in patches to a granular mineral of high birefringence (cancrinite?) and radial aggregates of zeolite. Small fragments of green pyroxene are included in the phenocrysts, and some very small well-formed prismatic crystals of aegirine-diopside are also present. The base is fine and brown-stained, felspar, analcite and brown amphiboles being the main components.

(iii) *Uaso Narok phonolite flows*

Sections on the escarpments show many hundreds of feet of these flows. Lava of this type is best seen in roadside cuttings at the point where the Thomson's Falls-Rumuruti road runs near to the Uaso Narok river. This, the most common type in the Rumuruti phonolites, is characterised by a dark green porcellanous matrix in which are set anorthoclase phenocrysts and a few golden-brown flakes of biotite. Phenocrysts of aegirine-diopside, rather uncommon in the Rumuruti phonolites, are sometimes present, as are nepheline phenocrysts.

In thin section the Uaso Narok lavas are seen to be of the type previously described as Losuguta-type phonolites. A great many slides of the Uaso Narok division of phonolites have been examined and since a great degree of uniformity is seen throughout, the main characteristics are summarized here.

Phenocrysts are abundant, especially of anorthoclase and soda-orthoclase; both may be seen in a single thin section. The felspar shows either a broad oblong crystal form or a thin elongate form, with Carlsbad twinning. Nepheline phenocrysts are not uncommon, often showing alteration to cancrinite. Aegirine-diopside phenocrysts are seen in some thin sections, occasionally fringed by green amphibole. Biotite phenocrysts are nearly always present, very ragged and decomposed and often partly outlined along cleavage planes by granules of secondary opaque iron oxide. Aggregates of such oxide are nearly always seen, whether biotite is present or not, the iron oxide being frequently associated with apatite. The fine aggregates of melanocratic minerals—diopside, riebeckite, and brown sodic amphiboles—have a markedly even distribution throughout the rock. The leucocratic portion of the base is composed of finely crystallised felspar, nepheline and analcite. Vesicles, as in all the higher members of the Rumuruti phonolites, are rather uncommon.

(iv) *Wasagess flows* (*phonolites and trachytes*)

These are dominantly very coarsely crystallised lava flows with prominent and numerous felspar phenocrysts which give the rock a rough granitoid appearance. They are particularly well seen in the Solai Escarpment, the best specimens being collected near borehole C2272 at the foot of the escarpment. On this escarpment they are interspersed with phonolitic trachytes and trachytes of the Sipili type, and at the top of the succession, on the east side of the horst surmounted by Solai trigonometrical beacon, they appear to interdigitate with the lowest speckled lavas of the Iguamiti division. Farther to the north, on Leitman's farm, they are again associated with light weathering trachytes of the Sipili type, and overlain by the speckled Iguamiti lava types. North of Murogor's Camp they form a great expanse of barren, rock-strewn and virtually soil-less country around Bechot summit. These lavas are quite extensive in the northern part of the escarpment country but appear to pass into finer lavas of very similar type in the lower Ol Arabel valley (The Ol Arabel flows). The boundary between the Wasagess division and the Marmanet flows is purely arbitrary, the latter being an equivalent formation on the Laikipia plateau, which shows an absence of intercalated trachytes.

The typical lava in the Wasagess flows is seen in specimen 35/376 from near borehole C2272, which is a holocrystalline trachyte, grey in colour, and showing numerous platy felspar phenocrysts. Both soda-orthoclase and anorthoclase are present, though soda-orthoclase predominates. The base consists of an aligned felt of felspars together with interstitial riebeckite, cossyrite and kataphorite. Though aegirine-diopside is not prominent in this slide it is a common associate of the riebeckite. A little iron ore is present.

Rough textured rocks of similar appearance near Murogor's Camp were found to be coarsely crystallised phonolites. Specimen 35/754 from Murogor's Camp, a grey lava with prominent felspar phenocrysts, shows in thin section, besides felspar phenocrysts, small phenocrysts of aegirine-diopside and nepheline, the latter well formed and haloed by green aegirine-diopside, riebeckite and brown sodic amphiboles. The texture is holocrystalline and the base is intergranular, consisting of triangular areas between the orthoclase laths. Analcite is present in these areas together with amphiboles and pyroxenes. The texture suggests a coarse variety of the Kenya type, rather than the Losuguta type.

(v) *Marmanet phonolite flows*

A thick series of phonolites characterised by unusual white and dark patchy textures is developed around Marmanet, being particularly well developed on the summit. Some of these lavas are similar to the phonolites in the Wasagess and Jorokokwa subdivisions. Intercalated in the Marmanet flows are fine, dark, fissile flows, some of which are identical with the Thomson's Falls phonolites. The boundary between these lavas and Thomson's Falls phonolites is very difficult to determine north of the township, being densely forested, and the exposures in the Uaso Narok river are quite impossible to follow. The idea that the Thomson's Falls phonolites might be a lateral development of these Marmanet flows is discussed later.

There are many differing types within the Marmanet flows. A typical specimen is seen in a blackish brown, green and white mottled phonolite from the summit of Marmanet. The rock has a pronounced fissility and shows some resemblance to the Iguamiti flows though, unlike them, the Marmanet flows show no abnormal radioactivity. Felspar phenocrysts are usually present in these rocks, but in this slide only a few clustered nepheline phenocrysts are seen. The base is composed of patchy streaks of dark minerals—kataphorite and riebeckite—with a pronounced parallel alignment, alternating with clear streaks composed of aligned elongated felspars set in an aggregate of small nephelines and analcite. A specimen from nearby (35/1134) shows orthoclase phenocrysts, in part resorbed, together with small yellowish green aegirine-diopside phenocrysts with dark rims. The patches of dark minerals in the base of this rock are mainly kataphorite and aegirine-diopside.

An example of the coarsely crystallized type of flow which shows an unusual white and green coarsely mottled texture in which glassy felspar phenocrysts and creamy nephelines are prominent, is seen in specimen 35/1013 from east of Trent's farmhouse on the Thomson's Falls-Ol Arabel road. Phenocrysts include anorthoclase, soda-orthoclase and nepheline. The base is similar to that in the lavas described above, and has a strong flow orientation. Kataphorite, cossyrite, aegirine-diopside, the latter altering around its fringes to a riebeckitic amphibole, and black opaque iron ore are present.

A similar lava type from the Ol Arabel gorge (35/1356) shows phenocrysts of both nepheline (almost entirely altered to analcite) and orthoclase in a base composed of aligned felspars together with riebeckite, kataphorite, aegirine, and a light brown amphibole akin to barkevikite, common in this series of flows and in lavas of the Wasagess series. There is some black opaque iron ore.

(vi) *Jorokokwa phonolite flows*

Porphyritic phonolites of an entirely different type are to be found underlying the Dispei-Lake Hannington lavas at the foot of the Legisianana Escarpment and west of Mugurin. They are best exposed in the Jorokokwa horst. To the north of Mugurin they underlie the Goitumet basalts, which can be confidently correlated on petrographical grounds with the Kwaibus basalts which themselves underlie Lake Hannington lavas farther to the north.

These lavas are so strikingly similar to phonolites of the Marmanet and Wasagess flows in the Rumuruti group that a correlation was made based entirely on this lithological resemblance. The mapping of Walsh to the west has supported this correlation (verbal communication) since he found these phonolites occur between Kijabe-type basalts (Samburu?) and the Kwaibus-Goitumet formations overlying them.

The phonolites are very uniform and consist of dark coloured lavas characterized by numerous large felspar and nepheline phenocrysts. In thin section 35/584 from Turugulu large well-formed Carlsbad-twinned soda-orthoclase phenocrysts and smaller nephelines are set in a finely granular groundmass. Smaller felspar laths and patches of amphibole, riebeckite and kataphorite, occur in the groundmass. Minute nephelines, largely analcitized, show in outline in the light coloured parts of the base. This type of base showing minute felspars crammed together with analcitized nepheline crystals is characteristic of the Rumuruti phonolites, and never found in the younger Lake Hannington phonolites. As in the Rumuruti phonolites the occurrence in the Jorokokwa phonolites of anorthoclase and soda-orthoclase together is not uncommon.

(vii) *Sipili flows* (*Phonolitic trachytes*)

These fine textured fissile trachytes and phonolitic trachytes occur in the north-east corner of the area where they locally form the uppermost flows of the Rumuruti group. Shackleton differentiated the outliers of trachyte which he found in the Nanyuki-Maralal area (1946) but in the present area strikingly similar lavas occur in the Ol Arabel Forest between the Iguamiti and Marmanet flows, and farther south on the Solai Escarpment similar fine-grained lavas, including trachytes and phonolitic trachytes, are interspersed in coarser lava of the Wasagess flows, which again include both phonolites and trachytes. Trachytic lavas also occur in the Rumuruti Forest. Thus the Rumuruti group has been widened to include both phonolites and trachytes and the outlying patches on the Laikipia plateau are not here distinguished from the Rumuruti phonolite group.

The lavas of the Sipili exposures are greenish grey in colour, but elsewhere in the Ol Arabel Forest and on the Solai Escarpment a feature of these lavas is a well-developed light coloration, pale-brown to white, caused by weathering. An example of the Sipili lava flows from Sipili hill (35/1428) is a finely porphyritic trachyte showing aligned anorthoclase phenocrysts together with a smaller generation of aligned felspars. Riebeckite and brown sodic amphibole are present in irregular aggregates. There is a little turbid material which could be a fine cancrinite aggregate but otherwise felspathoid and analcite are absent.

Specimen 35/1436 from farther east, on Sipili Estate, shows no directed texture and is much coarser. It shows beautiful blue riebeckite. Felspathoid and analcite appear to be absent. 35/1445, from near Ol Donyo Oliep, shows aegirine-diopside phenocrysts. Again there is little or no analcite or felspathoid.

However a lava from north of Nixon's farm closely resembling the Sipili flows does contain a little analcite interstitial to the felspars which form a coarse decussate network. The texture is intergranular, and aegirine-diopside altering to riebeckite at the edges, brown sodic amphiboles, and black iron oxide are also distributed in the interstitial spaces.

On and below the Solai Escarpment the lavas exposed include types (for example 35/242 and 35/230) which closely resemble the Sipili flows. These lavas, which include felspathoid- and analcite-free trachytes and phonolitic trachytes with very little felspathoid and analcite content, are apparently fine-textured flows intercalated in the coarser phonolites and trachytes of the Wasagess flows. The phonolitic trachytes (35/230) sometimes contain sparse yellowish analcite pseudomorphing nepheline or else (35/242) may show turbid brownish patches suggesting a small felspathoid content.

The Sipili lavas are perhaps best classified as phonolitic trachytes as they vary rapidly from felspathoid-free to a weakly felspathoidal composition, and differentiation between these types is impossible in the field.

(viii) *Ol Arabel phonolite flows*

Fine phonolitic lavas, closely resembling some of the Dispei-Lake Hannington group, make their appearance near Tikamur manyattas, forming flat tops to the fault blocks to the west of the village. Though these lavas show a considerable resemblance to the later Lake Hannington group, and were at first mapped as such, the writer has concluded that they are in the older sequence, and closely allied to the phonolitic trachytes which outcrop on the Solai Escarpment.

Specimen 35/1475 from the lower Ol Arabel river shows small brown dark-haloed nephelines and parallel-aligned felspars (anorthoclase?) which give the rock a trachytoid texture. There are two generations of felspar. The nephelines are turbid and only recognised by their outlines: they are now composed of finely granular aggregates of secondary minerals. Riebeckite and brown amphibole are present in the base. Specimen 35/1577 from a mile to the west is similar, the resemblance to the Sipili lavas being even more striking. It contains some aegirine-diopside, and the nephelines are rather larger, and not so completely altered.

(ix) *Iguamiti phonolite flows*

The uppermost lavas of the phonolitic succession in Laikipia are a series of speckled phonolites, showing no very large phenocrysts. These phonolites would seem to be of the Kenya-type first described by Gregory (1900, pp. 210) and later described by Prior (1903, p. 239) under 'Phonolites with nepheline in small crystals surrounded by aegirine'. Shackleton however, uses the term Kenya-type for his Thomson's Falls and Losiolo phonolites (1945, p. 16 and 1946, pp. 34-35) which, from the description, do not appear to show such prominent nephelines as seen in the porphyritic Kenya-types of the Rumuruti and Dispei-Lake Hannington sequences.

These lavas occur as a thin veneer at the top of the succession in the Ol Arabel Forest. They are not seen farther north, and never extend far to the east away from the edge of the Rift Valley. In the south of the area, on the Lolderodo Escarpment between Thomson's Falls and Subukia, several hundred feet of these lavas are exposed. The thickness, even allowing for faulting, cannot be less than 600 feet, and over 400 feet were penetrated in borehole C1747 on Maryland Estate at the foot of the escarpment. However on McLellan's farm, only four miles to the east, they are entirely absent.

These phonolites are seen at the top of an excellent section in the thousand foot deep valley traversing the Ol Arabel Forest north of Icely's dam. Here the succession is:—

Iguamiti lava	(not more than 100 feet)
Trachyte (white weathering, fine textured, identical with the Sipili lavas)	(not more than 20 feet)
Marmanet lavas	(about 700 feet)
Uaso Narok lavas	(200 feet)
Base not seen	

The speckled lavas of the Iguamiti flows form the most southerly exposures of the Rumuruti group near to the south-east corner of Menengai crater on the Nakuru-Subukia road. These lavas are almost invariably characterized by a radioactivity anomaly, the ratemeter placed on an exposure showing readings of two to three times background. No source has been detected for the radioactivity, which occurs in many of the Rift Valley lavas.

The lavas of this subdivision are fine textured and show only sparse small felspar phenocrysts and cloudy-white nepheline microphenocrysts. Aggregates of riebeckite and kataphorite give a green and red mottled effect. Occasionally, in very altered samples, a yellowish tinge is imparted to the whole rock by secondary decomposition products.

A typical example of the more coarsely crystallized lavas in the Iguamiti series of flows is seen in specimen 35/1102 from one mile to the east of "A2" trigonometrical beacon. Nephelines are more numerous than in the phonolites of the Marmanet flows and felspar phenocrysts correspondingly reduced in number. There are none in this slide, but a few can be recognised in the fresh quarry face from which the specimen was taken. The melanocratic minerals, instead of being aggregated in streaky patches, tend to form dark haloes around the nephelines, which are little altered and show fairly good crystal outlines. The amphiboles are riebeckite and kataphorite together with a little cossyrite, and there are numerous small felspar laths (soda-orthoclase or anorthoclase) forming a decussate network in the base, which also contains interstitial analcite.

(x) *Glassy phonolites*

The phonolites of the Rumuruti group and the associated trachytes are dominantly holocrystalline, but glassy lavas are not unknown in the series. The occurrences appear to be of two types:—

(*a*) Glassy surface layers to flows. This is typically seen in 35/1374 from the upper surface of the uppermost porcellanous flow (Uaso Narok flows) in the deep valley section in the Ol Arabel Forest. The rock has a base of pale greenish brown glass in which are set anorthoclase phenocrysts. It is also highly brecciated, being taken from a fault zone. Another example is seen immediately east of the shop at the south end of the Ol Arabel valley. Black streaky obsidian here caps a lava flow.

(*b*) Lavas with a glassy base. These are not uncommon in the lower parts of the outcrops of the Rumuruti phonolites. They are found near Murogor's Camp and Italian Camp and on Chui farm, where they show felspar phenocrysts set in a dense black base. Superficially they resemble basalts, and often show spheroidal texture or columnar jointing, the latter suggesting rapid cooling, as is well seen at Italian Camp. The glassy types are almost invariably found near to the contact with the underlying Samburu basalt formation. It is believed that they are not distinct lava types, but phonolites and trachytes which have cooled rapidly in the sole of a flow on contact with a cold underlying land surface. Similar phonolites are seen in the Rumuruti Forest on the main road to Rumuruti from Thomson's Falls. Again they appear to be a variant of the normal type of phonolite since they show strong columnar jointing suggesting rapid cooling. These lavas show a peculiar annular pattern on air photographs.

A typical example of a glassy lava is specimen 35/736 from the Italian Camp which shows stubby anorthoclase felspars and a few attenuated crystals of aegirine-diopside set in a base of isotropic greenish brown glass. The glass, which contains infilled vesicles, has a lower refractive index than balsam which suggests that it may be analcitic or felspathoidal.

(xi) *Brecciated phonolites*

Brecciated phonolites are common in the fault zones, particularly on the "Gap" road, Solai, and on the new road between Subukia and Thomson's Falls. The stages of brecciation are firstly, cataclasis forming an obviously smashed but otherwise little altered lava; secondly, the introduction of networks of brownish veins along which secondary ferruginous minerals have crystallized; and finally the complete obliteration of the texture, the lava being converted into a brownish ferruginous secondary aggregate or a white kaolinitic mass, traversed by numerous dark ferruginous veinlets. Examples of the process of brecciation are seen in specimen 43/736 from Tinderess, specimen 35/1373 from the deep valley section in the Ol Arabel Forest, and the extreme case of a completely kaolinized phonolite is seen in specimen 35/1511 from the main fault zone on Chui farm.

(*d*) *Thomson's Falls phonolites*

An upper group of phonolites was described by Shackleton (1945, p. 3) from the Nyeri area. These were said to form a uniform series of flows characterized by twisted flow-structures. Minute parallel-aligned felspars give the rocks a glistening appearance on fresh fractures, though the finer lavas show a matt surface. A fissility along planes of flow is another characteristic feature (Shackleton 1946, p. 34). Phenocrysts of felspar of elongate form and small size have been identified as anorthoclase by Shackleton.

These phonolites, which have a blackish grey colour, resembling a basalt rather than a phonolite, weather into large boulders several feet across with a ferruginous coating. These are particularly well seen between Thomson's Falls and Ol Joro Orok. The field distinction of these phonolites was found quite easy by Shackleton working to the east of Leshau, and indeed at Leshau no difficulty was found by the writer in mapping the contact between the overlying blackish grey phonolites which form at least three distinct flows with marked terminations and the underlying porcellanous Rumuruti phonolites. At Thomson's Falls however the contact runs through a belt of impassable terrain along the forested rocky gorge of the Uaso Narok river, and the boundary there has been only tentatively delineated.

To the west of Thomson's Falls the last exposure of this type of lava is on Wace's farm, and porcellanous lavas of the Rumuruti group appear to rise from beneath them in the Ol Bolossat Forest. The phonolites of the Moridjo Forest and Supuko Lereko are quite clearly of the Thomson's Fall type, but to the south of Ol Joro Orok agricultural station lavas of this type seem to be intermingled with rather fine analcitic types more closely resembling the Rumuruti flows. The boundary has been drawn tentatively just south of Ol Joro Orok, but more detailed study might reveal occurrences of the upper flows farther to the south.

In the Oramutia valley lava of this type shows a streaky and fragmental crust, not dissimilar to the upper surface of many trachyte flows, and closely resembling the streaky fragmental trachytes of Kariandusi, which are believed to grade into "ignimbrites". Bouldery or pebbly upper surfaces are seen in the Pesi valley on Supuko Lereko and near Ol Joro Orok. The boulder or pebble inclusions consist of similar phonolite to the matrix.

The Thomson's Falls phonolites have been described by Shackleton as of Kenya-type. It is now known that there are phonolites of Kenya-type within the Rumuruti succession which also includes types which fit into the Losuguta-type and the Kapiti-type. There are certainly lavas identical with the Thomson's Falls lavas intercalated in the Rumuruti succession, and petrographic methods of distinction thus break down entirely. While anorthoclase predominates in the Thomson's Falls lavas, soda-orthoclase is also often present. Broad oblong felspar phenocrysts are rather uncommon, while such phenocrysts abound in the Rumuruti phonolites, but this is not really good diagnostic evidence. Olivine is sometimes present in both, as phenocrysts surrounded by green pyroxene. Riebeckite is rather more abundant in the Rumuruti lavas, aegirine-diopside in well formed phenocrysts in the Thomson's Falls lavas. The Thomson's Falls lavas typically show analcite in interstices between the small felspars forming a lattice-like or trachytic base, but this texture is also seen in some fine bands within the Rumuruti phonolite succession. Small altered nephelines may be present in both and are frequently haloed by dark minerals. Both contain cossyrite and kataphorite. The clustering of pyroxene and magnetite is rather more common in the Thomson's Falls flows. The most significant distinctions are the complete lack of biotite in the Thomson's Falls lava and the absence of porcellanous textures.

The writer feels that the clear distinction made by Shackleton may not be of more than local significance. The Thomson's Falls flows may perhaps best be considered as a series of flows of unusual type developed near the top of the plateau phonolite succession, and readily distinguished in the locality which gives them their name. Elsewhere similar types form minor intercalations in the plateau phonolite succession. The possibility that these flows are equivalent to some of the Marmanet flows in the Rumuruti succession—flows showing identical characteristics—and are thus slightly older than the Iguamiti flows cannot be entirely discounted.

(e) *Phonolites to the north of Ol Kalou*

Lava with an unusual slaggy appearance, characterized by streaky textures and large gas cavities, occurs in inliers to the north of Ol Kalou and is particularly well seen on Horvmand's farm. Thin sections suggest a trachytic composition but nepheline has been doubtfully identified in one slide and the rock would probably show a phonolite composition on analysis. Such lavas lacking visible felspathoids are common in the tops of flows of the Thomson's Falls phonolite on Supuko Lereko and it is probable that this lava represents the top of a phonolite flow and not a distinct lava formation. The Thomson's Falls and Rumuruti flows are not easily differentiated in the locality, fine textured lavas of both types being present and apparently intermingled, and the symbol Tvp has been used on the map to denote these unusual lavas, which have not been allocated to either division.

(f) *Sattima Lavas*

The lavas of the Sattima series, including phonolites and trachytes, have been described by Shackleton (1945, pp. 2–3). Fine textured greyish green lavas, weathering to a thin brown surface film, outcrop in a river valley near Kipipiri House. They are considered to be lavas of the Sattima series. They underlie the Kinangop tuffs, and though the nature of the contact is not seen an unconformity is suspected. Another exposure is seen on the roadside north of Kipipiri Police Station.

The thin section examined from this small area of outcrop revealed a trachyte of unusual type. Phenocrysts of anorthoclase are prominent with both neutral coloured augite and green aegirine-diopside. Some olivine phenocrysts are also present. The base is trachytic, and composed of parallel-aligned felspars together with small green pyroxenes, brown sodic amphibole and iron oxide. The rock is probably identical with Shackleton's olivine-trachyte. Much of the felspar is lamellar-twinned but seems from refractive index values to be anorthoclase not plagioclase, so the rock is classified as trachyte rather than trachy-basalt.

It was noted that the phonolites in the Sattima series on Sattima itself were not dissimilar in appearance from porcellanous members of the Rumuruti group. There does not seem to be any valid objection to a correlation between the Rumuruti and Sattima volcanics as the result of contemporaneous eruptions. It is significant that Shackleton does not describe any contact between the plateau phonolites and Sattima series.

(*g*) *Laikipia Basalts*

On the western margin of the area, along the Wanjohi road and in the smooth grass-mantled rounded hill of Oloronyi, a series of rough-textured vesicular olivine basalts are exposed. The Oloronyi feature could represent a small central volcano. The lava is very different in appearance to the Simbara basalts, Kijabe-types being completely absent, and the writer has followed Shackleton (1945) in putting these lavas in the Laikipia group. However, their age is not at all certain.

Specimens from the Wanjohi road showed in thin section (43/1067) fine textured basalts with only very sparse andesine phenocrysts. The base is intergranular, small clove brown granules of augite being set, together with altered olivines and magnetite grains, in the interspaces between small decussate felspar laths. Like all the basalts examined from Oloronyi the rock is holocrystalline. The small rounded empty vesicles seen in this specimen are characteristic of these flows. Another specimen (43/1066) from nearby is coarser and shows a trachytic alignment of the felspar.

Farther to the south, on the road which skirts Oloronyi hill on its west side, olivine-phyric basalts were recognized. The olivine phenocrysts are altered to golden-bronze aggregates of iddingsite (43/1107). The fine intergranular base contains augite, magnetite, and olivine besides small laths of plagioclase (andesine to labradorite). In another specimen from nearby (43/1110) some ragged aggregates of a brown amphibole are present. A suggestion of flow-orientation is seen in the texture of 43/1112 from Franklin's farm, the southernmost exposure of this type of basalt in the area.

(*h*) *Rumuruti Forest Basalt*

Basaltic lavas outcrop on Meyler's farm, and in the Rumuruti Forest. From their position in relation to the Thomson's Falls and Rumuruti phonolite contact, they are thought to represent a flow or flows separating the two formations. Shackleton (1946, map) shows a basalt denoted by the symbol Bl on the Nanyuki-Thomson's Falls road to the west of Lomborai beacon, and this basalt, which is identical in appearance with the Rumuruti Forest basalts, is at the contact between the two phonolite groups. The two occurrences of basalt at this junction are probably not coincidental, and it is considered that a later eruption of lava of similar type to the Samburu lavas intervened between the two phonolite sequences.

Shackleton notes that in the samples from borehole C118 (which is within the present area) basalt was recognized under the Thomson's Falls phonolites. This borehole is situated between the two occurrences described above, and may well have struck the Rumuruti Forest formation rather than the Simbara basalt as suggested by Shackleton (1946, p. 52).

The Rumuruti Forest basalts include rough textured coarsely vesicular varieties, which are well exposed on the road to the bridge at the Uaso Narok fishing camp from Crampton's farm. Varieties marked by conspicuous augite phenocrysts set in a dark compact base are exposed in the dense undergrowth of the Rumuruti Forest to the north-west of the bridge.

Specimen 35/985 from Meyler's farm shows prominent augite and olivine phenocrysts set in a very heterogeneous holocrystalline base streaked with dark fine textured schlieren. The small andesine felspars in the base swirl around the larger augite and olivine phenocrysts. There is a smaller generation of augite and olivines set in the fine granular base, which is dusted with magnetite. A similar porphyritic type contains an earlier generation of plagioclase showing vaguely defined twinning. Neither of these specimens could be distinguished from Samburu, Kwaibus or Goitumet lavas on petrographic grounds alone.

(*i*) *Ol Donyo Oliep Basalt*

A specimen of dark basalt was collected on the north west slope of Ol Donyo Oliep. As the phonolites are known to be over a thousand feet thick in borehole sections close by, it is deduced that this represents a later flow and not an inlier of Samburu basalt, though the rock is petrographically indistinguishable from the earlier basalts. In thin section (55/1432) it is seen to be an olivine basalt, with prominent titan-augite and olivine phenocrysts set in a base of plagioclase laths, pyroxene, olivine, iron ore and some analcite.

(2) The Pliocene Volcanic Rocks

During the Pliocene period renewed eruptions of great magnitude took place in the central Rift Valley. These eruptions were followed by the second major faulting episode probably involving some of the greatest displacements in the central Rift Valley of Kenya.

The general geological history of the area in the Pliocene has been outlined in Table I. The geological formations which are here described include:

(i) Central volcanoes—Menengai and a subsidiary crater south of 'F' trigonometrical beacon.
—Sirrkon
—Hypothetical volcano west of Gilgil.

(ii) Lava flows extruded from fissure sources.

(iii) Thick and widespread tuff formations, including subaqueous tuffs deposited in lakes.

(iv) Welded tuffs and "ignimbrites" (*a*) Thin discontinuous but widespread deposits, typically represented by the "claystones".

(v) —do— (*b*) Much thicker deposits forming massive features resembling thick lava flows. The exact mode of derivation of these deposits is obscure, but it seems doubtful if many are of true air-borne origin from vulcanian showers.

The last three types of eruptive are apparently largely derived from the central volcanoes but it was impossible within the scope of this survey to determine from which of the several possible central sources any particular deposit derived. Katmaian eruption from fissures appears also to have occurred.

For ease of description the following subdivisions have been made, but to some extent boundaries are arbitrary:—

(*a*) Mau tuffs and associated lavas

(*b*) Kwaibus and Goitumet basalts

(*c*) Dispei-Lake Hannington phonolites

(*d*) Lower Menengai volcanics

(*e*) Sirrkon volcanics

(*f*) Bahati tuffs, and Kinangop tuffs and associated lavas.

(a) Mau Tuffs

The volcanics of Menengai on the west of the volcano merge into a thick series of tuffs analagous with the Kinangop tuffs. The successions to the west of Menengai have been for the most part derived from boreholes since deep surface sections are rare. The successions to the west are:—

Rongai	*Kampi ya Moto*	*Njoro*	*West of Lake Nakuru*
Pumice	Pumice	—	—
Dark green or grey porous vitreous tuff not more than 20 or 30 feet thick (may be a later deposit)	"Ignimbrite" and streaky vitreous trachytes of Menengai	Purplish friable vitreous tuff, passing laterally into "ignimbrite"	Purplish friable vitreous tuff, passing laterally into "ignimbrite"
Pumice tuffs several hundred feet thick, including sub-aqueous tuffs and diatomite	Pumice tuffs as at Rongai	Pumice tuffs several hundred feet thick, including sub-aqueous tuffs	Pumice tuffs several hundred feet thick, including sub-aqueous tuffs
Phonolite flows within tuffs near the base of the known succession.			Phonolite flows within tuffs near base of the known succession.

The bottom of the succession of tuffs is never seen: the lowest level known is about 800 feet down, where tuffs are still encountered.

Borehole C419 on Townsend's farm east of Njoro shows the following section:

Feet		*Probable Age*
0—1	Soil	Lower/Lower Middle Pleistocene
14—103	Phonolite (Ronda lava)	
103—509	Yellow pumice tuff and clay	Pliocene?
509—589	Phonolite	
589—600	Yellowish brown and grey pumice tuff.	

The phonolites from borehole C419 were sliced, and thin sections showed the following details:—

569 ft. Slide 43/1323: Phonolite (Kenya-type)—small turbid aggregates after nepheline. Haloes of dark minerals—aegirine-diopside, kataphorite, cossyrite, riebeckite. Trachytic to decussate arrangement of felspar laths. Some brown glass in interstices. A little iron ore present.

574 ft. Slide 43/1324: Similar to 1323, but coarser textured. Hexagonal phenocrysts show some clear isotropic material (nepheline or analcite).

To the west of Island farm the "ignimbrites" and welded tuffs become thin and patchy, and the Mau Escarpment south and west of Njoro seems to be mainly composed of yellow pumice tuffs, for the most part outcropping at the surface, with no "ignimbrite" cover. "Ignimbrites" appear less abundant on the west side of the Rift Valley than on the eastern side.

The yellow pumice tuff that forms the greater part of the Mau is well seen on Prettyjohn's farm to the west of Island farm. It is a soft light brown rock with rounded insets of yellow pumice up to a centimetre across, and smaller fragments of angular trachyte. This rock decomposes to a clayey aggregate on contact with water.

The "ignimbrite" within the Mau tuffs is typically seen in 43/1247 from a scarp north of the Njoro river. It is composed of streaky, brownish glass flowing around fragments of well crystallized trachyte.

The purplish tuff is a crumbly porous rock, and is seen in thin section 43/1249, from south of the Njoro river, to be a spongy welded tuff composed of brownish glass, in the form of coalesced fragments, the outlines of which are discernable. Some crystal fragments are also set in the glass base.

(*b*) *Kwaibus and Goitumet Basalts*

These basalts outcrop in two areas to the west of Lake Hannington. An extensive series of thin flows of basalt and a few cindery basalt cones form a series of inliers in the Dispei-Lake Hannington lavas, to the west of Maji ya Moto (Ndolaita). The actual contact is not well exposed in the area but a good section can be seen in the Marigat river to the west. Here the junction is abrupt and the two formations appear to be concordant. In parts of the Marigat river section sediments intervene between the two formations, and there appear to be some coarse stratified tuffs overlying the Kwaibus basalt just north-west of Kwaibus peak, a few yards outside the margin of the area. Flows of these basalts, like the Samburu basalts, are separated by weathered zones, but tuff intercalations are not seen and agglomerates are absent. The superimposed tiers of these thin flows are magnificently seen in the eastern cliff of a very high standing horst north-west of Kwaibus, part of which lies within the area.

The petrography is almost identical with the Samburu basalts but the Kijabe-type is never seen and the felsparphyric types are grey rough-textured rocks, with numerous small glassy and poorly formed plagioclase phenocrysts. The augite- and olivine-phyric types are identical with similar lavas in the Samburu succession.

An olivine-phyric basalt from west of Loboi, on the western margin of the area, shows olivine phenocrysts partly altered to golden-brown iddingsite aggregates. Substantial amounts of magnetite granules are present and the base which is finely intergranular is composed of plagioclase laths (andesine) and augite granules. There appears to be some untwinned granular plagioclase present in the base. A similar olivine basalt (35/689) from between Kwaibus and Kironde shows a trachytic texture.

Andesine phenocrysts are abundant together with smaller olivines in 35/719 from Kwaibus, and there are also some large titan-augite phenocrysts. There is a little secondary white mica in this slide.

A porphyritic lava from Kwaibus (35/717) shows augite phenocrysts dominant, with smaller felspars (in this case labradorite) and olivines.

Spongy cindery basalt, red in colour, is seen at the top of individual flows and in the rounded cones east and north-west of Kwaibus peak and on Kwaibus summit. This spongy lava is either glassy (35/685) or finely holocrystalline (35/720).

The Goitumet basalts, which seem to radiate in a series of lava tongues from Goitumet, a cone shaped hill to the west of Mugurin, overlie the Jorokokwa phonolites. The contact with the Dispei-Lake Hannington lavas is not seen, but Walsh (verbal communication) is satisfied from the mapping carried out farther to the west that they are a southward extension of the Kwaibus basalts, which underlie the Lake Hannington lavas.

The Goitumet feature appears to be a central volcanic cone. The lava is typically a rough-textured grey and vesicular basalt showing small glassy plagioclase phenocrysts. No division into flows could be made, and the lava is remarkably uniform. A specimen (35/622) from south of Makoi is remarkably fresh and shows a "diabasic" texture. It is composed of a network of labradorite laths together with a clove-brown augite, olivine and iron ore. The base is much coarser than anything seen in the Samburu group. There appears to be an older generation of plagioclase showing poor form and indistinct twinning. The rock is spongy, being riddled with open vesicular cavities.

Another specimen, from just outside the area at Makuyuni, shows an intergranular texture. Once again the rock is remarkably fresh and labradorite in two generations is set in a granular base composed of olivine (altering to iddingsite), augite, plagioclase and iron ore.

The Kwaibus and Goitumet basalts are thought to be representatives of a series of eruptions which initiated the Pliocene vulcanicity in this part of the Rift Valley. This view is based on their position above the Jorokokwa lavas and apparent conformity with the Dispei-Lake Hannington lavas, for which a probable Pliocene age has been suggested.

(c) *Dispei-Lake Hannington Phonolites*

An extensive phonolite plateau, disrupted by later faulting, occupies about 300 square miles in the north-west corner of the area, extending northwards from the Ol Punyata swamp to Marigat and Logumkum. The limit of extension into the Lake Baringo area to the north is not known. The plateau consists of a series of superimposed lava sheets which formerly had an even upper surface, and infilled the central area of an existing Rift Valley depression, the floor of which was stepped down by a succession of major fault displacements belonging to the earliest set of movements in the central Rift Valley. At the time of eruption of the phonolites these fault scarps had been considerably dissected.

The fault blocks seen at the present day are characterized by a very level platform-like upper surface, contrasting with the more dissected surface of the older Rumuruti phonolites. The fault scarps which disrupt the lava plateau are cliff features, only slightly degraded, and are believed to be of Pleistocene age. The great escarpment bordering Lake Hannington to the east and south is almost certainly somewhat older than these grid faults.

Part of the flat topped plateau of the Dispei-Lake Hannington phonolite forms a narrow facing along the rim of the 2,000 foot scarp east of the lake. Sections of this scarp are composed entirely of these phonolites, but near Bechot the older Samburu basalts are exposed in the scarp face below these phonolites. The facing never extends more than a mile from the edge of the escarpment. The origin of this facing is further discussed under structure (p. 97).

The lavas of this eruptive sequence are seen in section in the Dispei Escarpment, immediately east of Kisinana Camp and on many other scarp sections, notably the Legisianana and Emsoss escarpments. As many as five separate flows have been counted, each 50 to 80 feet thick, and frequently showing columnar jointing. They show rather rapid variations in the thickness of individual flows. Occasionally much greater thicknesses are seen—at the Sandai Gorge a single flow exceeds 300 feet in thickness.

To the north of Kisinana Camp these lavas are overlain by an "ignimbrite" capping a succession of 80 feet of sediments and pumice tuff. The "ignimbrite" is undoubtedly part of the Kinangop, Bahati and Mau tuff succession. To the south of Kisinana at Kabragai they are again overlain by the "ignimbrite". Equivalent lavas near Eldama Ravine, however, overlie yellow pumice tuffs of the Mau succession (verbal communication, Walsh) and thus it seems that the Lake Hannington phonolites must have been erupted in the middle of this sequence of tuff and "ignimbrite" eruptions.

Agglomerates are absent in these lavas and there are no boulder inclusions, but a veneer of apparently tuffaceous material resembling the uppermost vitreous fragmental layers of the Lower Menengai succession is occasionally seen on the surface of the highest lava flow. Whether this represents a distinct pyroclastic or ignimbritic deposit or is just a glassy layer with fragmental inclusions is not certain, but in view of its insignificant development it is thought that the latter is the case.

Another characteristic feature is the presence of sparse pebbly inclusions of similar lava to the main body of the flow. This feature is matched in the Thomson's Falls phonolites and is believed to be an autobrecciation feature, fragments of the already crystallized selvedges being churned up in the still flowing lava body.

No sediments occur within the lava succession except at Marigat, where sections just outside the limits of the area show several intercalations of finely bedded tuffs and silts with diatomite, clearly of lacustrine origin (p. 73).

The petrography of these lavas is not exactly matched in the Lower Menengai volcanics though there is degree of superficial resemblance, and they could be lateral variants of the Menengai lavas. In contrast, the petrography of the lavas intercalated in the main tuffs (recognized only in borehole samples west of Lake Nakuru) and the later Ronda lavas is identical. It is suggested that the lavas recognized in the borehole are indeed the equivalent flows, but the Ronda lavas are certainly of later age. There can be no doubt that the Dispei-Lake Hannington lavas are contemporaneous with the central eruptions of Menengai, but derivation from quiet welling out along fissures is considered more likely than derivation from this central source, since petrographically they are dissimilar and they extend at least forty-five miles to the north of the volcano, rather too far for flows emanating from a single southern source. The idea that some of the Dispei-Lake Hannington lavas might have emanated from Kilombe, a smaller shield volcano associated with a caldera situated near Eldama Ravine, has been entertained: the lavas of Kilombe are now known to be of Kenya-type phonolite matching the Dispei-Lake Hannington lavas and are overlain by the yellow Mau pumice tuffs.

In general these lavas are much finer textured than the Rumuruti phonolites, and phenocrysts where seen are not usually very large or numerous. The square-shaped anorthoclase phenocrysts and biotite flakes typical of many of the Rumuruti phonolites are never seen, and neither is the characteristic base texture of leucocratic pools of minute nepheline and felspar crammed into an analcitic groundmass. Instead a characteristic base composed of a decussate network of felspar laths with interstitial analcite and a little brown glass is seen. This texture is related to intergranular and intersertal textures in basalt. Where nepheline is present it closely resembles the base of the Thomson's Falls phonolites. These phonolites show the characteristics of the Kenya-type (for example 35/555 from the Kisinana Escarpment), small nepheline phenocrysts being scattered evenly through the rock and haloed by dark minerals, among which aegirine-diopside, acmite, cossyrite, kataphorite and riebeckite are typical. In many of the phonolites the nepheline is entirely altered to analcite, cancrinite and other secondary minerals. Aegirine-diopside phenocrysts aggregated with black opaque iron ore are not uncommon. In these lavas, as in the Rumuruti phonolites, the green pyroxene tends to grade into riebeckitic amphibole due apparently to a process of alteration. Olivine is a very rare constituent.

A great many of the phonolites (for example 43/922 from Kabragai) show no nepheline, the analcite in the base being the only indicator of phonolitic rather than trachytic composition. This is especially noticeable in the very fine textured lavas, which tend to predominate near Maji ya Moto in the north of the area. Glassy lavas are more common than in the Rumuruti phonolites. Typical streaky and glassy lavas are seen in 35/157 and 159 from Kisinana Escarpment. The latter shows in hand specimen very fine banding contorted into very small fold structures. Spheroidal growth of crystallites is seen in some glassy flows (35/251 from Kapicha). In this lava the phenocrysts are of soda-orthoclase which seems to be far more common than anorthoclase in this series of flows. The glassy lava tends to form the surfaces of individual flows.

Well crystallized trachytes have also been recognized in this lava succession. Some, which resemble lavas of the older Rumuruti succession, may be enclaves of the older lava caught up in the newer flows. But 43/808 from Majani Mingi more closely resembles the Dispei-Lake Hannington phonolites and is almost certainly a localized felspathoid-free variant. Very coarsely porphyritic trachytes, seen on Loboi Hill (35/515) and in the eastern escarpment, have been tentatively included in this series though they could be inliers of the older series. Rumuruti phonolites outcrop under the Dispei-Lake Hannington lavas in the great escarpment south of the lake but the field relations are too jumbled in the fault zone for more than a generalization to be shown on the map. There is also some reason to believe that west of Lake Hannington a few more inliers of Rumuruti phonolite may exist than are shown on the map, since some loose boulders of the older types were collected from this area.

The southern boundary of the Dispei-Lake Hannington phonolites is arbitrarily drawn. The Kenya-type phonolites have been recognized as far south as Ol Banaita Sisal Estate, but the long east-west ridge south of Ol Punyata station is composed almost entirely of glassy trachyte, and all the lavas between here and Menengai are similar. The most northerly occurrence of the flows provedly erupted from Menengai is thus put on the north of this ridge.

In the railway cutting at Ol Punyata station the glassy trachytes overlie yellow pumice tuffs, crudely stratified and containing angular fragments of trachyte and obsidian. These are identical with the pumice low down in the Lower Menengai succession and tuffs widely exposed on the Mau, at Eldama Ravine, in Bahati and the Kinangop plateau. It is clear that the trachytes south of Ol Punyata are only slightly younger than the Dispei-Lake Hannington flow and differention in the field is difficult.

Analysis of a phonolite from Ol Banaita Sisal Estate is given in Table 2J.

(d) Lower Menengai Volcanics

Menengai volcano has been described in two previous works (McCall 1957 (*a*), (*c*) pp. 13-21). In neither of these papers however were the petrographic details of the lavas and tuffs included, and these details are incorporated in this report. Also in the course of the present survey some further details of the caldera walls were obtained. Contrary to the suggested age of the older volcanic formation (exposed in the walls) given in these previous works, this formation is now known to be equivalent to the Bahati, Kinangop and Mau tuffs, and probably of Pliocene age. The dating previously given (McCall, 1957 (*a*), pp. 58 and 61) was based on two misconceptions.

(i) The grid faults of the Rift Valley floor were seen not to transect the caldera walls. This was taken as evidence that Menengai volcano erupted later than this faulting. It is now accepted by the writer that Menengai and the Eburru massif to the south formed stable areas on the floor of the Rift Valley, and the grid faulting petered out on their flanks.

(ii) A mis-correlation on the grounds of close lithological similarity was made between the uppermost vitreous tuff of Menengai and the Makalia ash. This involved placing formation of the caldera in comparatively recent times. It is now realized that the Menengai vitreous tuff must be much older than the ash referred to, since it and the underlying "ignimbrite" are now recognized in the Bahati tuff group. In any case the vitreous tuff used as building stone and excavated from quarries on the north bank of the Makalia river is now known to be of almost certain Upper Pleistocene age, and not of Makalian (epi-Pleistocene) age.

The volcanics of the caldera wall and outer slopes have been termed the Lower Menengai volcanic series. The succession has now been fully worked out on the precipitous cliff known as the Lion's Head, immediately to the north of the summit trigonometrical point (Finn 2) and this has led to a much clearer picture, since this is the most complete section in the caldera wall.

The succession is:—

Rock type	*Approximate estimation of the maximum thickness of the flows (feet)*	*Details of occurrence and petrography*
Pumice and boulders of obsidian and scoria. Syenite blocks.	20	
17. "Vitreous tuff"	20	Well developed north and east of the ballast quarries on the Solai road. Very thin on the upper slopes of Menengai. Carries syenite enclaves.
16. Trachyte	50	(43/1201) Green spongy trachyte. Devitrified glass with prominent soda-orthoclase phenocrysts, some aegirine-diopside. Base of brownish glass inset with minute felspar microcrysts, brown sodic amphiboles, riebeckite and iron ore.
15. Trachyte (phonolitic)	70	(43/1203) A coarse porphyritic trachyte, holocrystalline. Soda-orthoclase and olivine phenocrysts with haloes of iron oxide. Pyroxenes, pleochroic from green to grey, with high extinction angle (38°) in elongate section. Coarse trachyte base with prominent riebeckite and kataphorite. Sparse turbid pinkish grey isotropic aggregates showing markedly hexagonal outlines are believed to be pseudomorphs often nepheline.

Rock type	Approximate estimation of the maximum thickness of the flows (feet)	Details of occurrence and petrography
14. Trachyte	70	(43/1204) Porphyritic, glassy. Spheroidal crystallites set in the glass. Some olivine with black iron ore haloes. Anorthoclase and some aegirine-diopside phenocrysts.
13. Trachyte	70	(43/1205) Porphyritic trachyte grey massive compact, slightly fissile. Texture trachytic. Phenocrysts of felspar set in a base of aegirine-diopside, kataphorite, cossyrite and iron ore.
12. Trachyte (Phonolitic Trachyte?)	80	(43/1198) Grey, compact, greenish-streaked trachyte. Non-porphyritic. Soda-orthoclase, brown amphibole and riebeckite. Possibly a little analcite.
Old Land Surface	(inaccessible)	Weathered intercalation between the flows.
11. Trachyte	20	(43/1199) Non-porphyritic holocrystalline trachyte. Felspar laths; cossyrite and kataphorite, riebeckite, acmite all prominent.
10. Trachyte	80	(43/1200) Spongy non-porphyritic trachyte. Composition as 43/1199 above, but a little glass appears to be present.
9. Trachyte	30	No slide.
8. Trachyte	80 (Insensible gradation)	(43/1298) Massive, slightly fissile, holocrystalline, with a trachytic texture. Orthoclase, riebeckite and kataphorite prominent, the amphibole being aggregated in parallel aligned lenticles.
7. Trachyte	80 (Insensible gradation)	(43/1299) Streaky vitreous trachyte composed of feathery brown glass bands alternating with slightly better crystallised light coloured bands. Three discontinuous bands of trachyte rubble (auto-breccia) at the base.
6. Trachyte rubble (auto-breccia)	2	(43/1301) The slide shows lenticles of fine trachyte with glass subordinate to crystallised material. The whole band forms a bouldery aggregate of this lava cemented by finely crushed material of similar kind, showing a strong adherence suggesting a certain amount of welding while hot.
5. Trachyte	2	(43/1302) Streaky trachyte composed of bands of brown glass, closely spaced and contorted, forming a discrete layer with an abrupt contact with the rubble layer above. Voids separate the glass bands and some crystal growth has occurred, tending to form a dentate felspar fringe to these voids.

Rock type	*Approximate estimation of the maximum thickness of the flows (feet)*	*Details of occurrence and petrography*
4. Reddened "Ignimbrite"(?) (Old Land Surface-? pause in eruption)	2	(43/1303) A fragmental rock resembling the rocks termed "ignimbrites". Discrete angular inclusions of grey trachyte set in a reddened compact vitreous base. Some light yellowish pumice insets.
3. Streaky trachyte	2	(43/1304) A discrete band of glassy lava, rubbly in part. Thin streaks of brownish glass, closely spaced, enclosing lenticles of well crystallized trachyte.
2. Pumice tuff	100	Brownish to yellowish pumice tuff. The best section is in a deep gully a quarter mile east of the main section, where about 100 feet of soft tuffs are exposed underlying a thick rubble (auto-breccia). The tuff is identical with the yellow tuffs of Bahati exposed near Ol Kalou, and those of the Mau, Kinangop and Eldama Ravine, characterized by small angular trachyte, phonolite and obsidian inclusions. Cut in the main section by a narrow vertical dyke of similar material.
1. Porphyritic trachyte	50	(43/1306) Holocrystalline. Soda-orthoclase phenocrysts, part resorbed, coarsely crystallised base. Cossyrite, kataphorite, riebeckite prominent. A yellowish isotropic mineral interstitial to minute decussate felspars in the base may be analcite. Aggregates of natrolite show brush polarization.
?	100	Obscured by scoria mantle.
Total section	928	(approximate)

The Lion's Head section shows a succession of flows interrupted by reddened old land surfaces marking pauses in eruption. The lavas are dominantly trachyte, grading to phonolite trachyte. Quartz is not seen, though an analysis of 43/1193 from the same flow as 43/1298 shows a little normative free quartz (Table 2K). The lavas grade rapidly from homogeneous holocrystalline to heterogeneous vitreous types, and the heterogeneous streaky fragmental flows indistinguishable from "ignimbrites" grade insensibly into glassy banded trachyte lavas. These show much the same variation in structure as has been recognised from Kariandusi, but the holocrystalline end member is also present in Menengai. A lot of the spongy vitreous tuff well developed east of Menengai appears also to have an effusive origin, having been erupted as a flow of viscous material. On the whole there is a lack of true pyroclastic material except possibly for the yellow pumice tuff near the base of the succession (which may, however, be an incandescent avalanche deposit) and the enclaves are of a type indicative of derivation from segregation in a single parent magma, together with some xenoliths of earlier crystallized trachyte caught up in the flow. Vesicles are not common, though spongy textures are. The rubbly autobreccia can be explained by destruction of first formed bands near the chilled sole of the flow by movement of the yet uncooled body of the flow.

Other sections of importance are in the south-west corner of the caldera, on the western promontory, in the ballast quarries on the outer eastern slope and in the district council quarry on the Eldama Ravine road, Nakuru. The main details are summarised below:—

South-west cliff (c. 500 ft.)

6. Pumice	
5. "Ignimbrite"(?)	Columnar jointed. Streaky green glass base in which are set dark lenticles of trachyte, a few felspar "phenocrysts" and some obsidian enclaves.
Old Land Surface—reddened layer	
4. Trachyte (Massive)	
Old Land Surface—reddened layer	
3. Trachyte (Massive)	
Old Land Surface—reddened layer	
2. Trachyte	(43/829) Massive holocrystalline. Large anorthoclase phenocrysts. Smaller aegirine-diopside altering to riebeckite amphibole. Brown amphiboles and iron ores.
Old Land Surface	Two feet thickness of reddened streaky trachyte (43/833) composed of thin bands of glass with microcrysts of felspar. Resembles "ignimbrite" but is apparently the top of the lower flow.
1. Trachyte	Green spongy streaky trachyte. Minute felspar phenocrysts.

Western Promontory

The details of the western section, about 400 feet high, on the north side of the promontory (McCall, 1957 (*a*) Fig. 2 and 3) are:—

5. Pumice	Crudely stratified coarse pumice lapilli beds dipping apparently conformably with the underlying flow in towards the caldera.
4. Trachyte	(43/821) Streaky glass flow composed of brownish glass alternating with lenticles of well crystallised trachyte, not xenolithic in origin. This flow includes a friable layer composed of cellular dark green devitrified glass, inset with clear felspar phenocrysts (43/827) identical with the vitreous tuffs east of Menengai. To the south of the promontory the uppermost flow passes into a light green vitreous rock showing dark parallel streak of trachyte, and identical in appearance with the "ignimbrites" near Gilgil. This flow locally carries boulders of porphyritic trachyte up to four feet across. In one locality two similar flows are superimposed in the caldera wall and are seen to be separated by an old land surface.
Old Land Surface (reddening).	
3. Trachyte	(43/822) Non-porphyritic. Cossyrite and kataphorite prominent. Some glass.
Old Land Surface (reddening).	

2. Trachyte — (43/823) Spongy and porphyritic texture; anorthoclase and aegirine-diopside phenocrysts set in a base containing dark opaque patches of glass.

Old Land Surface (reddening).

1. Trachyte — (43/825) Spongy green cellular lava composed of alternating bands of brownish glass and well crystallized bands. Small microcrysts dispersed throughout the glass. (only top of flow exposed).

To the north of the caldera the succession closely matches the sections described and calls for no detailed comment. The "ignimbrite" type of flow is particularly well seen on Rhodora Farm near the south-east lateral graben (43/836) where a columnar jointed flow of green glass marked by dark flattened lenticles of well crystallized trachyte forms the uppermost flow in the wall of the caldera. Near "F" beacon a similar glassy rock (43/1201) showing crystallization around the voids, is seen. There appears to be a minor subsidiary crater to the north of "F" beacon, of similar size to that on Sirrkon.

In the Menengai ballast quarries, west of Solai road, the succession is:—

3. Pumice mantle

2. "Vitreous tuff" (up to 20 feet) — Green cellular and streaky partially devitrified glass. In specimen 43/746 seen to be composed of spongy yellowish glass carrying aegirine-diopside and felspar phenocrysts aggregated with iron ore. No pyroclastic fragments. Thin section 43/741 from the small quarry east of the tarmac road shows streaky, partly divitrified, turbid green glass carrying irregular fragments of felspar and small patches of well crystallized trachyte. The petrography does not suggest an airborne deposit, and these were probably erupted as flows.

1. Trachyte — (43/749) Massive, porphyritic, trachytic texture, compact with small anorthoclase phenocrysts. Decussate aggregates of riebeckite and brown amphiboles set in a finely crystalline base. Little or no glass. Base not seen.

The lava surface dips at up to 60° to the south-east, the highest dip noted in the Menengai lavas.

The section in the Nakuru District Council quarries shows a compact flow characterized by parallel flattened trachyte lenses in a glass base. At first sight it would be called an ignimbrite. In thin section it was seen to be composed of streaks of brown glass in which are set small crystals of felspar, cossyrite, kataphorite, riebeckite, etc. Well crystallized patches of uniform texture, and trachytic composition, similar to that of the glassy portion are inset in the vitreous base. The rock shows a rather abrupt gradation upwards into the green "vitreous tuff" type seen east of Menengai. This is a cellular rock composed of glass, in parallel bands, and inset with cavities fringed with spheroidal clusters of felspars. In this quarry the upright tree moulds previously figured (McCall, 1957 (*c*) Plate 1) were recognized. That trees were left standing until the flow enveloped and burned them away is evidence of an extremely fluid type of flow.

All these sections strengthen the idea that the volcano was originally built up almost entirely of trachyte, showing rapid gradations from massive flows, through streaky heterogeneous vitreous types and the characteristic "ignimbrite" type with included flattened lenticles of trachyte, to the green cellular devitrified glass flows which form the building stone quarried east of Menengai and appear at first sight to be vitreous tuffs. In fact the ignimbritic types with flattened lenticular inclusions are almost certainly either the top portions of flows of which the main body is a well crystallized, or part-vitreous heterogeneous lava (or even a homogeneous lava) or else form complete flows. The question of how much of the similar thick bodies of ignimbrites situated many miles from eruptive centres, in the Kinangop, Bahati, Solai and the Mau, are of pyroclastic origin, derived from vulcanian showers or *nuées ardentes* involving respectively air transport of fragments and derivation from incandescent air-borne clouds or are glassy fragmental effusives issuing from the vents or fissures on the land surface and flowing as a fluid, gas-charged lava is questionable, and is further discussed in a later section of this report (p. 51).

Syenite boulders are numerous on the eastern slopes above Menenhill Farm. They occur in the pumice mantle and can be recognised as enclaves in the "vitreous tuff" forming the uppermost flow of the Lower Menengai volcanic series, from which they are probably almost entirely derived, though some may have been ejected with the pumice. Similar syenite boulders are known at Longonot, Eburru and in tuffs of the Kinangop, Bahati and Mau formations. They are best seen however on Kilombe volcano, near Eldama Ravine, where large blocks form a prolific mantle on the outer southern slope of this trachyte volcano (McCall, 1964). The syenites are holocrystalline granitoid rocks with felspar predominant. They are usually decomposed but thin sections (43/1274) reveal a composition of anorthoclase with subordinate deep green aegirine, and black iron ore. A little olivine appears to be present, and a very dark brown mineral with straight extinction, probably a sodic amphibole. Analysis (Table 2L) indicates a little normative nepheline.

While there is no reason to doubt the general validity of the conclusions reached in the previous work (McCall, 1957, (*a*), pp. 60-62) there seems no certainty as to when the caldera was formed. What evidence there is suggests an age not much later than Middle Pleistocene since the pumice mantle has the highest Gamblian shore-line cut into it (p. 66). The Upper Pleistocene sediments of the Nakuru basin appear to have been largely derived from the pumice mantle. The possibility that the caldera is contemporaneous with the Lower/Lower Middle Pleistocene grid faulting cannot be entirely discounted as the physiographic forms produced in both sets of structure are similar. This would put it in the Lower or Lower/Middle Pleistocene just before the Kariandusi deposition. It is clear that the heterogeneous trachytes of Menengai, akin to ignimbrites, preceded the caldera formation, probably by a substantial time interval, and are not closely connected with it. They are however connected with a volcano tectonic depression (cf. Smith, 1960, p. 818-20).

The only evidence for craters existing at the time of the first Menengai system is in two small depressions on Sirrkon summit and near "F" beacon. It is probable that the Menengai and Sirrkon volcanic piles had a few small craters rather than any large central crater. Eruptions of welded tuffs from open craters are not well documented (Smith, 1960, p. 816) and it seems possible that the mode of eruption in Menengai was from fissures in a domelike volcanic pile devoid of craters

(*e*) *Sirrkon Volcanics*

The lavas now called Gilgil trachytes, Ronda phonolites and the lavas of Sirrkon (Lion Hill) were originally named the "Nakuru phonolitic trachyte" formation (McCall, 1957 (*a*), p. 5). They are now differentiated since further field work has suggested that the Sirrkon lavas are older than the other two and are, in fact, continuous with the Lower Menengai volcanic succession through Plaat and the small hill to the east of the Solai road junction with the main Nakuru-Nairobi road.

On Sirrkon the succession in the uppermost flow is:—

3. Rubbly cellular devitrified glass, resembling the uppermost member of the Lower Menengai succession.
2. Streaky, glassy trachytes in some localities indistinguishable from "ignimbrites." Grading downwards into.
1. Phonolitic trachytes.

The upper veneer of glassy rocks is not very thick on Sirrkon. The whole hill feature, which forms a hog-back running north-south, is believed to be a subsidiary central volcano of elongate form much disrupted by subsequent grid-faulting. From a study of air-photographs it appears that the crater is partly preserved in a small half-moon shaped depression immediately west of the summit trigonometrical beacon.

The lavas of Sirrkon are, unlike those of Menengai, strongly affected by grid-faulting, the faults with the main displacement on the west side virtually bisecting the mountain. There are several trachyte flows exposed, though the succession is difficult to follow in the broken terrain.

On Plaat hill, to the west of Lanet, the succession is:—

3. Green vitreous upper layer ("vitreous tuff" of Menengai).
2. Bouldery rubble-breccia of trachyte (?). Such rubble-breccias have been described from Menengai, and are believed to be derived by autobrecciation.
1. Massive trachyte lava.

The total thickness is about 100 feet, and may represent a single flow.

A thin section of the top layer of the Sirrkon volcanics (43/1227 from the south-west part of the massif) shows a glassy trachyte with a streaky texture, and a carious appearance due to the presence of numerous voids. It closely resembles streaky glassy flows of Menengai.

Massive lavas from lower in the succession (43/1228 from south of Nderit House, and 43/1230 from near the summit of Sirrkon) show a phonolitic composition and a texture of the Kenya-type, haloed aggregates pseudomorphing nepheline and some analcite being present. Sparse anothoclase phenocrysts may be present but textures are usually aphyric. A little glass is present in 43/1228 which has a patchy texture composed of holocrystalline coarser patches set in a finer partly vitreous base. 43/1230 has a holocrystalline trachytic texture.

There seems to be a tendency for the upper part of individual flows to be trachytic and the lower part phonolitic, but the felspathoid content may be represented in the glass fraction. Petrographically these flows may best be classified as phonolitic trachytes.

(*f*) *Bahati and Kinangop tuffs*

A continuous series of tuffs and "ignimbrites" extends from Bahati, immediately east of Menengai, to the plain of Ol Bolossat and the Kinangop plateau where older lava formations, the Simbara basalts and lavas of the Sattima series, emerge from beneath the tuffs, and the basalts of Oloronyi (called Laikipian by Shackleton) appear to do the same. To the north of the Aberdare massif however a thin succession of members of this tuff formation extends eastwards in a series of discontinuous outliers through Aberdare farm, beyond the Sattima Escarpment to Ndaragwa. Beyond Ndaragwa the easternmost recorded exposure is in the Nairutia river near Ngobit (Shackleton, 1946, map). Some distance to the south the same tuffs reappear at Nyeri, but the direction from which these Nyeri tuffs were derived is obscure. To the north of Menengai, in the Bahati Forest, phonolites of the Rumuruti formation come out from under the tuff group, and northwards the tuffs gradually thin out and disappear. The northernmost outliers are seen to the north of Subukia, on Leitman's farm. To the north-east of Bahati the tuffs are fairly well developed in Lower Solai but thin out into a series of minor outliers overlying the Dispei-Lake Hannington phonolites at Kisinana and Ngendalel, and to the north of these localities are absent. To the west of Solai there is a northerly trending belt extending from Menengai through Ol Punyata and Lomolo where the tuffs are completely absent (except for one exposure at Ol Punyata station), but further to the west they thicken to deep successions of "ignimbrite" and pumice tuffs, and associated sediments at Kampi ya Moto and Rongai. A chain of central volcanoes forming a north-south ridge which includes at least three craters appears to have extended from Sirrkon through Menengai and "F" trigonometrical beacon: the pumice tuffs and sediments were either developed only on the flanks of the ridge or were obscured by these volcanics.

To the north of Ol Bolossat the tuffs are last seen as thin outliers of "ignimbrite" at Thomson's Falls airfield. They are absent in the great tracts of phonolite forming the Rumuruti plateau.

At Solai and in Bahati the unconformity on the older phonolites is clearly seen. This unconformity is due to the phonolites having been disrupted by fractures before the eruption of the tuffs. It is most strongly developed in the heavily faulted area within the Rift Valley but up on the shoulders, on Ol Bolossat and Supuko Lereko, it is not manifest since there was little or no previous disruption of the older phonolite substratum, faulting there being almost entirely of later date than the tuff eruptions. The unconformity is seen to the north of Black Hill, in a gully traversing the Solai Escarpment; at Subukia where the tuffs fill a deep graben; at Tindaress where the "ignimbrite" forms a facing on the westernmost scarp of the complex Solai Escarpment; at Ngorika where a partly buried hill of phonolite rises through the tuffs. The main rock types in the succession are:—

(*a*) Cream to yellow pumice tuffs (with local development of water-lain graded tuffs).

(*b*) Thin welded tuffs of the type known as claystones.

(*c*) Massive flows of welded tuff with coarse fragmental, laminar and lenticular textures. All the evidence suggests that they are overland flows and not the products of rapidly moving air-borne incandescent clouds. The term "ignimbrite" is used in inverted commas in this text to indicate flows or bodies of this type however formed.

(*d*) Trachyte lavas, both well-crystallized types and streaky vitreous fragmental types, similar to those types on Menengai which grade into lenticulate fragmental flows indistinguishable from "ignimbrites".

(*e*) At the base of the succession, under the tuffs of the North Kinangop, basalts and a very different type of tuffaceous sediments occur. These and the distinctive North Kinangop trachyte immediately above them are described separately with other members of the Turasha succession (p. 58).

The series shows a great variation throughout the area and attempts to extrapolate any succession have proved entirely abortive. All that can be said is that there is usually one substantial "ignimbrite" near or at the top of the succession, which forms such a prominent feature capping the mesas in the Kinangop and west of Kipipiri. It is locally overlain by thin pumice tuffs. There is a lower "ignimbrite" throughout the area from Ol Kalou south-eastwards to the North Kinangop, and many lower "ignimbrites" near Gilgil. In other localities also additional bodies of "ignimbrite" make their appearance. The claystones are of minor importance and appear to be to some extent unconformable on the main succession. The pumice tuffs occur throughout the succession, and within them lacustrine sediments (graded tuffs of similar composition) occur locally at many different horizons. Lavas of normal types are found within this succession only near Gilgil and Kariandusi, and in the valleys of the Melawa and Turasha rivers. The maximum total thickness of the succession is about 1,000 ft.

The tuff formations occur as follows in different parts of the area:—

Ol Legisianana.—To the north of the trigonometrical beacon small areas of "ignimbrite" with flattened lenticular texture cover the phonolites of the Dispei-Lake Hannington series.

Kisinana.—On the east side of the Kabragai plain "ignimbrites" overlie the Dispei-Lake Hannington phonolites. Two separate "ignimbrite" flows are seen in juxtaposition in the fault scarp immediately south-west of the trigonometrical beacon, but to the north only isolated outliers are seen. In one of these, north of Kisinana camp, a section in a fault scarp shows:—

"Ignimbrite" . . . . (Whitened at the bottom)	20 ft.
————Reddened upper surface————	
White pumice tuff and coarse buff graded tuffs (lacustrine sediments) . . . . with fine tuff intercalations	80 ft.
————Vitreous and scoriacious top of lava flow————	
Phonolite	

These sediments contain obscure plant remains. No artifacts were found in them. They dip at an appreciable inclination to the south-west. There appears to be no significant unconformity here, though the underlying phonolite flow is of irregular thickness and has a rather undulating upper surface.

Solai.—At Solai a substantial thickness of "ignimbrite" showing columnar jointing forms a plateau, much disrupted by later faults, at the base of the Solai Escarpment from the Olobanaita river northwards to Tindaress. Only patchy outcrops in valleys and grabens (for examples at Gendin) are seen in Upper Solai above the escarpment. "Ignimbrites" are the only rocks represented below the escarpment but pumice tuffs with some thin "ignimbrites" predominate above. To the north of Tindaress the "ignimbrite" disappears, only a few minor outliers occurring on the northern part of the Solai Escarpment.

Subukia.—The tuffs filling the Subukia graben, where no deep sections are seen, may well form a comparatively thin veneer. The section at Lord Waterpark's airfield shows coarse obsidian-rich "ignimbrite" overlying yellow and brown pumice tuffs. The "ignimbrite" forming low facings at the foot of Lolderodo Escarpment is of a finer type, and probably represents a different flow.

Thomson's Falls.—The formation is not seen between Thomson's Falls and Subukia but on the extreme northern end of the Ol Bolossat plain on Thomson's Falls airfield coarse obsidian-rich "ignimbrites" are seen in small quarries, with some fine claystone carrying plant remains. Whether this claystone is in the main succession or a later eruptive is not clear, and it has been given the symbol "Tvf4" on the map, together with a similar outcrop in the Iguamiti river bed, to indicate possible later age.

Ol Joro Orok.—Southwards from Thomson's Falls the tuff formation gradually thickens and becomes more continuous, obscuring older phonolites. The only rocks exposed in the Ol Bolossat plain belong to this formation and most of the high country along Pierce's and Sykes' roads is underlain by yellow tuffs of this formation. The "ignimbrite" is here very thin and discontinuous. It is exposed on Pierce's road, and to the east of this road some well stratified tuffs, apparently of lacustrine origin, are intercalated in the massive pumice tuffs. In the Oramutia valley both the pumice tuffs and capping "ignimbrite" are recognised, but the succession shows a complication in an overlying succession of welded-tuffs of the claystone variety. This locality is described in detail on page 56.

Ndaragwa-Pesi River-Aberdare Farm.—On the surface of the Supuko Lereko plateau to the east of the Sattima fault tuffs overlie the older phonolite and basalt. They include a coarse obsidian-rich "ignimbrite" exposed where the Aberdare farm road crosses the Pesi river, and cream to yellow pumice tuffs showing very coarse grading into bands several feet thick separated by weathered zones. The upper surface of the yellow tuffs is covered by a considerable depth of reddened clayey soil derived from the underlying tuffs. A thin very finely stratified clayey bed near to the Pesi crossing contains plant remains. It resembles insect and plant bearing beds on Hallowes' farm, Ol Kalou. It may be a swamp deposit much younger than the Kinangop tuff succession.

Ol Kalou.—At Ol Kalou the succession becomes more complicated.

On Hauschild's farm to the west of the township the succession is pumice tuffs (some grading), overlying pumice tuff in two massive units. In a horst south-west of the township two successive "ignimbrites" overlie the two layers of pumice tuff.

North-west of Ol Kalou near a dam on de Bruin's farm the section shows pumice tuffs dipping 9° to the east in bedded units a foot or so thick, with several thicker layers, the bedded units being separated by red weathered zones and containing mascareignite and fossil wood. They overlie phonolites with a weathered upper surface. Elsewhere on de Bruin's farm an "ignimbrite" overlies the pumice tuffs.

To the west of the exposures on Hauschild's farm pumice tuffs predominate and "ignimbrites" are discontinuous. In the Oleobar valley and near Dundori cross-roads there is a claystone which appears from its field relations to be unconformable on the older pumice tuffs (cf. Oramutia section, p. 56). A similar welded tuff is seen to the west of the Dundori crossroads in a newly cut section on the Nakuru road. It thins out and disappears westwards. It overlies pumice tuffs and the attitude of the two formations does not appear to be coincident—the welded tuff appears to have been erupted after the fault blocks were tilted into their present ratchet pattern. On the Ol Bolossat Plain exposures are few. A reasonable section is seen on the hill carrying Ol Bolossat South trigonometrical beacon, and is of "ignimbrite" (locally showing trachyte inclusions) overlying pumice tuff. On the north side of the hill are exposures of claystone, carrying plant remains, similar to that seen on Thomson's Falls airfield and in the Oramutia valley.

This agglomeratic or bouldery formation carrying trachyte inclusions in a base of "ignimbrite" of a fine devitrified type is a common feature of the country north of Ol Kalou. The name "Ol Bolossat volcanics" has been used by Bristow for these rocks, which outcrop on the hill mentioned above, on the roadside north of Ol Kalou, on the Ol Bolossat Plain, and on Horvmand's farms. In the latter locality the section is "ignimbrite" (carrying boulders and drawn out magmatic lumps of trachyte) grading down into a rubbly layer composed of trachyte boulders and earthly material separated by an unconformity from the underlying pumice tuffs. The rubbly layer at the base is like that described from Plaat Hill and is in the opinion of the author an autobrecciation phenomenon, much decomposition masking its true nature.

There are some very finely graded tuffs and clays exposed on Hallowes' farm east of a bridge on the Nakuru-Ol Kalou road. There are well preserved insect and plant remains in these beds, but the beds are very fragile and preservation is difficult. Whether these beds are within the main tuff succession or are a much later swamp filling is open to question.

Oleolondo.—South of Ol Kalou a good succession is seen at the railway bends:—

	feet
"Ignimbrite" (coarse with obsidian streaks)	50
Earthy tuffs and sediments	120
Grey tuff	10
Massive pumice tuff	80
Tuffaceous sediments	210
"Ignimbrites" devitrified type, base not seen (Thicknesses measured from air photos with parallax bar).	

The two "ignimbrites" appear to be quite distinct in type. The well-stratified sediments carry neither artifacts nor fossils. These sediments are exposed at many localities throughout the country between here and the Melawa river to the east, and running south-east through the valleys of the Oleolondo and Simba rivers to the Turasha river valley. They are well seen on Agget-Griffin's farm, where they include thin gravels composed of small rounded lava pebbles, and thin white diatomite bands. There is also much secondary silicification and manganese development here (p. 109).

In the valley of the Turasha river graded tuffs showing current bedding have been recognised (Fig. 4 (*d*)). It seems clear that a lake occupied the area south-east of Oleolondo and west of Kipipiri during parts of the eruption of the tuff series. Whether the lake originally extended into the Nakuru basin is not known: the fact that the yellow tuffs appear to pass under the trachyte and "ignimbrite" ridge at Gilgil suggest it did so, but there is also evidence that the sediments thin out against the trachyte and "ignimbrite" ridge.

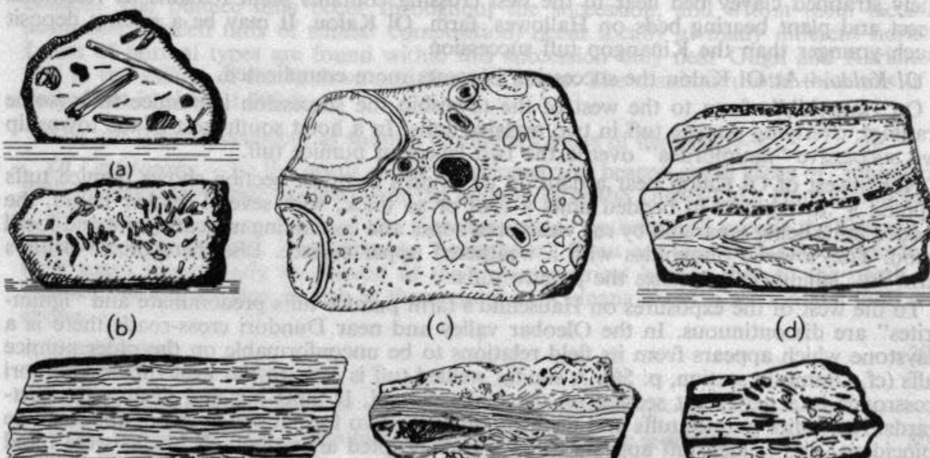


Fig. 4—Textures in volcanic rocks of the Pliocene succession:—

(a) (b) Mascareignite—from graded tuffs near Oleolondo manganese mine.
(c) Koishiram breccia—showing orbicular appearance produced by partial kaolinisation of fault breccia.
(d) Current bedding and graded bedding in silt-grade tuff—Turasha river.
(e) "Ignimbrite"—Solai.
(f) Sole of an "ignimbrite"—alternating greenish glass and black obsidian laminae—Kariandusi.
(g) Streaky fragmental trachyte (clasto-magmatic)—Charts farm, Gilgil.

Mascareignites and fossil tree trunks (monocotyledons resembling palm trees) are abundant in graded tuffs just south of the manganese mine (Fig. 4 (*a*) (*b*)), and other plant remains were noted in fine beds south of YXXI beacon.

To the east of Oleolondo lacustrine sediments are less well developed, but are seen in the Oleobar valley above an "ignimbrite" at the top of the succession. At the north end of Sabugo there is a succession of thick units of pumice tuff with poor stratification carrying mascareignites and much obsidian in irregular lumps. No artifacts are present. On Kwetu farm the succession is pumice tuff capped by murram, a common feature in this part of the area, with intercalated "ignimbrite" thirty feet thick. The "ignimbrites" nearby are of a very coarse type carrying much obsidian. The total thickness of the tuff group here is over three hundred and fifty feet.

Bahati.—In the Bahati Forest the tuff formation outcrops under unconsolidated pumice lapilli beds of the Menengai pumice mantle. The succession includes "ignimbrites", some of which outcropping near Bevan's sawmills are extremely coarse and rich in obsidian, pumice tuffs and sediments. The latter are well seen near the Mereroni river close to the Nakuru-Thomson's Falls road at the foot of the escarpment. They show good stratification and carry plant remains. Similar lacustrine sediments are seen under an "ignimbrite" in a valley to the north of Milton's farm. Other similar sediments occurring to the south of Lolderodo represent the north-eastern limit of the sediments in the Kinangop succession in the Bahati massif. To the north in the Bahati Forest and in Solai and Subukia only massive unstratified tuffs are exposed.

To the south of the Nakuru-Ol Kalou road "ignimbrites", pumice tuffs and sediments outcrop, but no succession has been worked out. Well-stratified lake beds have been recognized on Ngorika.

Gilgil-Kariandusi.—The area around Gilgil and Kariandusi contrasts with the remainder of the localities noted above, more closely resembling the volcanic centres of Menengai and Sirrkon in the comparative absence of pumice tuffs and graded tuffs of subaqueous derivation, and in the predominance of "ignimbrites" and trachyte lavas. It is believed that the confused jumble of fault blocks near Gilgil represents a central volcano probably closely resembling Sirrkon, with a north-south ridge form, and a very small central crater, now unrecognizable, or perhaps without a crater, eruption being from fissures on a volcanic dome. Probably the site of the actual centre of eruption is obscured by later formations somewhere south of Kariandusi.

Temperley has carried out prolonged investigations of the volcanic rocks in Gilgil and Kariandusi (Fig. 5). It seems doubtful however if even now a full understanding of these unusual rock types has yet been reached. The main rock types may be divided into:—

(*a*) Quartz trachytes	Normal crystalline types.
(*b*) Quartz trachytes	Streaky vitreous and fragmental, closely resembling those of Menengai.
(*c*) Welded tuffs—coarse "ignimbrites"	Thick apparently "fragmental" flows, frequently columnar jointed, showing coarse laminar and lenticular textures.
(*d*) Welded tuffs—claystones	Very subordinate thin bands of claystone.
(*e*) Pumice tuffs	Very subordinate.

The pumice tuffs are either true pyroclasts of airborne origin or glowing avalanche deposits; welded tuff layers may represent *nuées ardentes* and catastrophic eruptions of incandescent gas and fragmental (though an alternative derivation is suggested on p. 53). The coarse massive bodies of welded tuff are not, however, easy to place in the volcanic series and their nature is discussed in some detail below. The conclusion is reached that neither they nor the thinner claystones are *nuées ardentes* deposits but are a peculiar type of lava flow.

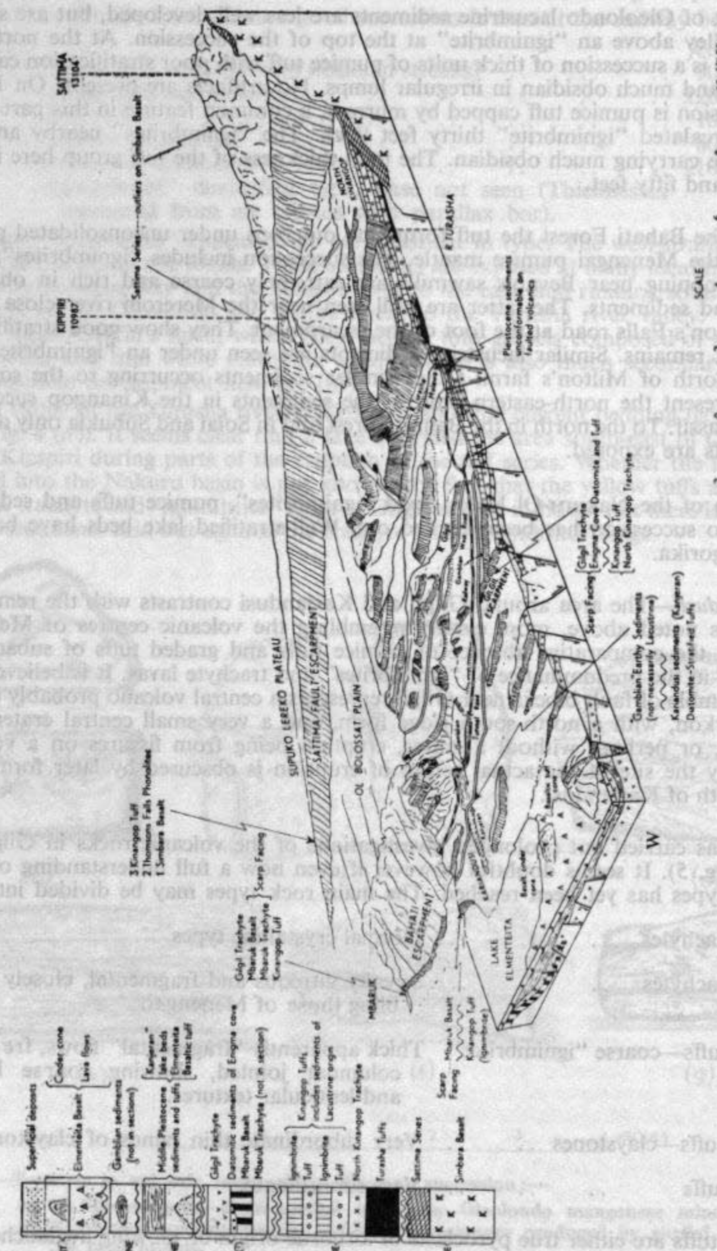


Fig. 5—Block diagram showing the country north of Gilgil. (Drawn from an original topographic sketch by B. N. Temperley).

DETAILS OF THE ROCK TYPES

(i) *Pumice Tuffs*

The yellow to creamish buff pumice tuffs are dominantly composed of coarse vitric tuff, grading into lapilli tuff. These tuffs consist of glass fragments and felspar crystals, the latter being particularly abundant in some localities (notably near Oleolondo Station) where the tuffs are perhaps best termed crystal tuffs. These tuffs weather readily to clayey material and also show a deep red clayey soil capping where they form the land surface. The individual particles of the tuff are not easily distinguishable, owing to tight packing and fragility, and the decomposed condition of the rocks. Many of these yellow pumice tuffs contain both angular boulders of trachyte (more rarely syenite) and pumice and obsidian lumps, and it seems clear that they represent both products of vulcanian showers and pumice avalanche deposits. A typical specimen is composed of pumice fragments 1 to 2 inches in diameter embedded in a matrix of sand-grade pumice fragments.

(ii) *Graded tuffs—lacustrine sediments*

As already noted there are many occurrences of finely stratified lake beds within the yellow pumice tuffs. The question of how much of this pumice tuff is of waterlain origin cannot be entirely resolved, but certainly the finer and better stratified members are so derived. These sediments are composed of particles of glass derived from disintegrated pumice. In the silt-grades the vitroclastic textures cannot be seen, but it is visible in the coarser sand-grades. The matrix is of similar material to the clastic fragments. In some of the coarse grades however the particles are so angular and so well compacted due to their fragility that the outlines of individual grains are not readily distinguishable. Rounding of fragments suggestive of transport by water is unusual and deposition directly into a lake from air-borne showers seems indicated, rather than reworking by rivers and transport into a lake.

(iii) *Trachytes and "ignimbrites"*

The trachytes discussed here are of the type called "clasto-magmatic" by Temperley, which are so intimately connected with the "ignimbrites" that both these volcanic types must be considered in conjunction.

The holocrystalline trachyte of the Turasha River sections (North Kinangop trachyte) is an entirely normal lava and is discussed separately (p. 58).

The streaky heterogeneous trachytes of Kariandusi.—The heterogeneous trachytes of Kariandusi are quartz-trachytes and are texturally different from the North Kinangop trachyte, though of similar composition except that they carry more quartz than the latter. In hand specimen they show a faint to pronounced laminar structure and enclaves of different material are either faintly or clearly distinguishable.

In thin section they are seen to contain broken soda-orthoclase phenocrysts and sparse entire aegirine-diopside phenocrysts. Phenocrysts are frequently somewhat resorbed. The groundmass contains felspar in microcrystalline aggregates or minute laths. Sodic amphiboles and pyroxenes, together with quartz, are either interstitial to the felspars or form a sub-ophitic base. The heterogeneous composition is effected in part by the presence of included trachyte fragments, which make up only a small fraction of the rock. Some of these are small, equidimensional, and show sharp contacts, being apparently xenoliths composed of previously crystallized trachyte caught up in the flow. Other inclusions consist of lumps, lenses and laminae of lighter coloured and better crystallized glassy trachyte with distinct but gradational outlines. These laminae show small included felspars with a weak trachytic orientation, and larger broken phenocrysts of felspar identical with those in the less well crystallized laminae forming the base material of the lava. In these leucocratic laminae quartz pools are more abundant than in the remainder of the rock. The amphiboles and pyroxenes, which occur in aggregates and minute single prisms distributed through the area between these aggregates in the less well crystallized base material, are only seen in scattered prisms in these laminae, and there can be no doubt that the laminae consist of better crystallized segregations of a single parent magma. Again, the idea of liquid immiscibility (Steiner, 1960)* springs to mind, and in this connexion the compositional difference is significant.

*Much of this report was written before publication of Steiner's paper.

Four types of structure were recognised in these lavas:—

(*a*) Sub-homogeneous—with a few equidimensional sharply defined trachyte enclaves.

(*b*) Foliate —with leucocratic lenses of better crystallized material, also lumps and laminae.

(*c*) Heterogeneous—with sharply defined equidimensional enclaves as in type (*a*) and leucocratic laminar segregations as in type (*b*).

(*d*) Transitional —with more included material than base material: the fragmental structure resembles that of the "ignimbrites" but the degree of crystallization is more advanced, suggesting hotter conditions.

The field relations of these rocks are not altogether clear. However, Temperley has noted that:

In the Kariandusi horst they appear to replace the "ignimbrites".

In the railway cutting nearby they underlie "ignimbrite".

Near the tunnel they appear to be a local variation of the "ignimbrites". This suggestion of a lateral gradation supports the contention that the greater part of the "ignimbrites" in this succession are the distal members of this series of heterogeneous trachyte effusives, and supports the conclusions reached in Menengai (p. 41).

The petrography suggests a rapidly cooled magma. The comparative lack of trachytic texture has been cited by Temperley as evidence for lack of flow during crystallization, but it may be due to the lack of substantial felspar laths—where laths have formed in the better crystallized laminae they do tend to adopt a flow alignment. In the writer's view megascopic evidence of flowage is ubiquitous. The heterogeneous character is probably due in part to segregation, either into fractions of differing composition, possibly segregates containing different percentages of volatiles, and partly due to the collection of lumps of earlier crystallized lava.

"*Ignimbrites*".—Within the scope of this term are included the coarse fragmental rocks of considerable thickness, characterized by crystallization of the matrix in fibrous fringes and spherulites or a complete absence of crystallization, and also finer welded tuffs (claystones). The inclusion of both these rock types under the heading "ignimbrite" follows Marshall (1932, pp. 198-200, 1935, pp. 323-366) who uses it for all types of *nuées ardentes* deposits. The term *nuées ardentes* has been defined by Perret (1935, p. 112)—"gas charged lavas, subdivided into discrete particles, that are enveloped in a tightly compressed gaseous atmosphere due largely to continuous vapour emission of the particles themselves. Eruption is due to vesiculation in a viscous condition".

The coarse massive "ignimbrites" are considered, according to the *nuées ardentes* theory, to be the products of late frothing, related to pressure conditions in a Pelean volcano, and seem to fall into the first of two distinct types defined by Cotton (1952, pp. 199-215) viz:

(*a*) Those welled up from central volcanoes when the volcano is in Pelean condition, or from fissures around the volcano—Katmaian eruptions—flows of vast dimensions in which more or less continuous vesiculation occurred. There can be little doubt that the greater part of the "ignimbrite" in this area falls into this category.

(*b*) Those erupted abruptly, laterally around Pelean tholoid spines. The thin sheets of welded tuffs (claystones) are generally accepted as being the thin but very widespread derivatives of this second type of eruption which characteristically yields only small deposits in a single eruption. However there is evidence that at least some of the thin welded tuffs in this area are of type (*a*) and of Katmaian origin, erupted from fissures, and some doubt remains as to whether they have any connexion with *nuées ardentes*.

The term "*nuées ardentes*" tends to suggest the type of catastrophic incandescent cloud eruption made famous in Martinique. Perret in his definition uses the word lava, and some of the *nuées ardentes* of type (*a*) are clearly much more substantial than might at first be imagined. Smith (1960, p. 802) notes that the basal avalanche is an essential part of *nuées ardentes*. There is no evidence of such a feature in the claystones or in the coarse "ignimbrites".

Williams (1941, p. 279) believes there are all gradations from lava to tuff in this type of vulcanicity, and in Menengai we have seen that holocrystalline homogeneous trachytes grade into heterogeneous laminated part-vitreous trachytes, some showing fibrous fringes and spherulitic crystallization, which are indistinguishable from "ignimbrites". But are these *nuées ardentes* deposits? Williams (verbal communication) believes that the glass shards are of vital significance and even where the ignimbrite grades into what is apparently a lava glass shards can be detected by careful study under the microscope. Steiner (1960) considers that glass shards are not always indicative of explosive fragmentation.

The "ignimbrites" near Gilgil apparently are the distal members of a heterogeneous trachyte suite erupted from the obliterated centre near Kariandusi, and only differ from the trachytes in the lesser degree of crystallization and more markedly heterogeneous and vitreous texture. What crystallization there was occurred in spherulites and fibrous fringes instead of in fairly well crystallized laminae. The fragmental trachytes at Kariandusi probably grade into the massive well crystallized trachytes also seen there, but unlike at Menengai, no gradation has been recognized.

The boundary line between effusives and pyroclastics appears to be a difficulty since "ignimbrites" are classified as pyroclastics. But Temperley has noticed that the "ignimbrites" in the sections in the railway cuttings west of Gilgil:—

Plough up underlying rock, incorporating it in sigmoid contortions in their base material:

Carry substantial gas cavities distorted by differential horizontal flow movements:

Show glassy fused soles, resembling chilled soles seen in overland-flowing bodies of lava. An element of chilling is almost certainly present besides pressure of the superincumbent body of the "ignimbrite", which would, if it were the sole agent, effect a much more gradational change from sole into the body of the rock. This concept of the effect of the weight of the flow itself was advanced by Marshall (1935) but Steiner (1960) considers it incompatible with the evidence.

These features are compatible with the idea that these "ignimbrites" moved overland as fluid frothing lavas and are not the products of vulcanian showers. Among other authorities Cotton (1952) doubts that vulcanian showers are ever hot enough when deposited to form moving incandescent flows of agglomeratic material. The conclusion is inescapable that to try and find a hard and fast boundary between "ignimbrites" and heterogeneous streaky trachytes is to chase something that does not exist: one has only to accept a radical widening in the scope of the *nuée ardente* eruptions or else join Steiner in removing ignimbrites altogether from the *nuée ardente* deposits. No one, as Steiner (1960, p. 11) and Smith (1960, p. 802) remark, has ever seen a *nuée ardente* produce an ignimbrite. The writer has always considered the derivation of these thick flows from *nuées ardentes* a dubious hypothesis, and joins Steiner in calling the coarse massive ignimbrites lavas. Smith (1960, p. 802) appears to retain the *nuées ardentes* connexion, but invokes quite another mode of origin to the classic Pelean *nuées ardentes*.

The widely accepted division of volcanic rock is:—

INTRUSIVE			
EXTRUSIVE ..	Effusive ..	.. Lava .. Tholoids	
	Pyroclastic	.. *Nuées ardentes* .. —	.. Welded tuffs .. Ignimbrites
		.. Vulcanian showers	

As far as this area is concerned, in view of the Menengai, Gilgil and Kariandusi occurrences the eruptive rocks appear to fall into the following divisions:—

INTRUSIVE			
EXTRUSIVE ..	Effusive	(i) Normal lavas grade into (ii) Heterogeneous very fluid lavas—liquid immiscibility control?	Coarse "ignimbrites" + ? claystones, thin massive welded tuffs usually fine textured.
		(iii) Ash flows ..	Some pumice tuffs Pumice lapilli flows
	Pyroclastic ..	Airborne tuffs (Products of Vulcanian showers)	Some pumice tuffs

The trachytes probably show a complete gradation between the following types:—

Massive holocrystalline

Massive hemicrystalline

Streaky hemicrystalline (well crystallized laminae)

Streaky hemicrystalline (well crystallized laminae and fragmental inclusions)

Streaky hemicrystalline, dominantly vitreous (spheroidal crystallites and fragmental inclusions) } "ignimbrites"

Vitreous (streaky and homogeneous) } "ignimbrites"

The friable cellular spongy glass, containing broken and resorbed phenocrysts, obsidian and lava enclaves, is considered to be a localized variant of the "ignimbrite" flows developed in the upper layers of the flows of both "ignimbrites" and streaky trachytes.

The question whether the eruptions are central or Katmaian (from fissures) is difficult to determine. The extreme disruption by faulting of the volcanic series prevents the geologist from being certain that the original land form was such that the outlying coarse "ignimbrites" such as those at Gendin, Subukia, Thomson's Falls and the Pesi River could have flowed overland from volcanic centres now standing up from the floor of the Rift Valley. There is nothing in the petrographical details to suggest that they are not just the outlying members of the volcanic series erupted from the Kariandusi centre or Menengai, which may have been volcanic domes around which the lava streamed from numerous fissure vents. The concentration of lavas, including "ignimbrites", in certain distinct centres (Menengai, Sirrkon, Kariandusi) suggests central eruption rather than welling out from fissures all over the Rift Valley.

Single flows of "ignimbrite" are up to 100 feet thick, and frequently show columnar jointing. At Gilgil a lower set of flows and a single upper flow appear to comprise the "ignimbrite" succession, but away from the eruptive centre many of these flows do not persist. The upper flow extends as far as Subukia, Thomson's Falls and the Pesi river. Being characterized by an unusual abundance of obsidian blebs it is easily distinguished. The "ignimbrites" locally have a friable texture and show a superabundance of enclaves giving an appearance of a true tuff of pyroclastic origin, but flattened magmatic enclaves of considerable dimensions locally indicate that they cannot be deposits derived from vulcanian showers. Many of the "ignimbrites" show localized weathering and alteration to yellow and brown rocks easily mistaken for pumice tuffs—incandescent avalanche deposits or true pyroclasts.

Classification.—Temperley has classified the "ignimbrites" according to degree of agglutination and the degree of crystallization. His classification is based on the concept of independent particles fused together or agglutinated as they travel along in the "ignimbrite" flow.

The main types seen are:—

Top of flow:—

Incoherent Friable, vitreous except for phenocrysts and accidental fragments of rock.

Body of flow:—

Agglutinated Particles adhere to form solid rock, but the fragmental nature is obvious. All degrees of crystallization from vitreous to well crystallized. Some fused lumps, well crystallized, spheroidal texture.

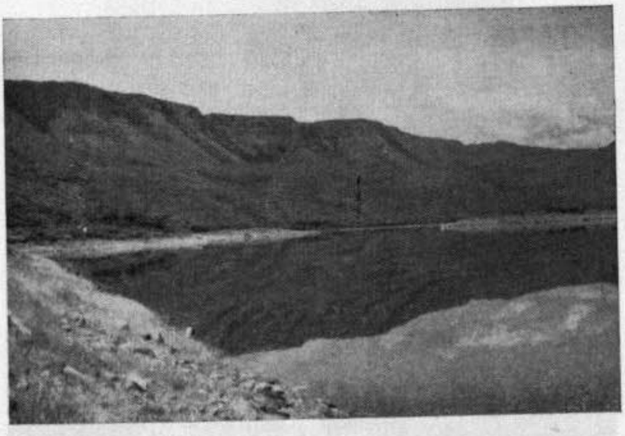
Base:—

Welded Fragmental nature visible but small fragments in the matrix have coalesced. Conchoidal fracture. Vitreous to hemicrystalline.

Fused Complete absence of fragmental structure (Never present or subsequently obliterated?). Replaces hemicrystalline and vitreous bands in the sole of the flows. Indistinguishable from flow-banded trachyte and trachy-obsidian.

Composite occurrences showing several of these types may be seen in single exposures and it is only in certain good sections that the strict subdivision of the flow on this ideal basis is seen.

Plate I—(a) Steam fumaroles above the Molo river, Arus.



(b) The 2,000 ft. escarpment south-east of Lake Hannington. Hot springs are situated on the two peninsulars in the middle distance. The screes terminating half-way down the escarpment are well seen in this photograph.

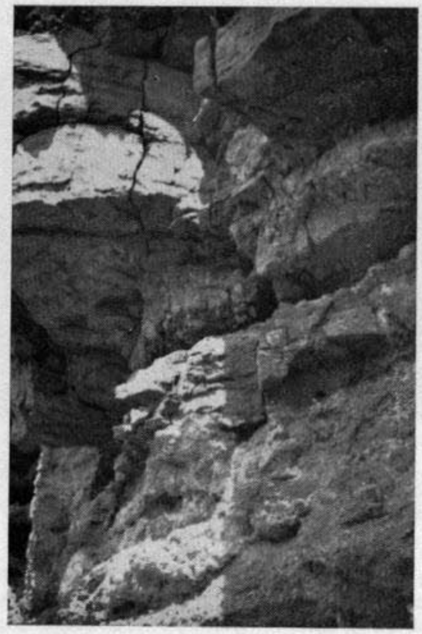
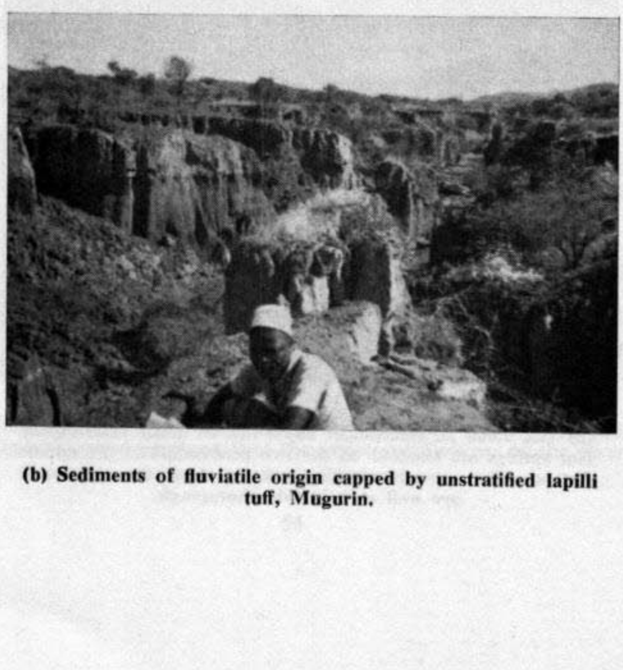


Plate II—(a) Rubbly auto-breccia layers in streaky trachyte, Menengai, Lion's Head section.



(b) Sediments of fluviatile origin capped by unstratified lapilli tuff, Mugurin.

Plate III—(a) Boiling pot, Kiboriit.
[*Photo*: *R. Edmondson.*

(b) Geyser, Kwaibeipei.

Plate IV—(a) Hot mud-crater, Kiboriit.
[*Photo*: *R. Edmondson.*

(b) Spouting springs, Kwaibeipei. A gout of steam is blowing off a fumarole under the lake in the middle distance and the cloud above the Kwaibeipei geyser, then inactive, is behind.

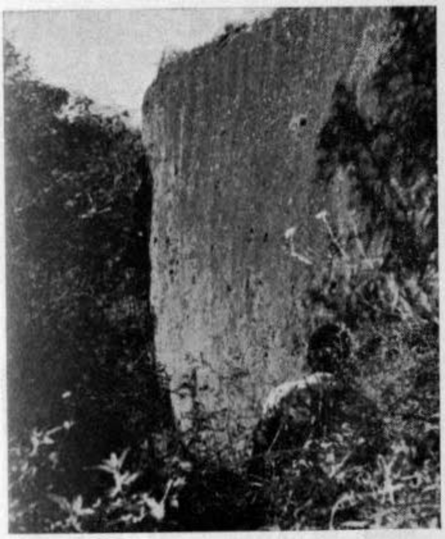
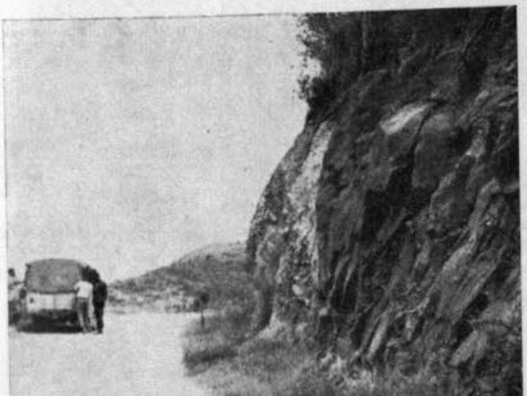
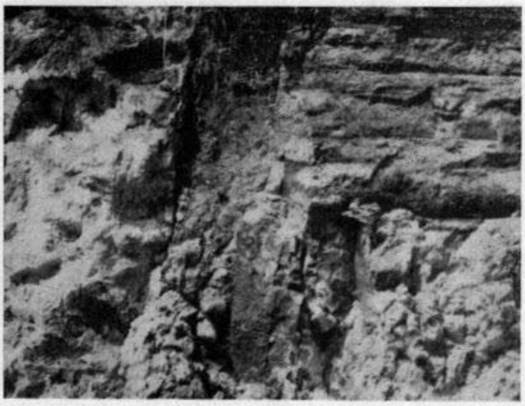


Plate V—(a) Recent fault cutting Solai lapilli tuff, Milton's Farm, Solai.



(b) Fault plane and breccia in Rumuruti phonolite, Subukia-Thomson's Falls escarpment road.

Plate VI—(a) Fault plane in sediments within the Kinangop tuff succession, Kipipiri road.



(b) Fault plane in sediments within the Kinangop tuff succession, Kipipiri road.

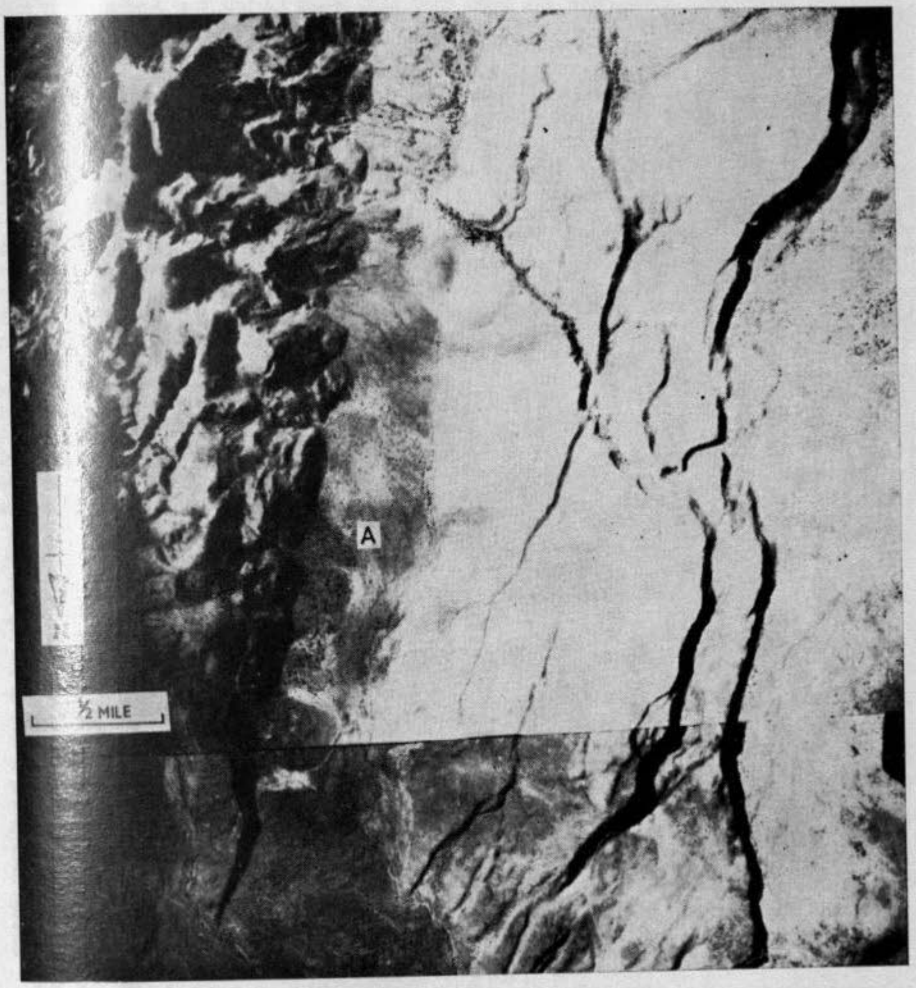


Plate VII—Air photograph, south-east of Logumkum, showing the contact between deeply dissected Samburu basalts and Rumuruti phonolites (Miocene?) on the left and the later phonolite plateau of the Dispei-Lake Hannington lavas on the right. The later lava shows a flat relatively undissected surface cut only by comparatively fresh faulting, which dies out close to the boundary of the lava plateau erupted just previous to this movement. The distinct facet produced by renewal of movement on the older scarp is apparent at point A.

[*Photo*: 82 *Squadron, R.A.F.*

Plate VIII—Air photograph showing Lower Pleistocene grid faulting disrupting the plateau of Dispei-Lake Hannington phonolite south-west of the lake. The blocks tilt towards the lake, this being the general slope of the lava plateau, and most of the faults throw down to the east. The Emsoss Escarpment is seen in the top left-hand corner.

[*Photo*: 82 *Squadron, R.A.F.*

This classification of Temperley does not seem to include any criterion directly indicative of discrete particles in an incandescent avalanche (*nuée ardente*) becoming welded together, in fact there seems nothing to show that they have not segregated. The writer has been impressed by the two-fold nature of the "ignimbrites". They are always composed dominantly of two distinct components, each with a uniform appearance and composition. These components vary rapidly from exposure to exposure—lateral variation in the flow—but in any hand specimen show a marked individual uniformity. The included "xenolithic" material—fragments of lava and glass, often unsorted—forms but a small part of the rock, and can be explained as accidental fragments picked up by the very fluid flow, as flowing water picks up flotsam. The two phases closely resemble the "base" and "mesostasis" of Steiner (1960, p. 19) the "mesostasis" being in this case dark and less well crystallized, and the "base" the light fraction. The degree of crystallization in both base and mesostasis is better than Steiner describes from the classic New Zealand ignimbrites, particularly in the base, where decussate patterns typical of the sodic trachytes nearby leave no doubt that this is primary crystallization, though occurring after the segregation of the immiscible liquids. Resorbed and broken phenocrysts, mainly soda-orthoclase or anorthoclase, are present in both phases. Temperley has noted a marked difference in quartz content between the two phases in the streaky trachytes, and such a compositional difference is what the liquid immiscibility theory requires (Steiner, 1960, pp. 25-26). In any agglutination or welding concept this is unlikely. The sorting of the majority of the enclaves must surely weight heavily against a *nuée ardente* origin. The usual characteristic of *nuées ardentes* is lack of sorting (Smith, 1960, p. 807). Little detailed petrographic work has yet been attempted and compositional differences make direct comparison with the classic New Zealand rhyolitic field—the field that has given birth to the immiscibility theory—of only limited value.

At this stage we can only summarize:—

1. The "ignimbrites" grade into streaky vitreous trachytes and even well crystallized trachytes of homogeneous character, showing textures related to intersertal and intergranular.
2. They show field characteristics indicating flow overland as a heavy overriding mass akin to a lava.
3. They appear to have chilled soles—though this may be an illusion.
4. They have a "two uniform components" composition suggestive of segregation and subsequent partial crystallization in a trachyte magma in which crystallization had been impeded before eruption. Late nucleation due to pressure build-up in the magma chamber of a Pelean volcano is suggested as the cause of this impedence of crystallization.
5. There is some evidence of compositional disparity between the two phases.
6. Unsorted accidental fragments are present but not in any great quantity except in the surface layers of flows.
7. A considerable amount of volatiles appears to have accompanied these eruptions.
8. They appear to have been centrally erupted from the vicinity of syenite stocks, probably in a Katmaian mode of eruption from fissures around volcanic domes.
9. They grade from phonolitic trachyte composition through sodic trachyte to sodic quartz trachyte.
10. Identical rocks form the top surfaces and layers near the under surface of massive flows—trachyte or even phonolite.
11. Liquid immiscibility as suggested by Steiner (1960) is favoured as a mode of origin —caused by volatiles (probably water+ CO_2—the principal observed fumarole gases of trachyte volcanoes in this field) being concentrated near the top of a magma chamber in a repeated sealing volcano of Pelean type.
12. Very fluid properties are inherent in any such theory. Such abnormal fluidity of the intermediate lavas is explained by Steiner (1960, p. 27) by the abnormal volatile content. The Yatta plateau in south-east Kenya demonstrates the existence of abnormally fluid intermediate lavas.
13. Branching tails to the lenses and flow textures, similar to those cited by Grange (1934) who considered the classic New Zealand "ignimbrites" to be lavas, are common.

(iv) *Claystones*

Welded tuffs were first described by Mansfield and Ross from Idaho (1935, pp. 305-321). They were said to show characteristically a remarkably even thickness over a wide area around the source, and to extend a great distance from the source. Both the coarse "ignimbrites" already described and the finer and thinner claystones seem at first sight to fit into the welded tuff category, though the above definition seems to be only partly apposite. However, as with the coarse "ignimbrites", the derivation as a fragmental deposit subsequently united, implicit in the welded tuff nomenclature, is open to doubt.

The claystones are fine rocks with a matrix of devitrified glass, and enclaves of glass of a rather different colour and texture. Again, a distinct two-segregation nature is apparent, each specimen being dominantly composed of two uniform phases. Crystal fragments and xenolithic fragments of lava or pumice are sparse. The thickness of individual flows is small, rarely exceeding twenty feet. This rules out the possibility of compression effects due to the weight of the flow and crystallization by the agency of residual heat. There is a limited degree of crystallization, partly in the form of secondary growth of crystallites on devitrification, but how much primary crystallization is present is difficult to determine. The individual fragments have apparently been drawn out into flattened trains before crystallization, and these flattened textures seem to suggest a considerable degree of flow. The glassy enclaves are very porous, more so than those of the coarser "ignimbrites". There is field evidence in the Oramutia exposures that many of these claystones were erupted from local fissure sources a long way from any central volcano. The claystones show a marked predilection for existing valleys (e.g. Oramutia, Metabosso and Ndolaita valleys) and this suggests a flow overland. They lack any basal avalanche suggestive of *nuées ardentes* and appear to have been erupted as very fluid lava flows containing abundant volatiles. Segregation due to liquid immiscibility is again favoured as a mode of origin of their heterogeneity.

Petrography of the "ignimbrites" and claystones.—The petrography of the claystones is a finer textured more vitreous reflection of the coarser "ignimbrites". Both are essentially of trachytic composition.

The "ignimbrites" are all essentially trachytic in composition, and the fragmental enclaves are all of trachyte. The "ignimbrites" near Gilgil contain appreciable quartz but it is not very conspicuous farther afield. Typical examples are seen in specimen 43/889 from Moore's farm Bahati, specimen 43/1035 from Oleolondo and specimen 43/1070 from Heldo farm. In the first laminae and lenses characterized by some crystallization of felspars are present, in the second crystallization in the matrix is minimal, and in the last the matrix is entirely vitreous. Some broken felspar fragments and sharply bounded equidimensional crystalline trachyte and glass enclaves are present in all these thin sections.

Specimen 43/1050 from Ol Kalou shows a fragmental (so called "agglutinated") "ignimbrite" with only a very little hemicrystalline base material into which the fragments are crammed.

The members of this series most distant from any central eruptions (such as specimen 43/961 from the Pesi river) show very poor crystallization in the matrix and one envisages a progressive decrease in the temperature of the flow away from central volcanoes. This "ignimbrite", 40 miles from Kariandusi, could have travelled overland (Howell Williams, 1941, p. 273, reports an "ignimbrite" flowing 35 miles) but the possibility that the distal members of the "ignimbrite" series were erupted from fissures around the central volcanoes cannot be entirely rejected.

(v) *Oramutia and Ol Bolossat volcanics*

The existence of later volcanic rocks unconformable on the main volcanic sequence near Ol Kalou and Ol Joro Orok has been mentioned above. There are numerous occurrences of shallow fillings of yellow-brown pumice tuffs and welded tuffs in the valleys in these localities. It was not possible to map all these occurrences in detail, but the Oramutia section was chosen for an especial study by Bristow (1962—*see* also McCall, 1962).

Here a series of thin claystones rest unconformably on the older pumice tuff and coarse "ignimbrite" of the Bahati tuff succession. These later "ignimbrites" and tuffs are of later age than the Oramutia fault which disrupts the earlier tuffs and the underlying phonolite. They pass over the line of this fault into the eastern part of the Oramutia valley undisturbed by any movements except minor renewals on the fault line, which displace the welded tuffs a few feet down to the west and show nearly vertical fracture planes. The older tuffs are displaced about 200 feet vertically on the Oramutia fault.

The claystones form a series of flows, each a few feet thick, and have recognizable outlines suggesting that they flowed in the river valley. They appear to be of local origin and Katmaian eruption from fissures in the fault zone of the Oramutia fault is suggested, since one narrow vertical body was recognized as probably a feeder dyke. They are unconformably overlain by a layer of brownish yellow speckled pumice tuffs similar to those seen in the nearby valleys. These are very localized, occurring in certain valleys and not others in the Oramutia depression. They appear to be valley flows like the welded tuffs, and a fissure source in the immediate vicinity is suggested to account for their restriction in outcrop, and the fact that such bodies could not flow any distance from the west over an already faulted topography. Their absence from other valleys nearby seems to rule out an origin in widespread vulcanian showers, and they are thought to represent fissure erupted pumice flows of glowing avalanche type. No dykes that could be the feeders of these pumice tuffs are known, but the absence of any central volcanic craters or cones for many miles from the Oramutia valley seems by a process of elimination to indicate fissure eruption.

Katmaian eruption so far from a central source seems unusual judging by the literature, but fissures have apparently been the locus of a welling out of pumice tuff and welded tuff in the area, twenty miles and more from any central volcano. The Ol Bolossat volcanics are most likely of similar origin.

The minor Oramutia occurrence suggests that the much greater vulcanicity which produced the older tuffs, "ignimbrites" and claystones, may well have been in part Katmaian, part at least of the vitric pumice tuffs and the "ignimbrites" being erupted from fissures as glowing avalanche flows. This explanation fits in with the inclusion of angular lava boulders in the pumice tuffs. Cotton (1952, p. 201) notes that the Riviere Blanche *Nuée Ardente* of Mount Pelee carried large stones down the mountainside.

(*vi*) *Superficial deposits on the Kinangop tuff succession*

There are some later infillings in the river valleys overlying the rocks of the main Kinangop succession, especially evident on the Ol Bolossat plain. Some of these later infillings such as those in a drift east of Ol Kalou on the Wanjohi road resemble the laterites and diatomaceous earths of Durie's and Weatherall's sites on the Kinangop (Shackleton, 1955, pp. 260–1). They are stratified in units a foot or so thick, no very fine bedding being present. They are of minor importance compared with the great thickness of the Kinangop formation, being nowhere more than 100 feet thick.

It has been the practice of the geologists of the Ministry of Works (Temperley and Bristow) to refer to these as the "Superficial Series", but these deposits are so similar in lithology to the main body of the tuffs that it is felt that to differentiate them by boundaries on the map is not justifiable at the present time in view of the lack of detailed mapping. They are clearly composed in part of material reworked from the older deposits, and include waterlain deposits. It is at the present day a little difficult to envisage a shallow body of water on the top of the Ol Bolossat plateau to the west of Ol Kalou, since the land falls steadily southwards to the floor of the rift at Gilgil, but there may well have been some occurrence of warping since these beds were deposited. Alternately they may be related to aggradation of overcharged river valleys. There is a thin mantle of diatomaceous earth high up on the plateau surface near the Wanjohi road which can only be waterlain. There is a considerable amount of murram associated with these deposits. It is tentatively suggested that these superficial deposits near Ol Kalou may be Pleistocene, like the Kinangop laterites which carry artifacts. Plant remains have been recognized in some of these beds but no datable fossils.

(*vii*) *Turasha Succession*

Turasha basalts.—Dense black spheroidally weathering basalts are the lowest formation exposed in the Turasha gorge section. They are exposed near the Turasha Fishing Camp, and also much higher in the course of the river where it flows northwards from the Kinangop Plateau.

A thin section (43/1143) from near the Fishing Camp is seen to be an olivine basalt, with conspicuous olivine showing haloes of brown iddingsite and outer rims of blue-green serpentine. Augite is present in clove-brown crystals. The felspar is andesine and the texture is finely intergranular. Iron ore grains are numerous in the slide and some mica is present, both biotite and white mica. There is a certain amount of finely-granular colourless aggregate of low birefringence in the interstices of the rock. Another specimen (43/1150) from nearby shows abundant brown iddingsite after olivine, both pseudomorphing it and in veinlets. The texture is again finely intergranular. A fine spongy basaltic glass is seen in 43/1144.

These basalts do not resemble the Simbara basalts, nor do they closely resemble the so-called Laikipia or Oloronyi basalts, though they are petrographically similar. They may either represent an extension of the Laikipia basalts westwards or an entirely different series at the base of the Kinangop succession. The latter alternative is preferred by the writer.

Turasha tuffs.—Between the Turasha basalts and the overlying North Kinangop trachyte are some beautifully stratified tuffs, quite unlike the Kinangop tuffs. The best section is at the Turasha Fishing Camp where the basalts are exposed on the roadside north of the river, and a cliff section along the south bank shows a thickness of about a hundred feet of tuffs dipping west at 13° under the North Kinangop trachytes, with which the tuffs appear to be concordant. The series include coarse tuffs composed of angular fragmental material. Pumice is not as conspicuous as in the Kinangop tuffs. The individual bands are characterized by green, red and purplish colorations. Finer clayey bands are present, but diatomite was not recognized. Further tuff exposures are seen near St. Maurs' Bridge where the tuffs are coarse, and red and green speckled, the matrix being creamy yellow. They are traversed by small veinlets of clear lilac-coloured calcite.

In thin sections (43/1142, 1246) the base is seen to be a later cement of carbonate and an isotropic colourless aggregate which appears turbid under crossed nicols, as if composed of minute granular crystallites. Set in this are deep green and red sub-angular fragments, irresolvable in their present highly altered state.

These tuffs are so highly stratified and sorted that sub-aqueous deposition must be referred, though the lack of rounding of the fragments suggests little or no transport. In spite of a diligent search no fossils could be found.

(*viii*) *North Kinangop and Kariandusi trachytes*

Massive trachytes occur at the base of the Kinangop tuff successions in the lower parts of the Turasha and Melawa valleys. In the former they overlie the Turasha sediments. At Gilgil, on the east road near Pembroke House and on the west side of the same horst, similar trachytes underlie the "ignimbrites". Whether these represent the same flow as the Turasha and Melawa occurrences is not certain—they appear to be higher in the succession and the samples recovered from borehole C2388 at Gilgil suggests that a great thickness of pumice tuffs and sediments may underlie the pile of "ignimbrite" and trachyte seen on the surface. However the maps and sections have been drawn assuming that the great thickness of tuffs seen to the east wedges out between the "ignimbrite" and the trachyte.

Trachyte of similar type underlies "ignimbrite" on the Gilgil Escarpment, below the diatomite in the facing at Enigma Cove, and is seen in a small inlier near Gamble's farm west of Kariandusi, where it underlies "ignimbrite". The Turasha and Melawa trachyte occurrences have been named North Kinangop trachytes while both fragmental streaky and massive well-crystallized trachytes underlying the "ignimbrite" at Gilgil and Kariandusi are referred to as the Kariandusi trachytes.

Petrographically these are all quartz trachytes, though they show very variable quartz content. Typical porphyritic specimens are 43/1151 and 1158 from Turasha gorge. These trachytes are also characterized by an absence of pyroxene and the presence of sodic amphiboles, cossyrite, kataphorite and riebeckite, usually decomposed to red iron oxides which give the rock a reddish coloration on fresh surfaces. The blue tint of riebeckite is very conspicuous in all these trachytes. Quartz is present in irregular granules, aggregated in pools, in the base, which contains either decussate or aligned microcrysts of anorthoclase felspar. The analysis of specimen 43/1146 (Table 2 M) indicates just over two per cent normative free quartz. Porphyritic (felspar-phyric) textures are more common than non-porphyritic textures (43/1146, 1287) and trachytic textures are frequently observed. Holocrystalline lavas predominate but a vitrophyric lava (43/1164) was collected north of the Turasha river.

The exact relation of these trachytes to the streaky fragmental trachytes is not known. The writer thinks that they represent magma in which frothing and nucleation occurred at an early stage, perhaps due to lack of pressure, and that though they do not necessarily grade into streaky part-vitreous fragmental varieties, the fact that similar well crystallized and porphyritic varieties grade into streaky fragmental lavas in Menengai suggests the strong probability of such a gradation. There is no reason to doubt that the well crystallized North Kinangop and Kariandusi lavas are part of the eruptive series poured out from the now obscured central volcano west of Gilgil, from which source the "ignimbrites" and streaky fragmental trachytes are also considered to have been erupted. These quartz trachytes show a petrographic similarity to the Limuru quartz trachytes of the Nairobi area (Sykes, 1939 p. 23).

(3) The Lower/Lower Middle Pleistocene Succession

(a) *Willan's Farm Porphyritic Trachyte*

At the foot of the Bahati Escarpment, due west of Ngorika, black porphyritic trachyte is exposed in the facing under the Mbaruk basalt. This lava, which is seen only in this locality, is believed to be the lowest member of the facing succession and equivalent to phonolite under the Mbaruk basalt in the Nakuru Lake Syndicate quarry.

In thin section 43/1187 the rock shows large well formed phenocrysts of lamellar-twinned anorthoclase. The base is holocrystalline and largely composed of decussate anorthoclase laths. Aegirine-diopside is present in the form of small phenocrysts and there is much aegirine-diopside, brown sodic amphibole, riebeckite and iron ore in the base.

(b) *Nakuru Lake Syndicate Quarry Phonolite*

A dense black compact lava underlying the Mbaruk basalt is quarried at the foot of the escarpment in the north-west corner of Lake Nakuru, near to the disused plant of the Lake Syndicate. The rock (43/1224) is composed of green spongy glass dotted with black opaque specks and inset with minute decussate felspar laths. The cavities in the glass are infilled with a pinkish isotropic mineral of low refractive index, probably analcite. There are traces of small partially resorbed felspar phenocrysts. From the nature of the secondary minerals it seems probable that this rock is a phonolite.

(c) *Mbaruk Basalt*

The name "Mbaruk basalt" was given by McCall (1957 (*c*), p. 9) to the porphyritic felspar-phyric olivine basalt which forms a prominent facing cliff at the foot of the Bahati Escarpment at Mbaruk. It was also recognized on Soysambu Estate, and in the cliffs immediately west of Lake Nakuru, where it again seems to form a facing on an older eroded escarpment in the Mau tuffs.

The basalt is not very thick, probably little more than a hundred feet in all. In only the two localities mentioned above can the underlying flow be seen. Sometimes more than one flow can be recognized. From the revised interpretation of the Sirrkon (Lion Hill) ridge it becomes clear that the Mbaruk basalt forms rather restricted flows localized along certain fault zones and does not extend continuously from Elmenteita to the west side of Lake Nakuru as previously suggested (McCall 1957 (*c*), p. 9).

The rock type in this formation is very uniform. The lava when fresh is a light grey rough-surfaced rock, showing prominent well-formed white, slightly translucent, felspar phenocrysts. It somewhat resembles the Kijabe-type but the base is less dark and compact, and the felspars are neither so substantial, nor show the same platy form and parallel alignment. Vesicles are very common, and alteration by weathering to a reddish brown decomposed lava is a very common feature, decomposition being apparently accelerated on account of the easy break up of the rock by a process of crumbling along cracks bordering the large felspars.

In thin section a typical specimen (43/755) from Mbaruk shows broken and partly resorbed labradorite phenocrysts up to half a centimetre in length set in a moderately fine base composed of similar felspar in the form of small rather short laths, deep red-brown pseudomorphs after olivine and a very few crystals of neutral-coloured pyroxene. The finer material in the base consists of black iron ore dust and small granules of pyroxene. There is no analcite or felspathoid.

In specimen 43/1253 from west of Lake Nakuru, on the edge of the Lake Nakuru Forest, a clove-brown augite predominates over pseudomorphs of olivine in the base and small vesicles infilled with radiating secondary aggregates are present.

An analysis of Mbaruk basalt (Table 2D) shows a very small content of normative free quartz. The composition is almost identical with that of the Simbara basalt (Table 2B) of probable Miocene age.

(*d*) *Gilgil Trachyte*

Trachytes overlie the Mbaruk basalt in small outliers in the facing at the foot of the Bahati Escarpment north of Mbaruk. The trachyte is fissile and usually well crystallized, and is characterized by a carious weathered vesicular upper surface. Similar trachytes overlie the Mbaruk basalt on Soysambu Estate and extend as far east as the Gilgil Escarpment where they form a facing on the older succession of "ignimbrite" and trachyte. At Kariandusi these trachytes underlie the Middle Pleistocene sediments (Kanjeran) and form a ridged, faulted terrain, on which the sediments were deposited.

The trachyte in the Gilgil facing (43/750) is holocrystalline and porphyritic, small rather stubby partly resorbed phenocrysts being set in a trachytic base composed dominantly of small felspar laths. The felspar appear to be mainly soda-orthoclase, not anothoclase. There are some aegirine-diopside phenocrysts of a dull green colour: iron ore and amphiboles make up the remainder of the rock.

The lava underlying the diatomite at Kariandusi is very similar, some anorthoclase being present together with soda-orthoclase. The texture is trachytic and the rock holocrystalline. Greenish yellow turbid patches suggest alteration products after nepheline.

A trachyte (43/1178) on the north bank of the Mereroni river north of Mbaruk is spongy in texture and contains a little glass. Some yellowish turbid patches suggest analcitic aggregates after nepheline, and it may well be phonolitic in composition. The rock is brecciated, being traversed by irregular iron ore filled veinlets.

In 43/1211 from the scarp south-east of Lake Elmenteita the phenocrysts are all anorthoclase. The rock is otherwise similar to the lavas from Gilgil and Kariandusi.

Other workers have claimed to recognize quartz* in these trachytes but there appears to be none in the slices examined by the writer; if present at all it is in negligible quantity. These lavas seem to be classifiable petrographically as trachytes, grading into phonolitic trachytes.

(*e*) *Ronda Phonolites and Phonolitic Trachytes*

The upper part of the sheer cliff feature west of Lake Nakuru is composed of phonolite grading into trachyte. There seems to be a tendency toward trachytic composition in the upper layers of the flows, but cryptocrystalline felspathoid may be present.

These lavas, which are petrographically similar to the Dispei-Lake Hannington lavas, are commonly fissile and banded. The phonolites are of the Kenya-type with small dark haloed nepheline phenocrysts. 43/1237 from Ronda hill shows this feature. Much of the nepheline in these rocks is altered to analcite but some fresh nepheline is sometimes present, as in this thin section. There are parallel aligned anorthoclase phenocrysts, and kataphorite and riebeckite are prominent in the base which contains a little brown interstitial glass and a considerable amount of analcite. Iron ore is present, and there is a yellow granular mineral, believed to be acmite, haloing some of the nepheline phenocrysts. A yellowish pyroxene forms prominent phenocrysts in 43/1226 from a flow above the Mbaruk basalt in the escarpment west of Lake Nakuru, near to the old Lake Syndicate buildings. Green aegirine-diopside, riebeckitic and brown soda amphiboles are also present in the slide which contains analcite and cancrinite in the base. The rock contains streaks composed partly of dark glass.

*Temperley doubts if any petrographical distinction can be drawn between these trachytes and the earlier quartz-trachytes of North Kinangop and Kariandusi.

A specimen from the lower Makalia gorge is representative of the phonolitic trachytes containing very sparse turbid aggregates apparently pseudomorphing nepheline. A similar phonolitic trachyte with a strongly directed texture is seen in 43/1266 from the upper Makalia gorge.

The abrupt and short narrow horst of Island Hill is composed of streaky vitreous trachytes. They probably are the equivalent of the Ronda lavas, though of a very different type; they may however represent strongly up-faulted older lavas within the main tuff succession. In thin section the uppermost of the two flows (43/1261) is seen to consist of a finely banded highly contorted glass, with included well crystallized streaks and lenses of trachyte. The lower flow (43/1262) is also composed of streaky glass with inset anorthoclase phenocrysts, and again well crystallized streaks and lenses of trachyte.

(*f*) *Lacustrine Sediments*

Enigma Cove sediments

In a small gully situated immediately below the viewpoint where the main road goes over the Gilgil Escarpment, named Enigma Cove by Dr. Temperley, diatomite forms a thin layer separating two trachytes. The thickness here is a foot or less, but a few yards to the north, on the face of the escarpment, a thicker section of the same sediment is seen underlying the Gilgil trachyte. There are stratified pumice tuffs in the northern exposure, besides pure white diatomite, but the lower trachyte is absent.

These sediments have been previously considered as part of the Kariandusi formation, but as they clearly underlie the Gilgil trachyte this is not acceptable. They are believed to lie between the Gilgil trachyte of the facing and the North Kinangop trachyte which underlies an "ignimbrite" on the roadside a few yards away. The relations suggested by Temperley, who has made a close study of this confused section, are illustrated in fig. 15 (*a*).

These sediments, which are affected by the third major faulting episode of the Rift Valley, are thought to be of an age close to that of the Gilgil trachyte—Lower Pleistocene or Lower Middle Pleistocene.

Lake Nakuru West Cliff sediments

A few feet of stratified pumice tuffs and some diatomite separate the Ronda flows from the underlying Mbaruk basalt flows at two places in the cliffs west of Lake Nakuru. A red weathered surface separates the sediments from the overlying lava, which probably indicates a time interval. A Lower Pleistocene or Lower Middle Pleistocene age seems likely for these sediments, since the Mbaruk basalt is thought not to be very much older than the Gilgil trachyte, which appears to have immediately preceded the Kariandusi sediments (Upper (?) Middle Pleistocene).

Ronda Hill sediments

Coarse yellowish stratified tuffs, slightly younger than those of the West Cliff sections, overlie the Ronda lava flows on Ronda hill. These sediments appear to be conformable with the underlying lava, and are strongly faulted and warped, being situated in a horst bounded by strongly developed faults with throws of up to 200 feet. They probably represent lacustrine deposition immediately preceding the third and last major faulting of the Rift Valley floor, that which formed the grid structures. No fossil remains or artifacts could be found in these sediments.

(4) Late Pleistocene and Recent Volcanic Rocks

(*a*) *Elmenteita Tuff Cones*

The broken cones of Elmenteita have been previously described (McCall, 1957 (*c*), p. 22). Three of these lie within the area to the south of Lake Elmenteita, and two more, Honeymoon hill and Crescent hill, lie south of Nakuru township. There may well be several more obscured by the sediments of Lake Nakuru. They are steep-sided, and composed of light coloured stratified tuffs containing boulders of lava. The stratification dips are often very steep. The tuffs of Honeymoon hill contain boulders of porphyritic trachyte and basalt and those of Elmenteita boulders of Gilgil trachyte and Mbaruk basalt. The tuffs, where they contain lithic inclusions, are boulder agglomerates, no bombs being included in them, and the included fragments are apparently torn-off fragments of the underlying lava formations.

The median graben which transect these cones has been considered as a possible illustration of the process of rifting in microcosm (McCall 1957 (*c*), p. 22). The possibility that a phreatic mechanism was involved in the formation of these cones has also been suggested. They are not unlike basaltic tuff-ring structures in New Zealand described by Cotton (1944, pp. 259–267), and the section given in Fig. 141 of that book is identical with the structure of the Elmenteita cones. The presence of large blocks torn off the underlying formations is considered by Cotton as consistent with a phreato-magmatic origin.

The stratified tuff of the cones south of Lake Elmenteita is indistinguishable from the Kanjeran lake beds, and the two formations appear to be continuous (McCall 1957 (*c*), p. 24). The presence of shore lines identified by Nilsson (1932, p. 49) as one of the Gamblian (Upper Pleistocene) series on the flanks of two of the larger cones south of Lake Elmenteita, confirms the dating of these cones as not later than Middle Pleistocene.

Tuff (43/1212) from a cone immediately south of the Gilgil-Elmenteita road is composed of spongy yellowish glass in which are set fragments of lava and crystals. There is some plagioclase present and the rock is considered to be a basaltic tuff. Secondary carbonate forms a prominent infilling of the cavities. The tuff from Honeymoon hill is similar, and also appears to be basaltic in composition.

Analysis of a basalt from near Elmenteita crossroads (Table 2E) shows a lack of normative free quartz, but the composition is remarkably similar to that of the older basalts.

(*b*) *Elmenteita Basalts*

Recent flows of olivine basalt which form the so-called "Badlands", an area of sparsely-grassed broken lava flows north of the disused Elmenteita station, have been described in a previous report (McCall, 1957 (*c*), p. 23). Only a small part of these flows along the west shore and immediately south of Lake Elmenteita lie in the present area. To the south of Soysambu House similar basalts are seen forming low faulted ridges, and these may be of earlier date (Pleistocene?) but the main body of these flows are unfaulted, being not even displaced by minor renewals of movement, and preserving their tongue-like form undisrupted. From the sparsity of vegetation on their surface these flows are believed to be of Recent age, comparable with the Recent glassy trachytes filling Menengai caldera.

In the centre of the Badlands area to the south are many small basalt cinder-cones, and these seem to be intimately connected with the flows and probably represent the vents from which they were erupted. Only one such cone, a conical pile of cinders without any central crater, lies in the present area, at the south-east corner of Lake Elmenteita. The flows slope evenly from the Badlands northwards to Lake Elmenteita, and the source of the lava is certainly within the Badlands. The lava flows do not extend southwards beyond the old Elmenteita railway track, so are not connected with Eburru.

A specimen (43/1213) from the recent flows from the roadside south-east of Lake Elmenteita is a spongy rough textured grey basalt. In thin section the rock is seen to be very fresh, but some substantial plagioclase crystals, apparently of an early formed generation, show considerable decomposition. Large green and grey zoned augite phenocrysts are present. The olivines are fresh, and their occurrence is restricted to small crystals in the intergranular base. The felspar laths in the base, which are fresh and show clear twin lamellae, are andesine. There is much black opaque iron oxide and a little iddingsite.

The cinders forming the nearby cone (43/1214) are seen to be composed of a spongy olivine basalt, consisting of a dark red opaque glass riddled with spongy cavities, and in which are set olivine, augite and plagioclase crystals.

A finer basalt with a spongy, aphyric, intergranular texture is seen in specimen 43/1217 from the north-west corner of the lake. A flesh coloured titan-augite is prominent in this slide.

A vesicular basalt of this formation (43/1269) partly mantles a narrow horst of Gilgil trachyte south of the main road, due west of Elmenteita crossroads. The lava again shows a generation of plagioclase phenocrysts partly resorbed in the base. The felspar phenocrysts in this slide appear to be oligoclase.

The tuffaceous sediments of the Kanjeran series on the north-east shore of the lake are cut by a dyke an inch or so thick of very fine basalt of similar type to those described above. This suggests a derivation from fissures as well as central vents.

(c) *Quaternary Eruptions of Menengai*

(i) *Pumice*

The mantling pumice deposits which cover a great area mainly to the west of Menengai have been previously described (McCall, 1957 (*a*), pp. 62–66). The coarse agglomeratic beds exposed in the railway cutting near Lanet (op. cit. p. 66) are now believed to be part of the lapilli tuff associated with the Upper Pleistocene (Gamblian) sediments of the Nakuru basin. These Gamblian sediments are thought to be composed mainly of reworked pumice mantle material, since the uppermost of the Gamblian shore lines is cut into the true pumice mantle on the south-west slope of Menengai.

The pumice mantle forms a coarse crudely stratified deposit, up to 50 feet thick, composed of light coloured fragments of much the same size, up to an inch in diameter. The obvious sorting and large dimension of the fragments makes a marked distinction from the recorded pumice deposits of other calderas (Smith, 1960, p. 807).

Obsidian, trachyte and syenite fragments have all been noted in the pumice, but the latter makes up about 99 per cent of the deposit. The pumice mantle is believed to represent the first stage in the formation of a caldera of Krakatoan type (McCall, 1957 (*a*), p. 60). The pumice is older than the flows of the Upper Menengai series which infill the caldera. Near Menengai summit however a few ejected blocks of these black vitreous lavas are mixed with the pumice mantle on the outer slopes. To the south-west the lavas overlie the pumice mantle.

From the structural evidence it is now considered that this pumice mantle may be as old as Lower Pleistocene. It is certainly older than one of the early Gamblian shorelines.

The mode of origin of these pumice lapilli eruptives is not certain, but stratification, sorting and lack of lithic inclusions suggest vulcanian showers rather than flowing avalanches, and their concentration to the west of Menengai suggests a control by wind direction. Against the airborne mode of origin is the fact that similar pumice layers have been observed by the writer in Suswa intercalated with lava in what appears to be a feeder zone along the line of the caldera fracture. This suggests the pumice lapilli were erupted as avalanche flows. The size of the pumice also seems to weigh against airborne derivation. It is concluded that they may be avalanche flows, not products of vulcanian showers.

The writer has recently reconsidered the whole mechanism of caldera formation, and an origin in catastrophic emptying of the magma chamber leaving the roof unsupported is not now thought to present a true picture. A comparison of the form of Menengai with the form of the deeply eroded syenitic ring-complex west of Oslo (Holtedahl and Dons, 1952) suggests that cauldron subsidence and deep seated migration of magma were contributing factors (cf. Howel Williams, 1952, pp. 324–327). The process is now envisaged as:—

Cauldron subsidence.—Migration of magma at depth and fracturing of the retaining roof of the magma chamber.

Sudden lowering of pressure resultant on subsidence.—Rapid release of gas. Catastrophic eruption of gas-charged pumice from numerous fissures formed by subsidence.

Further collapse and engulfment of volcano super-structure.—Due to void formed by the evisceration process.

(ii) *Upper Menengai Lavas*

Trachyte lavas completely cover the floor of the caldera, concealing the rocks of the older volcano. The products of these late eruptions which are believed, from the complete absence of vegetation on some of the youngest flows, to have continued up to the last few hundred years, have been described in a previous work (McCall, 1957 (*a*), pp. 66–7). They form slaggy tongue-shaped flows emanating from various points in the caldera but mainly from the vicinity of the secondary summit, and their flow was restricted by the caldera walls. They are characterized by beautifully developed pressure ridge patterns resembling those of a glacier. They include blocky flows apparently entirely composed of jumbled boulders, some massive flows, and also flows composed of twisted ropes of vitreous lavas. The lavas are characteristically black in colour and are for the most part vitreous, though they grade from nearly holocrystalline types to streaky obsidian. There are many conical piles of cinders of similar material within the caldera, but no well-defined secondary crater. Similar cinder cones have been recognized by the writer in Suswa as vents from which lavas emanated, the cinder piles being products of their waning stage.

These upper lavas are almost entirely restricted within the caldera but have spilled out over the caldera rim on the outer slopes at two points. The most conspicuous overspill is close to a line of small craterlets (McCall 1957 (*a*), p. 67) south-west of Nakuru and there may be some genetic connexion. The massive trachyte (43/1231) exposed in the Railway ballast quarry is believed to belong to the upper lava series, though unlike most of these late lavas it is holocrystalline. The overspill probably represents one of the very earliest of this second series of eruptions. The later lava seems to continue down the caldera wall into the caldera, and this may well be a ring feeder structure similar to the famous backward flow in Crater Lake, Oregon (Williams, 1942, p. 50-52), a ring feeder actually cut through by the caldera fault. Similar structures are seen in Suswa caldera.

In thin section most of these lavas are seen to be spongy, rounded voids being characteristic (43/835, 1275, 1277). They grade from banded spongy obsidian (43/1192) with alternating colourless and brown glass bands, some of the latter showing minute felspar crystallites, to better crystallized rocks. One of the slides showing partial crystallization is 43/826. Dark vitreous bands with included crystallites alternate with better crystallized bands, characterized by small parallel aligned anorthoclase felspars set in a colourless base, isotropic and of low refractive index, which could be analcite glass. These colourless glasses of low refractive index are typical of the Upper Menengai lavas, and the problem as to whether they are analcitic has not been completely resolved by the writer. The analysis of specimen 43/1192 (Table 2N) shows that these lavas contain normative free quartz.

Better crystallized trachyte is seen in specimen 43/827 which contains criss-crossing feathery prisms of aegirine-diopside altering to riebeckitic amphibole, together with brown sodic amphibole. The felspars are very prominent, in two generations, and are identified as anorthoclase. 43/1190, taken from a ropy flow, is seen to have very fine trachytic texture with a little glass. Clear blue pleochroic riebeckite is very prominent in specimen 43/824. Both cossyrite and kataphorite are conspicuous, together with anorthoclase. Some pale yellowish material of low refractive index in the base is believed to be glass.

Soda-orthoclase has been noted as well as anorthoclase (for example 43/1277) but the latter is the most common felspar. Quartz is possibly present in some clear uncleaved patches in 43/834, but the rather low refractive index suggests that it may be untwinned felspar. Otherwise no quartz has been recognized.

The cindery pile on which the main group of active vents is situated is composed of reddened scoria, seen in thin section (43/841) to be largely composed of glass with traces of felspars. A similar spongy glass (43/828) from a scoriacious lava flow in the south-west sector of the caldera floor shows incipient crystallization around the voids, a feature of the streaky vitreous lavas in the Lower Menengai succession.

Compositionally the caldera floor lavas are sodic trachytes; the possible presence of analcite glass suggests a tendency to grade towards a phonolitic composition, but the analysis (Table 2N) suggests pantelleritic variants. The composition closely matches that of the older Menengai lavas.

(5) Quaternary Sediments and Shore-lines (and Associated Tuffs)

(*a*) *Nakuru-Elmenteita Basin*

Solomon (in Leakey 1931, pp. 246-257) has described the sediments and shorelines of the Nakuru-Elmenteita basin. He considered it a suitable field for the investigation of Man's cultural stages in relation to the "pluvial periods which have plainly occurred in the area, resulting in an enormous extension of the lakes and considerable thickness of strata." The Nakuru basin was considered very favourable as it had no outlet, and could thus provide a complete record of the fluctuations that had occurred in the lakes and hence the climatic changes.

The writer is not entirely in agreement with this conclusion. This basin was perhaps an unfortunate choice, since tectonic movements and volcanic eruption altering the shape of the land surface certainly occurred there up to the end of the Pleistocene and are still continuing on a very minor scale. From this fact it is clear that factors other than climatic exerted a control on the extent of the lakes in this basin at any time. Further, the Quaternary lacustrine sediments are no more extensive than those deposited during the Pliocene and Miocene. Thick successions of lacustrine sediments are a feature of the whole Tertiary-Quaternary sequence throughout the central Rift Valley. There is, in fact, no direct evidence of any relation to pluvial periods, though Flint (1959 (*a*), p. 267) does accept evidence of climatic wettening in the Upper Pleistocene. In spite of this the Nakuru-Elmenteita basin has been accepted for years as the type-Quaternary succession in East Africa, though recently dissentient views as to its validity have been expressed (Flint 1959 (*a*). p. 27, 1958, p. 2–3).

From sequence of human cultures and the stratigraphic sequence revealed by Leakey the following classification has been adopted:—

Climatic conditions	*Division*
Second post-pluvial wet phase	Nakuran
Dry period First post-pluvial wet phase	Makalian
Dry period Second major pluvial	Upper Gamblian — pause — Lower Gamblian
Dry period marked by volcanic activity, rift faulting, etc. First major pluvial	Kamasian*

While the writer does not subscribe to the climatic basis suggested, which is unorthodox as a system of stratigraphic sub-division, it is accepted that there are three distinct sequences of sediments in the Nakuru basin distributed as follows:—

	Formation	*Locality*
Upper sequence ..	Makalia beds (Epi-Pleistocene)	Makalia river and Nderit river
Middle sequence ..	Larmudiac sediments (Gamblian beds) Kariandusi silts (Upper Pleistocene)	Makalia river, Nderit river, North and west of Lake Nakuru Mbaruk, Kariandusi.
Lower sequence ..	Kariandusi Lake Beds (Kanjeran) Soysambu Lake Beds (Middle Pleistocene)	Kariandusi Soysambu (possible occurrences in Nderit and Makalia sections)

Not all the sediments are lacustrine. The age dating is based on faunal and artifact assemblages, and is accepted as valid. The subdivisions of the Pleistocene are, however, not very clearly defined. As already noted above the subdivision of the Middle Pleistocene into two parts, Kanjeran and Kamasian, perhaps has no real validity on a regional scale, and the boundary between Middle and Lower Pleistocene seems very loosely defined in the Gregory Rift Valley owing to the lack of fossil evidence.

There are no ancient shore-line terraces preserved for the first lake (Middle Pleistocene). Contrary to other views the writer considers that the early lake occupied the Nakuru-Elmenteita basin, which was already moulded by tectonic events. The evidence indicates that the tectonic episodes subsequent to this lacustrine deposition were very minor and insufficient to radically alter the outlines of the basin. This concept is in direct opposition to the ideas of Leakey and Solomon.

The Upper Pleistocene lakes and recent lakes are represented by well preserved shore-line features. Nilsson has identified seven distinct lakes, the earliest two of which he believes were connected by a strait to the Naivasha basin.

*The term Kamasian was subsequently restricted by Leakey to the sediments of the type localities near Lake Baringo, and a new and slightly later division, Kanjeran, equated with sediments at Kanjera on Lake Victoria, was adopted (Leakey, 1950, p. 62–65). However, Flint (1959 a, p. 273) doubts the validity of this two-fold division of the Middle Pleistocene.

(i) *Ancient Shore-lines in the Nakuru-Elmenteita Basin*

The Nakuru basin is bounded by Menengai and Eburru volcanoes to the north and south, and the great complex fault scarp of the Mau to the west. The divide between the Naivasha basin and the Nakuru-Elmenteita basin is however low, being formed by the Gilgil Escarpment, a fault scarp which Solomon describes one of the latest series in this part of the Rift Valley, and the writer attributes to the last major faulting episode which formed the complex and closely-spaced grid structures. Solomon puts the altitude of the Gilgil divide as 6,600 feet which agrees with the measurements of the Survey of Kenya, but Nilsson obtained a somewhat lower figure (*see* below). It is important to note however that this divide is at a level higher than the lowest point in the margin of the Nakuru-Elmenteita basin, the Nakuru-Solai divide situated to the east of Menengai, at an altitude of just over 6,500 feet

Solomon describes a high-level shore-line at 750 feet above the present lake level of Lake Nakuru (5,776 ft.) on Lion Hill. This, the highest shore-line recognized, corresponds almost exactly with the altitude of the Nakuru-Solai divide. He describes another terrace also on Lion Hill at 600 feet above lake level and a beach 20 feet higher in Lion Hill Cave, and states that these shore-lines are not represented by widespread beaches. Nilsson however describes a shore-line on the southern slopes of Menengai which extends westwards on to the lower foothills of the Mau and eastwards around Menengai slopes. This would appear to correspond with Solomon's "600-foot" lake. Nilsson considers it to be the shore-line of the oldest of his seven lakes (Gamblian I). He levelled what he considered to be the equivalent terrace elsewhere: these measurements indicate a pronounced slope of the oldest terrace from Gilgil westward, but his levels appear to have a systematic error, and in the light of recent more accurate topographic surveys it is difficult to accept his figures without reserve. The level at Gilgil of Lake I was well above the divide at the Gilgil Escarpment, and his second lake is also believed to have spilled over the divide into the Naivasha basin, leaving a terrace just above the pass which he put at 2,006 metres (6,582 feet), a little lower than the figure of 6,600 feet given by Solomon, which is more nearly correct.

The subsequent warping in the lake basins was indicated by Nilsson in a series of profiles of differentially tilted terraces of seven successive diminishing lakes. The most notable evidence Nilsson produced is the suggestion of subsequent tilt to the west. Certainly if the lakes did spill over the divide a subsequent movement must have occurred since the divide is well above the present level of the Nakuru-Solai divide. Nilsson found no other shore-line on Menengai in spite of diligent search. He found a high level shore line on one of the Elmenteita tuff cones, giving an important indication of the age of these volcanoes.

Solomon describes a shore line at 500 feet above the present lake level as the most widespread in the Nakuru-Elmenteita basin. The beach in Gamble's Cave* belongs to this lake and has been dated by Leakey on the evidence of artifacts as in the upper part of the Upper Pleistocene (Gamblian) sequence.

The levels of this shore-line were surveyed by D. G. B. Leakey as follows:—

Gamble's Cave	500 ft. above lake level
Above the precipice to the west of Lake Nakuru	490 ft. above lake level
Terrace at the foot of Lion Hill	490 ft. above lake level
Beach and terrace in Gilgil Escarpment	530 ft. above lake level

This indicates a gentle (40 feet in 17 miles) slope downwards to the west caused by crustal movements after the Upper Pleistocene deposition. This is entirely compatible with the tectonic conclusions of this report—on the west side of the Nakuru basin faulting believed to be subsequent to the Upper Pleistocene deposition has occurred dropping the land surface by up to 100 feet.

Solomon describes a lower terrace at 375 feet above lake level at 'Elmenteita Camp' at Nakuru, on Menengai slopes and at Kariandusi. No Makalian sediments are seen above this terrace which is believed to mark the greatest extent of the lake correlated with this epi-Pleistocene sequence of deposition.

*About three miles to the south of the southern margin of the area.

The lowest shore-line in the basin is at 145 feet above the lake. It is seen only in the vicinity of Lake Nakuru and has been cited as marking a final epi-Pleistocene post-pluvial wet phase called the Nakuran. Leakey reports that this terrace is associated with artifacts of the type known as Gumban B.

(ii) *Middle Pleistocene sediments*

The sediments of Kariandusi were described by Gregory (1921, p. 116) who noted that they contained living species of diatoms. He thought they were thus slightly younger than the sediments of Kamasia* (1921, p. 112–114) which he considered to be Nyasan (Oligocene). He thought the diatomaceous sediments at Soysambu were possibly in part Nyasan.

Leakey and Solomon (Leakey, 1931, p. 34–37) definitely established the Pleistocene age of the Kariandusi sediments, recognizing palaeolithic artifacts (Acheulian and Chellean), notably hand-axes, in the sediments at Kariandusi. Very few fossils were discovered in them. The Kariandusi site has been preserved by the National Parks Administration of Kenya.

The sediments, which are of undoubted lacustrine derivation, are more fully described in the section dealing with the Kariandusi diatomites. They consist of beautifully stratified graded tuffs and diatomites. Locally a single band of the latter shows a thickness of over 100 feet. A pronounced dip westwards is apparent and these sediments are unconformable with the overlying Gamblian fluviatile silts which are nearly horizontally disposed.

The Kariandusi sediments were considered by Leakey to be strongly faulted. This assumption was made in an endeavour to explain the difference in level between these sediments and other sediments, believed by Leakey to be of equivalent age, exposed high up on the Kinangop Plateau.

Shackleton (1956, p. 260) and McCall (1957 (*c*), p. 24–25) however have both noted that the Kariandusi sediments lie on an older series of grid-faulted trachytes dislocated by the last major faulting movements of the central Rift Valley. The displacements affecting the Kariandusi sediments are, in contrast, very minor and could not have caused any appreciable remoulding of the Rift Valley, which was already roughed-out in its present form at the time of the Kariandusi deposition. There is every reason to believe these sediments were deposited in the basin of Nakuru-Elmenteita as we know it today. The concept of a great lake extending at that time right up the length of the Rift Valley has been favoured by many writers (Cole 1954, p. 47–8) but is quite untenable in view of the structural evidence.

McCall (1957 (*c*), p. 24) has suggested that south of Lake Elmenteita the Kariandusi sediments pass laterally into the graded tuffs of the broken tuff-cones in the Elmenteita basin.

The Soysambu sediments are very similar in appearance to the Kariandusi sediments but no good sections are exposed and only the top of the succession appears to be revealed at the surface. The diatomites are of a pure white variety and economically workable, but the individual bands appear to be thinner than those at Kariandusi.

Well stratified lake-beds at the base of the Nderit and Makalia sections have been identified tentatively as Kanjeran but no definite evidence that it is so has yet been obtained. There are no firmly identified Kanjeran deposits in the Nakuru basin, though there are some broken tuff cones resembling those of Elmenteita (Honeymoon hill and Crescent hill). Gravity measurements however suggest a great thickness of sediments underlying the lake and there may well be a thick succession of Middle Pleistocene sediments there, hidden from sight.

(iii) *Upper Pleistocene and Recent sediments*

Extensive deposits have been described by Solomon and Nilsson (op. cit.). The writer has recognized other important sections west of Lake Nakuru. In the subsequent descriptions Solomon's and Nilsson's sections are summarized, followed by further additional data gathered by the writer in the course of the present survey.

*Leakey originally called the Kariandusi sediments "Kamasian" in spite of the absence of any evidence of correlation with the Kamasian sediments. Later (1950, p. 62–65) he correlated them with the sediments of Kanjera on the Kavirondo gulf (as already noted) adopting the name "Kanjeran".

Nderit Drift

The most fully representative section occurs in the deep drift where the Elmenteita-Mau Narok road crosses the Nderit river a mile to the south of the southern boundary of the area.

Solomon produces an illustration composite section. The succession described is:—

Makalian		
(6) Sand	up to 14 ft.	Not always present, found in irregular hollows overlying Makalian silts. Not well stratified but probably waterlain.
(5) Evenly-bedded, white diatomaceous silts	up to 6 ft.	Thickening noticeable on approaching present river channel. Base often unconformable with underlying beds.
(4) Green unstratified ash..	up to 3 ft.	Occurs in irregular patches, often absent. Contains implements.
Upper Gamblian		
(3) Sands, silts, gravels		Gravels at top, diatomite towards the base. Upper part reddened and contains kunkar. Aurignacian, late Mousterian implements (rolled) in upper gravel. Little pumice, pebbles nearly all lava.
Middle Gamblian		
(2) Loamy sand	up to 7 ft.	Includes unrounded stones. Passes laterally into coarse rubbly gravel. Large lava pebbles and rounded tuff pebbles. This appears to be a mid-Gamblian valley infilling not coincident with the course of the present river. Rootlets in loamy sand do not penetrate overlying beds, indicating the mid-Gamblian old land surface, which shows that the lake water retreated as far as this during this time. The gravels yield Aurignacian implements.
Lower Gamblian		
(1) Diatomaceous silt		Gravel near the top
Well stratified ash gravel		No implements or fauna found

The whole section is undisturbed by later faults and there is no constant dip suggestive of later warping.

Nilsson gives a different section and diagram:—

(12) Sand
(11) Diatomaceous silts
(10) Sand and volcanic ash
(9) Gravel and sand
(8) Diatomaceous silts
(7) Sand

———discontinuity———

(6) Gravel and sand (some mudstones)—unsorted
(5) Sand

———discontinuity———

(4) Diatomaceous silt—small layer of sand and ash
(3) Gravel
(2) Sand

———discontinuity———

(1) Kamasian sediment—thick horizontal layer

According to Solomon to the north of the Nderit drift the Middle Gamblian unconformity is obscure and the Upper Gamblian thins out, but is readily recognized by the reddening of the upper portions. The Makalian on the other hand thickens and becomes gravelly.

At Long's drift on the Nderit river about two miles north of Nderit drift the section is given as:—

(6) Wash deposited on an uneven land surface	up to 9 ins.
(5) Stratified silts	up to 3 ft.
(4) Wash deposited on an uneven land surface	up to 1 ft. 6 ins.
(3) Diatomaceous silts	up to 20 ft.
(2) Fine water-stratified ash	up to 4 ft.
(1) Diatomaceous silts	base not seen

Bed 4 carries implements of Tardenoisean appearance described as 'Kenya Wilton' and both the Gamblian and Makalian north of Nderit drift carry hippopotamus remains.

The Makalia valley to the west of the Nderit river shows sections of Upper Gamblian and Makalian sediments. The Middle and Lower Gamblian are probably represented at the base of some sections and there is some reason to believe that borings at one point have uncovered Kanjeran sediments. The outcrops of sediments near the Makalia river have the form of small mesas, produced by the erosion of soft sediments by a meandering river frequently changing its course.

At the terraced cliff where the Makalia river turns northwards the section is given as:—

Makalian ..	Well bedded diatomaceous silts. Fine poorly stratified ash (probably laid in still water). Diatomaceous silts and gravel at base.	up to 15 ft.
Upper Gamblian	Silt and some gravel (reddened). Kunkar in upper part indicating aridity. Gravels at base.	up to 50 ft.

Here the Makalian carried Upper Aurignacian and Upper Mousterian implements.

"MacInnes site", 400 yards to the south, yields human and animal remains, the former of the type associated elsewhere with the Elmenteita culture.

Human skeletons of non-negroid primitive type were found with implements and pottery of the Elmenteita culture in a burial site covered by a thin series of well-bedded silts of believed lacustrine origin at Bromhead's site below a small waterfall above the main fall on the Makalia river.

(iv) *The Makalian ash* is variable in thickness and is reported as being 20 feet thick near the river and absent on higher ground. Solomon believes it to have been concentrated in the valleys mainly by wind action possibly aided by occasional storm wash. This, he believes, is the only way to account for its peculiar distribution. The 'red bed' underlying the Makalia ash is a brilliant red soil which occurs only on the high ground, and is believed to represent an arid period at the close of the Gamblian. It has yielded Kenya Stillbay and crudely made Aurignacean tools.

(v) *The Upper Gamblian sediments* above the Makalia fall (Lower Gorge) are similar to those below, but unfortunately no implements have been recovered from the places where superposition by the red bed can be seen, though nearby gravels of similar lithology and position have yielded late Mousterian implements. Leakey doubtfully identified Lower Gamblian and Kanjeran, the latter in a pit above the Makalia fall. The latter identification was believed by Solomon to indicate, if valid, dessication between the Kanjeran and Gamblian.

Further along the Makalia valley to the west of the Lower Makalia Gorge diatomaceous silts disappear. The ash loses its stratification, and also disappears, at Red Cliff to the north, the Makalian here having a total thickness of only three feet, resting on a strongly reddened surface of the Gamblian deposits. The Gamblian here shows gravelly pockets which are believed to be due to contemporaneous gullying or removal of sand by groundwater. The Gamblian as traced westwards also shows a slight easterly dip, which may be due to subsequent movements in the graben or may be a primary angle of rest.

A pit near the foot of the lava cliff which is pierced by the Makalia waterfall (Lower Makalia Gorge) produced implements of Kenya Stillbay type, confirming the association of this culture with latest Gamblian times.

Near to the waterfall by which the Makalia descends the first lava scarp redeposited tuffs occur within the Makalian. It is clear that lake water only extended over this scarp for a short time. The succession above the scarp is reported to be:—

Silt (Makalian)

Ash and tuff

Red bed

Silts, gravelly top, lower levels diatomaceous

(vi) *Gamblian sediments at Kariandusi*

Solomon (in Leakey 1931, p. 256) described at Kariandusi grey silts with intercalated ferruginous gravels, particularly noticeable near the base, chiefly occurring in valleys cut in older deposits. They contain unrolled implements of Aurignacean type, and a few crude, rolled Mousterian flakes were recovered in gravels at the base. The author follows Pulfrey (1944) in thinking these sediments are probably riverine. The unconformity of these sediments on the older more tilted Kanjeran beds is manifest.

The abrupt changes from pyroclastic material in the Kanjeran to detrital material of other kinds is explained by Solomon as due to the hot spring at the foot of the main escarpment, one mile up the Kariandusi river from the diatomite quarry, having been initiated in the interval between the Kanjeran deposition and the first sedimentation of the Gamblian in this locality. This is used as evidence for dating the main faulting of the rift at this interval, but such evidence carries little weight. A minor renewal of faulting such as is known to have occurred in the Elmenteita basin could equally have initiated the hot spring, and furthermore the concept of a direct relationship between the sedimentation and hot spring does not in fact bear examination. Hot springs do not produce silts and gravels, and these must rather be derived from the comparatively deep soils overlying the older volcanic rocks of the Bahati uplands whence the stream flows. The hot spring may in fact be of any age.

(vii) *Occupation Sites*

Gamble's Cave.—Gamble's cave is situated just south of the boundary of the area, as is the important Nderit drift section. Both are referred to here as being the most important localities in the Nakuru-Elmenteita basin. The fourth occupational level in Gamble's cave II which contains advanced Aurignacian tools has been correlated with the second shore-line of Gamblian maximum. The full details of the evidence on which this important correlation is based are given by Leakey (1931, p. 247). The second occupational level of this cave showed artifacts of Mousterian affinities.

Gamble's cave is also said to provide evidence of subsequent aridity, supporting the correlation of the Elmenteita industry with the Makalian wet phase.

Lion Hill Cave.—A beach at this site 620 feet above the lake is believed by Solomon to mark a rest stage during the decline of the lake in the Lower Gamblian. Upper Kenya Aurignacian tools were found above this beach in an occupational level, and a peculiar fauna consisting of hyrax, small mammals and a few ungulates (the latter near the base) was found above this beach. The beach of the second Gamblian maximum is 100 feet below the cave. Solomon suggests that Lion Hill must have been an island during both Gamblian maxima but was connected to the mainland in the interim period, which would account for the very limited fauna.

Above the Upper Aurignacian level lies red soil succeeded by levels bearing Elmenteitan and later tools, and this is said to confirm the validity of the succession in Gamble's cave II.

(*b*) *Larmudiac beds*

The descriptions of the sediments given in the preceding pages summarize the main features derived by previous workers in the area, and by the writer. There are however sediments exposed to the west and north-west of Lake Nakuru, which have been affected by minor faulting. These do not appear to have been previously described, though they appear to have a considerable bearing on the history of the Nakuru basin, for there is every reason to believe that these sediments are Upper Pleistocene and represent the lower part of the Gamblian deposition. The absence in the Gamblian of the Makalia and Nderit sections of the unstratified lapilli tuffs associated with these beds, suggests that the Gamblian of the plain south of Lake Nakuru may be younger than these beds, and it seems also probable that the minor faulting which affects these beds may have occurred before the deposition of the Gamblian beds of the Makalia and Nderit sections.

These sediments, which have been named by the author the Larmudiac beds, only occur below the high-level shorelines on the south-west of Menengai. There are numerous occurrences associated with tuffs and agglomeratic tuffs to the west of Lake Nakuru, and they are also seen near Nakuru Junction, Lanet and Mbaruk. Near Nakuru Junction and west of Lanet they show pronounced slump structures. The sediments are typically coarse graded pumice tuffs, bedded in thick units, with some intercalated finer silty beds. Immediately to the south-east of Nakuru they are exposed in many deep gullies in sections of up to 30 feet.

In the Larmudiac gorge a section of nearly 50 feet is seen, and the base of the sediments is not revealed. There is much coarse pumice and silt here in the eastern part of the sections while towards the lake a considerable thickness of well-stratified graded tuffs and finer clays come in. The succession here closely resembles the Kapthurin succession (p. 73) and the change from poorly stratified silts and pumice beds to well stratified lake beds is similar to the Kamasia type area except that no coarse bouldery torrent wash is seen here.

These sediments and the overlying unstratified tuffs carry prominent black pumice enclaves, a characteristic feature of the tuffs of Mugurin and Ndolaita, and the Kapthurin beds. In the Larmudiac section and everywhere in the area west of Lake Nakuru there is a pronounced capping of brown unstratified lapilli tuff, exactly like the capping at Mugurin and Maji ya Moto and like the tuff in those localities it occasionally grades into a soft greenish tuff with the appearance of a welded tuff, as in the dry valley section south-west of the lake. Agglomerates and lapilli tuffs occur in the railway cuttings at Lanet and thin white diatomite with pumice beds and rather earthy silts in a road cutting at Mbaruk.

To the west of Lake Nakuru these beds are cut by a very late series of faults, as are the Kapthurin beds at Marigat. The faulting is well seen in the dry valley section and the Larmudiac section.

At the Lower Makalia Gorge there is a capping of about twenty feet of very compact blackish green welded tuff, which is quarried as a freestone for building. It overlies reddish earthy sediments, which are above the phonolite of the gorge. This section may possibly have been mis-correlated with the Makalian succession by earlier writers, but it stands too high to belong to that succession. The tuff outcrops extend along the river bed as far as the Upper Makalia Gorge, which is just below 6,400 feet. Thin veneers of sediments only have been recognized above the second gorge.

The distinct separation of the Makalian and Gamblian beds of the plain south of Lake Nakuru from the Larmudiac beds appears to be primarily due to the fact that the Makalian sediments were deposited in a trough formed within the older Larmudiac sediments by later minor fault movements. These movements also result in considerable unconformity between the two successions. There is some evidence of aridity between the Makalian of the Nderit and Makalia sections and the underlying Gamblian beds, but only a very weak unconformity is seen locally. The Makalian are deltaic or estuarine sediments composed of material derived from the Mau and thus lack the coarse pumice content of the Larmudiac beds, which appears to have been derived from Menengai and its pumice-mantled environs. The Larmudiac sediments are only in part lacustrine, well-stratified lake deposits being seen only near to Lake Nakuru.

The distinct separation between the Kanjeran and the Gamblian is also probably primarily due to an intervening minor tectonic episode. Such a minor tectonic episode has been described (McCall 1957 (*c*), p. 24–25) and the unconformity at Kariandusi supports such a hypothesis. Flint (1959 (*a*), p. 273–4) finds no evidence of a Kanjeran pluvial. The writer considers that the three divisions—Kariandusi beds (Kanjeran), Larmudiac beds, Gamblian and Makalian of the plain south of Lake Nakuru—represent deposition following tectonic episodes. Deposition following the last major faulting was effected in a deep basin compatible with the magnitude of the displacement, hence the well stratified nature of the Kariandusi sediments and the presence of thick relatively pure diatomites. The succeeding lake basins were shallow, compatible with the very minor nature of the faulting which initiated them. In general there is a lack of such good stratification or pure diatomite horizons in the later sediments.

While climatic fluctuations have a bearing on the extent of the lakes the three subdivisions appear to owe their existence primarily to factors other than climatic, and at present the writer can see no real validity in correlation with the European glaciation. What is required to put such a hypothesis on a sure footing is a direct connexion with glaciation stages on Mount Kenya, and such a connexion is at present lacking.

In the foregoing description the Larmudiac sediments have been accepted as being of Upper Pleistocene age. There is no record of archaeological work on them, and no fossils were found. The validity of the separation between these sediments and the Kanjeran is thus not absolutely certain. The only evidence being (1) Similar lake sediments at Marigat, the Kapthurin beds (p. 73), appear to contain Levallois artifacts, a later culture than the Acheulian or Kariandusi, indicative of an early Upper Pleistocene age (Cooke, 1958, p. 40), (2) the Larmudiac sediments appear to be restricted to the area in the Nakuru basin below the highest Gamblian shoreline.

Palaeontological and archaeological investigation of these sediments together with the excellent sections of equivalent successions between Mugurin and Maji ya Moto might lead to an equation with the Kanjeran rather than the Gamblian. The marked differences in lithology might be entirely due to the much coarser material which has been reworked around Menengai compared with Kariandusi. The writer believes however that the Larmudiac sediments will prove to be of early Upper Pleistocene age, and quite distinct from the Kanjeran sediments.

The Present Day Lakes

Lake Nakuru and Elmenteita are very shallow pans. In 1929 Solomon found the maximum depth of Nakuru to be nine feet and Elmenteita twelve feet. Both are evaporation pans as their high salinity shows. The lakes are infilled with very fine clayey silts or gravel. There is no deep layer of trona, but in dry periods thin crusts are formed on the surface of the sediments and in shallow pools. This is dissolved when the lakes fill again in wet periods, and probably there is a continual movement of saline water into the water-tables nearby, so that deposition of soda never goes beyond a certain temporary stage of development. The essential difference between these lakes and Lake Magadi is that the latter is in a "sump" of the Rift Valley away from which there is no groundwater movement, in direct contrast to the conditions described above.

The present lakes are dwindled remnants of the Makalian and Nakuran lakes. The dwindling is probably due to an amelioration of the climate, a world-wide phenomenon which has been causing recessions of the worlds glaciers for a long period.

(*c*) *Baringo-Hannington Basin*

(i) *Sediments of the Kamasian type area*

Only a small part of these sediments (Gregory, 1921, pp. 149–174) outcrop in the present area, in the Molo river channel, where they underlie up to 50 feet of Loboi Silts. They consist of thick-bedded units of pumice tuff with black pumice enclaves. Some conglomerate with rounded pebbles is associated with the tuffs.

The Kamasian type-area has recently been reassessed by McCall and Walsh (McCall, Baker and Walsh, 1965). The most important conclusion reached is that the Kamasian sediments comprise two distinct sedimentary formations:—

Chemeron Beds

Very finely stratified lake beds with diatomite, underlying and intercalated in the Dispei-Lake Hannington phonolite lavas and intercalated in the Kwaibus basalt. Probably of Pliocene age.

Kapthurin Beds

Much coarser graded tuffs in thick units intercalated with torrent wash and silt. Only partly of lacustrine origin. Grading westwards into a piedmontine torrent wash formation. Levallois artifacts of doubtful provenance indicate a possible Upper Pleistocene age.

The beds exposed in the Molo river belong to the Kapthurin series of sediments, and are thus believed to be of Upper Pleistocene age.

(ii) *Mugurin and Maji ya Moto beds*

The river valleys of the drainage system extending from Mugurin to Maji ya Moto (Ndolaita) show discontinuous outcrops of a later infilling of tuffs and sediments overlying the faulted Dispei-Lake Hannington phonolites. The succession is everywhere capped by a prominent well-consolidated white, green or buff unstratified lapilli tuff about twenty feet thick which locally shows some resemblance to the coarse welded tuffs of the older eruptive series, classified as "ignimbrites". The sediments are for the most part earthy silts, bouldery silts and torrent wash, but more finely stratified graded tuffs are locally developed. Impure pinkish diatomaceous silts have been recognized, and near Maji ya Moto hot springs there is some pure white sediment which may be a fairly pure diatomite.

A section was measured at Ndolaita as follows:—

Travertine

White tuffs (15 ft.)

Thin bands of fine laminated tuffs

Pinkish diatomaceous clay (10 ft.)

Phonolite

North of Mugurin there are some plant remains in these sediments, but no other fossils were noted. At Mugurin the surface of the capping tuff layer is littered with Wilton type obsidian scrapers, potsherds and beryl beads.

This formation is seen in a few outcrops north-east of Menengai along the railway between McCalls' Siding and Ol Punyata where a very thin layer of unstratified tuff overlies graded tuffs. A further occurrence was noted to the north of Ol Legisianana. The tuffs forming the top part of this succession are well exposed in the valley of the Molo river near Mogotio, to the west of the boundary of the area.

The fact that these beds occur only along the present-day drainage channels indicates a fairly young age. They are absent from the Lake Hannington basin which was formed prior to their deposition, and thus an origin in local ponding along river valleys must be suggested rather than a lacustrine origin, a mode of derivation compatible with their lithology.

Fuchs (1950, p. 169), worried by the lack, to the south of Marigat, of any lake beds corresponding with his 3,800 foot shoreline (identified to the west of Marigat), suggested that these were the equivalent beds. In a very brief visit he did not recognize that they were overlying the phonolites at Ndolaita. The sediments he was looking for—the equivalent of the Chemeron sediments—are *under* the Dispei-Lake Hannington phonolites if they exist at all near Lake Hannington, and thus are not exposed at the surface in the Lake Hannington basin. The fact that the occurrence is at an altitude of 3,800 feet is pure coincidence—they occur at 5,000 feet to the south of Mugurin.

Like the Kapthurin beds, the Mugurin and Maji ya Moto sediments are believed to be Upper Pleistocene. The tuff is equated with a similar tuff capping the Larmudiac sediments west of Lake Nakuru, but there is no direct evidence of their age.

(*d*) *Solai Basin*

There are several hundred feet of sediments in the Solai basin, but their existence is only known from drilling records (boreholes C.298, C.299, C.303). To the west of Lake Solai some of the graben near Ngendalel contain deposit of thinly-bedded off-white diatomaceous silts, and at some time in the Quaternary a lake may have existed covering the Solai basin, and extending as far west as this point. Alternatively these silts may represent separated pondings in the graben. Their exact age is unknown.

2. Igneous Rocks

The only igneous rocks known in the area are syenite boulders on Menengai slopes, in the upper vitreous flows of the Lower Menengai series, and in the Kinangop and Bahati tuffs.

These syenites are aegirine-syenites devoid of nepheline (*see* analyses Table 2L). They presumably represent epeirogenic intrusions, probably of circular form, of alkaline magma underlying the great volcanoes such as Menengai, Kilombe, Longonot, etc. Alternatively there may be a continuous elongated plutonic mass underlying the length of the Rift Valley, and these volcanoes are but cupolas in relation to it. A petrographic description is given on page 44. The close compositional resemblance of the syenite and the lower Menengai trachyte revealed on analysis (Table 2K) suggests that the syenite may well be the parent magma from which the trachyte flows were derived.

3. Geothermal Activity

Geothermal activity is widespread in the parts of the area lying within the Rift Valley. The occurrences, shown on Fig. 6, are as follows:—

Steam and gas fumaroles in the caldera of Menengai

Steam encountered in boreholes north of Menengai

Hot springs at Maji ya Moto

Hot springs at Loboi

Fumaroles, hot springs and geysers around the shore of Lake Hannington

Hot springs at Emsoss

Hot springs at the foot of the Solai Escarpment

Hot springs at the foot of the Bahati Escarpment and hot springs near Gilgil, Ol Kalou and Thomson's Falls.

Steam and gas fumaroles at Arus* on the Molo River

Thermal water supplies encountered at numerous localities in drilling for water

Hot blow-holes.

Analyses of water and gases from hot springs are given in Table 3.

*The Arus occurrence is outside the present area, but is discussed here due to the important evidence it offers.

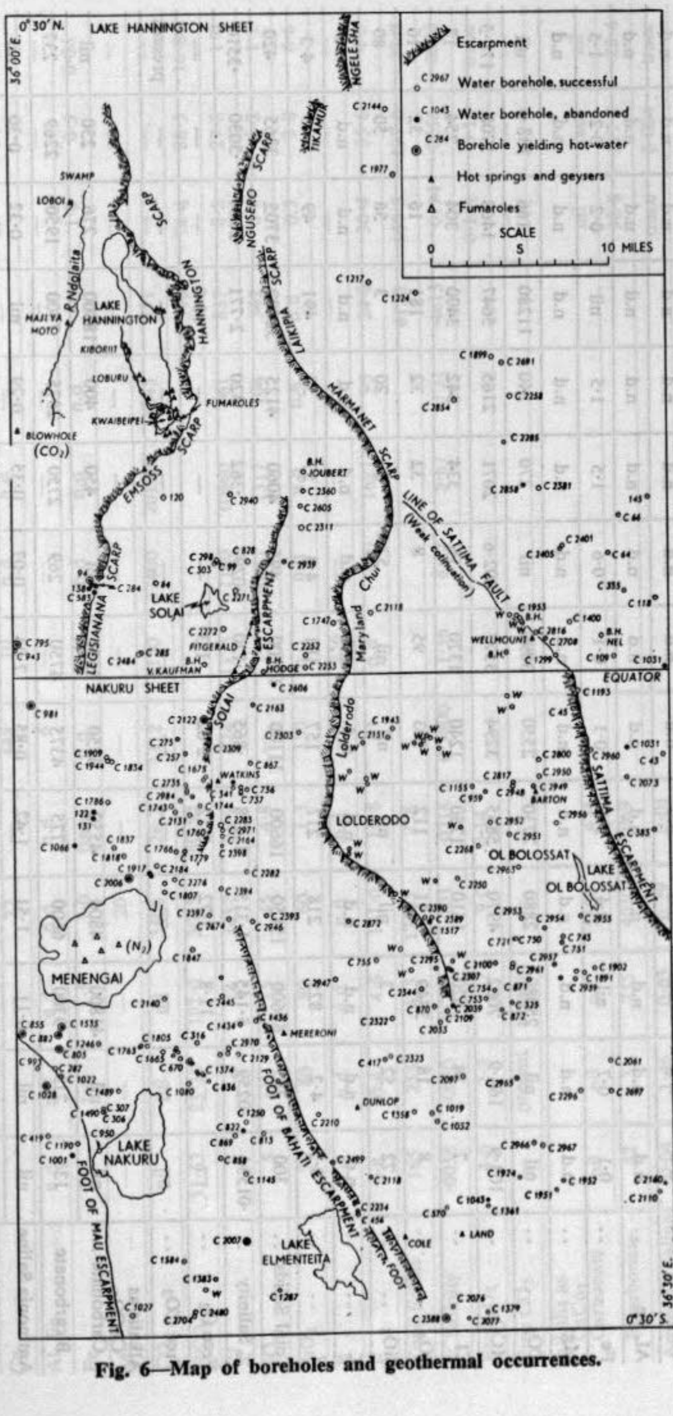


Fig. 6—Map of boreholes and geothermal occurrences.

TABLE III

Parts per Million	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Na Calculated	34·00	58·64	14573·5	3388·0	3625·7	1603·6	2895·5	66·53	855·5	340·6	6712·1	624·3	857·5	62·9
Ca	n d	n d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Al, Fe ..	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Fe	0·1	0·7	nil	0·4	1·5	0·1	0·1	0·6	1·5	1·5	nil	0·2	0·2	1·5
Mg	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
CO_3	nil	nil	25080	2880	2730	2550	3090	nil	270	240	11280	166	138·0	nil
HCO_3 ..	103·9	164·9	7002	4970	5855	3294	3577	202·6	2071	2165	5647	1468	1708	178·5
Cl	7	14	620	1610	1750	1240	1370	16	334	342	3400	304	254	17
SO_4	8	18	3349	91	112	103	95	8	32	32	181	16	32	16
SiO_2	72	52	3	nil	nil	nil	nil	52	50	20	3	56	50	80
K	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
F	0·5	4·2	825	218	217	157	181	4·3	57	59	491	49	45	4·3
Total Solids ..	300	365	63600	15850	16600	11100	13200	495	4060	4125	32000	3705	3365	420
% Salinity ..	·01534	·0259	5·145	1·315	1·428	·865	1·120	·0297	·362	·320	2·771	·2624	·3030	·3510
Free O_2 ..	—	—	11·8	5·72	6·12	2·62	1·3	—	—	—	10·0	—	—	—
Free CO_2 ..	—	—	—	—	—	—	—	—	—	—	—	—	—	present
Alkalis as $CaCO_3$ Carbonate ..	nil	nil	41800	4800	4550	3750	5150	nil	450	400	18800	276	230	nil
Bicarbonate	138	219	9300	6600	7775	4375	4750	269	2750	2875	7500	1950	2269	237
Ammonia Saline	nil	nil	0·11	1·51	1·42	0·85	2·04	0·07	0·35	0·29	nil	0·32	0·30	nil
Albuminoid ..	nil	nil	1·36	0·58	0·59	0·20	0·39	nil	0·03	0·04	1·11	0·03	0·04	nil
Total Hardness	30	30	110	10	20	20	10	40	10	10	90	10	10	20
pH	7·5	7·5	10·1	9·5	9·5	9·5	9·5	7·1	9·1	9·1	10·1	9·1	8·9	6·7

TABLE III—(*Contd.*)

Parts per Million	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Na Calculated	12·65	8·16	65·30	2925	56·63	1584	5550	33855	23271	1252	1460	72·2	97·4	13·8
Ca	—	—	—	22	—	448	10	n.d	n.d	—	—	—	—	—
Al, Fe	n.d	n.d	n.d	n.d	n.d	6	—	—	—	—	—	—	—	—
Fe	2·8	1·4	1·5	1·0	trace	n.d	n.d	n.d	n.d	n.d	—	1·8	0·3	0·06
Mg	—	—	—	20	—	—	—	—	—	—	—	—	—	—
CO_3	nil	nil	nil	3408	28·2	1312	6150	37400	20100	1245	351	—	—	—
HCO_3 ..	31·63	23·34	192·0	3035	80·50						1599	74·4	88·5	16·86
Cl	5	4	14	1437	26·9	424	1375	7160	10460	461	837	8·2	27·8	1·0
SO_4	5	nil	15	45	4·8	—	253	1457	1317	104	342	6·8	6·2	1·9
SiO_2	30	60	80	60	1·3	150	n.d	n.d	n.d	n.d	n.d	0.5	3·8	8·6
K	n.d	n.d	n.d	n.d	n.d	—	256	—	—	—	—	—	—	—
F	0·8	0·4	4·6	141·0	18·8	41	n.d	1400	1627	95	24·0	30·4	35·6	4·8
Total Solids ..	165	255	425	12595	238						6120	160·5	197·0	38·0
% Salinity ..	·0058	·0030	0·291	1·103	·0216	0·3800	1·36	8·12	5·67	0·31	·4613	·0194	·0256	·0038
Free O_2 ..	4·0	2·2	1·2	9·0	0·14							0·281	0·13	trace
Free CO_2 ..	—	present	present	—	—							—	—	—
Alkalis as $CaCo_3$ ..														
Carbonate ..	nil	nil	nil	5680	474							nil	trace	nil
Bicarbonate	42	31	255	4030	1069							98·8	117·5	22·4
Ammonia Saline	0·04	1·46	0·03	0·29	0·01							trace	0·004	trace
Albuminoid ..	0·82	0·53	0·11	2·61	0·54							0·058	0·007	trace
Total Hardness	10	20	20	137	2·0							1·0	1·5	1·5
pH	7·3	6·3	6·9	9·6	10·4							7·9	8·2	7·8

Table III—(*Contd.*)

Parts per Million	29	30	31	32	33	34	35	36	37	38	39	40	41
Na Calculated	5·8	95·2	46·7	71·2	52·0	61·6	171·2	69·5	11·4	11·4	17·3	10·5	18·8
Ca	—	—	—	—	—	—	—	—	—	—	—	—	—
Al, Fe ..	—	—	—	—	—	35	—	—	—	—	—	—	—
Fe	0·48	6·4	0·05	0·06	0·7	trace	0·17	2·5	1·6	3·2	3·6	1·6	1·2
Mg	—	—	—	—	—	10	—	—	—	—	—	—	—
CO_3	—	—	—	—	—	—	9·96	—	—	—	—	—	—
HCO_3 ..	8·13	198·8	62·34	152·8	115·2	154·4	326·8	94·88	24·85	21·83	32·38	21·83	38·40
Cl	1·2	1·6	4·7	19·0	13	2	1·0	17·0	2	3	5	2	6
SO_4	trace	28	2·0	trace	nil	4	1·5	40·0	trace	nil	nil	nil	nil
SiO_2	3·8	60	0·2	50·0	50	70	5·5	50·0	20	8	25	18	52
K	—	—	—	—	—	—	—	—	—	—	—	—	—
F	1·6	5·2	14·2	1·0	0·2	0·2	32·3	3·2	0·6	1·0	1·5	0·8	0·3
Total Solids ..	41·0	520	115·5	375·0	250	280	83·0	350	110	165	220	105	155
% Salinity ..	·0017	·0387	·0130	·0253	·0181	·02320	·05416	·02265	·00388	·00355	·00562	·00351	·00635
Free O_2 ..	—	—	—	—	—	—	—	—	—	3·72	8·3	2·9	0·5
Free CO_2 ..	—	—	present	present	—	—	—	present	present	present	present	present	present
Alkalis as $CaCo_3$													
Carbonate ..	nil	nil	nil	nil	nil	nil	16·6	nil	nil	nil	nil	0	nil
Bicarbonate	10·8	264	82·8	203	153	205	434	126	33	29	43	29	51
Ammonia Saline	trace	0·10	0·036	trace	trace	0·01	trace	0·05	nil	trace	0·16	0·04	nil
Albuminoid ..	0·006	nil	0·005	trace	0·02	0·04	trace	0·05	0·04	0·12	0·36	0·11	0·03
Total Hardness	4·0	20·0	5·0	70	30	125	2·0	50	30	20	20	20	10
pH	7·1	8·1	6·8	6·9	7·3	7·7	8·7	6·9	6·9	6·5	6·9	6·1	6·9

TABLE III—(*Contd.*)

Parts per Million	42	43	44	45	46	47	48	49	50	51	52	53	54
Na Calculated	10·3	13·2	40·5	4·5	60·0	—	—	—	—	—	—	—	—
Ca	—	—	4	—	16·0	3	10	4	5	8	3	6	8
Al, Fe ..	—	—	—	—	0·1	—	—	—	—	—	—	—	—
Fe	2·4	3·0	0·1	0·09	trace	trace	trace	trace	nil	trace	trace	trace	trace
Mg	—	—	1	—	4	nil	nil	nil	nil	nil	nil	nil	nil
CO_3	—	26·4	—	—	24	—	—	—	—	—	—	—	—
HCO_3 ..	19·57	26·35	28·61	6·77	90·36	—	—	—	—	—	—	—	—
Cl	4	4	4	0·4	2	5	6	2	3	8	11	11	16
SO_4	nil	nil	12	trace	12	10	4	4	6	55	8	52	41
SiO_2	40	84	45	5·2	90	90	90	85	35	90	90	60	3
K	—	—	—	—	—	—	—	—	—	—	—	—	—
F	0·2	0·5	0·1	1·4	0·4	1·3	1·8	1·0	0·6	0·6	3·0	5·4	5·4
Total Solids ..	120	250	110	230	210	150	260	135	100	170	365	350	420
% Salinity ..	·00341	·00705	·00852	·00130	·01888	·00318	·00632	·00262	·00272	·00277	0·0110	0·00911	0·01285
Free O_2 ..	2·0	2·3	—	—	nil	nil	nil	nil	nil	nil	nil	nil	nil
Free CO_2 ..	present	—	—	—	nil	10	35	20	nil	nil	nil	nil	nil
Alkalis as $CaCo_3$ Carbonate ..	nil	44	nil	nil	nil	—	—	—	—	—	—	—	—
Bicarbonate	26	35	38	9	120	60	135	55	55	50	235	155	245
Ammonia Saline	nil	nil	—	0·006	nil	nil	nil	nil	nil	nil	nil	nil	nil
Albuminoid ..	0·1	0·8	—	0·009	nil	nil	nil	nil	nil	nil	nil	nil	nil
Total Hardness	20	20	15	20	55	10	35	15	15	30	10	25	30
pH	6·3	8·9	6·9	7·5	6·8	6·9	6·7	6·7	7·8	6·7	7·0	7·0	7·0

1. Hot springs, Fitzgerald's Farm, Solai.
2. Hot springs, Emsoss.
3. Lake water, Hannington, S.W. corner.
4. Hot springs, peninsular, L. Hannington
5. Lake water, Hannington, S. end.
6. Hot springs, Kwaibeipei.
7. Hot springs, Kwaibeipei.
8. Hot springs, N. peninsular, L. Hannington.
9. Geyser and hot springs, Loburu.
10. Hot springs, W. shore, L. Hannington.
11. Lake water, Hannington, Kiboriit.
12. Boiling Pot I, Kiboriit.
13. Boiling Pot II, Kiboriit.
14. Hot springs, Maji ya Moto.
15. Molo river, Arus.
16. Hot springs, Arus.
17. Hot springs, Loboi.
18. Lake water, Hannington, N. end.
19. Hot springs, Ol Kokwe Is., L. Baringo.
20. Lake water, Baringo.
21. Lake water, Nakuru.
22. Lake water, Nakuru.
23. Lake water, Elmenteita.
24. Cole's hot springs, Elmenteita.
25. Lake Nakuru (artesian).
26. B/H C. 1246, Nakuru Showground.
27. B/H C. 1489, Honeymoon Hill.
28. B/H. C.1763 Nakuru.
29. B/H. C.2129, E.A.T.C. Lanet.
30. B/H. C.2930, Nakuru.
31. B/H. C.2388, Gilgil, (Hot).
32. B/H. C.804, Ol Kalou.
33. B/H. C.2858, Mayers, Thomson's Falls.
34. B/H. C.2939, Vale Estate Subukia.
35. B/H. C.1818, Eames, Solai.
36. B/H. Rhodora Estate ,Solai.
37. Crater stream.
38. Melawa river.
39. Mereroni river
40. Wanjohi river.
41. Ngosura river.
42. Rongai river.
43. Njoro river.
44. Watkins river.
45. Little Gilgil river.
46. Watkins' hot spring.
47. Dunlop's hot spring.
48. Mereroni hot spring.
49. Lands hot spring.
50. Wellmount hot spring.
51. Barton's hot spring.
52. B/H. C.2484, Kisinana.
53. B/H. 120, Ol Kokwe.
54. B/H. 84, Ngendalel.

Fumaroles in Menengai caldera

The thermal occurrences in and around Menengai have been mentioned in previous published works (McCall 1957 (*a*), p. 68, 1957 (*b*), pp. 50-52, 1957 (*c*), p. 20, 21). There are several areas of fumarole activity in the vast expanse of recent slaggy lava flows within the caldera which are recognizable by the absence of trees around them. A similar inhibition of vegetation is seen around the carbon dioxide fumaroles at Esageri (McCall, 1959). In the case of the Menengai fumaroles a considerable quantity of gas is mixed with the steam and one sample was analysed, revealing a composition of nearly pure nitrogen.

Analysis

Gas sample from the eastern fumaroles of Menengai caldera

	H_2	CH_4	N_2	O_2	A	CO_2
% Vol.	0·01	0·04	95·1	2·58	1·19	1·10

Anal. A.E.R.E., Harwell.

This analysis indicates a juvenile gas content and suggests that the fumaroles are derived from the admixture of hot juvenile gas and the meteoric water which passes under Menengai in groundwater bodies mainly derived from the Crater stream (McCall, 1957 (*c*), p. 13 and Map 2). This explanation is supported by the fact that most of the fumaroles lie on definite linear zones, and steam was encountered in boring operations north of Menengai on the extension of one of these linear zones. Linear fracture zones act as conduits for the juvenile gas at Esageri (McCall, 1959). There is little or no sulphur associated with the fumaroles, but soft reddish ferruginous deposits form very thin encrustations or mounds around the fumaroles.

The temperatures of the eastern fumaroles were measured by Richard (1957, p. 50) as follows:—

		1936	1944	1946	1948
	No. 1	75	74	78	64
	2	74	85	88	83
Degrees	3	92	94	94	90
centigrade	4	85	82	88	82

The western fumaroles in Menengai were revisited by the writer in 1960. Both these and the eastern group showed no appreciable change in their activity since 1952. The western group showed a slight radioactivity anomaly (two to three times background). An attempt at sampling the gas was made, but difficulty was experienced in filling the new pattern tubes used. An analysis of air mixed with fumarole gas carried out by the Industrial Research Laboratories, Nairobi, showed an excess of CO_2 over the normal content of air, and it seems likely that CO_2 not nitrogen is the main fumarole gas emanating here.

Steam occurrence north of Menengai

A considerable volume of steam, not under high pressure, was encountered (McCall, 1957 (*c*), p. 21 and p. 52) in boreholes 131 and C.1066 sited to the north of Menengai, near Ol Punyata station. The boreholes are sited close to a major fault line and on a northward extension of one of the Menengai thermal zones.

Hot springs at Maji ya Moto (Ndolaita)

Some hot springs bubble up in the rocky bed of the Ndolaita river at Maji ya Moto, west of Lake Hannington. Two points are of interest, firstly that the springs are in a zone of complex fracturing at the foot of a major fault scarp, and secondly that they are situated in a surface drainage channel and may well be due to seepage from the river in the fault zone meeting hot gas coming up a fracture. Their temperature is about 38°C. Chemical analysis (Table 3 (14)) suggests an origin in groundwater or groundwater with river water. Some movement of saline water underground from Lake Hannington might cause the rather high percentage of salines.

Hot springs at Loboi

There are some hot springs at Loboi discharging through a series of pools of clear water into the Loboi swamp. These springs lie on a major fault zone, and chemical analysis (Table 3 (17)) suggests an origin in rather saline groundwater, moving slowly northwards from Lake Hannington, mixed with rising hot gas in the fault zone.

Hot springs, fumaroles and geysers around the shores of Lake Hannington

The whole southern half of Lake Hannington presents an eerie sight in wet weather, when the clouds of steam streaming upwards along the edge of the lake are seen from the viewpoint on the rim of the escarpment two thousand feet above it. There are several groups of springs, all within a few yards of the lake, and many fumaroles bubbling under the surface of the lake water. The level of the lake has a considerable effect on the activity, and the most prominent geyser was on one occasion seen to be entirely swamped and passive.

Two geysers were seen in action by the writer, one at Kwaibeipei and one at Loburu. The former ejected every ten minutes from a hole about two feet in diameter on the foreshore, throwing a cloud of steam fifty feet in the air. The Loburu geyser ejected every two or three minutes. There are numerous spouting springs in more or less continuous activity along the foreshore north of the Kwaibeipei geyser, and also south of it, both on the foreshore and in the water. These springs have a recognizable linear arrangement along fault lines, including the major eastern fault bounding Lake Hannington. Farther along the same fault a few miles to the north is another group of springs.

There are also several springs on the shore of the peninsular which projects from the west shore of the lake, and underneath the lake fumaroles rise between the peninsular and the Kwaibeipei geyser. There appears to be a series of springs and fumaroles situated on a set of cross fractures extending across the lake at this point. Hot springs were noted at the foot of the immense fault scarp on the shore south of the lake, and near the south-east corner of the lake, where the ground rises from the lake shore, spouting springs give way to fumaroles which stream off a reddened iron oxide stained cliff in a deep east-west trending fissure. This occurrence suggests a hydrostatic connexion between the spouting springs and the lake water (cf. the condition at Arus described below). Here, as in the case of all the lakeside springs, the hot water in the springs rises a foot or so above lake level, a fact attributed to lesser density of the heated water due to temperature and a lesser salt content.

At Loburu there is a group of springs surrounding the geyser and the water flows down the shore in a terrace stained pink and orange with algae and colloidal encrustations. The periphery of some springs shows encrustation of a bright orange material, probably colloidal iron salts. Loburu is situated at the junction of the western bounding fault of Lake Hannington and a north-easterly trending transverse fault, and the Kiboriit springs farther to the north are in a similar structural position. At Kiboriit the springs form extensive boiling pots several yards in diameter, pock-marking the small delta on the edge of the lake.

Temperatures measured on the eastern peninsula at the south end of Lake Hannington were 98°C, 98°C, 97°C, 96°C, 93°C, 93°C, 86°C and 85°C. A hot spring on the south shore of the lake was measured as 42°C. The eastern springs at Kwaibeipei seemed even hotter than those on the eastern peninsular, but the thermometer in use was accidentally broken, so they could not be measured.

A slight increase in radioactivity to about twice background was noted over the more powerful steam fumaroles and geysers around Lake Hannington.

A gas analysis from a fumarole near the geyser at Kwaibeipei showed the following content by volume:

	H_2	CH_4	N_2	O_2	A	CO_2
% Vol.	5·7	—	27·8	17·3	0·8	47·5

Anal. A.E.R.E. Harwell.

The high CO_2 content makes it clear that it is derived from juvenile gas. The high oxygen content may be due to oxygen dissolved in the lake water and subsequently returned with the juvenile CO_2. Some air is also clearly present.

A triangular diagram (Fig. 7) representing chloride, sulphate and carbonate proportions (as carried out by Baker (1958, Fig. 10) for Lake Magadi) reveals a close correspondence of waters of the hot springs with the lake water, and in the case of Lake Hannington "Steven's hypothesis" (Baker 1958, p. 56) does not appear to be tenable. The contrast between the lake springs and hot springs away from the lake is apparent, and it seems that the lake is fed by surface water increments and water from a few hot springs issuing heated-up groundwater, for example the Emsoss spring and the spring on the neck of the peninsular, while the majority of the lakeside springs are issuing water which circulates down a system of fissures to underground thermal zones and returns to the lake. The hydrostatic connexion is obvious. The lower percentage salinities of the hot springs compared with the lake water may be explained by the fact that when the lake water reaches a critical temperature it throws out its salt content on being converted to steam which, returning upwards to cooler levels, condenses as more weakly saline water. In support of such a cycle there is a marked rhythmicity in the activity of the springs, spouting wells and geysers. Approaching Kiboriit one sees a regular spurt of steam from all the vents together, every five minutes or so, followed by a period of inactivity. Alternatively the decreased salinity of the hot springs may be due to admixture of lake water and groundwater.

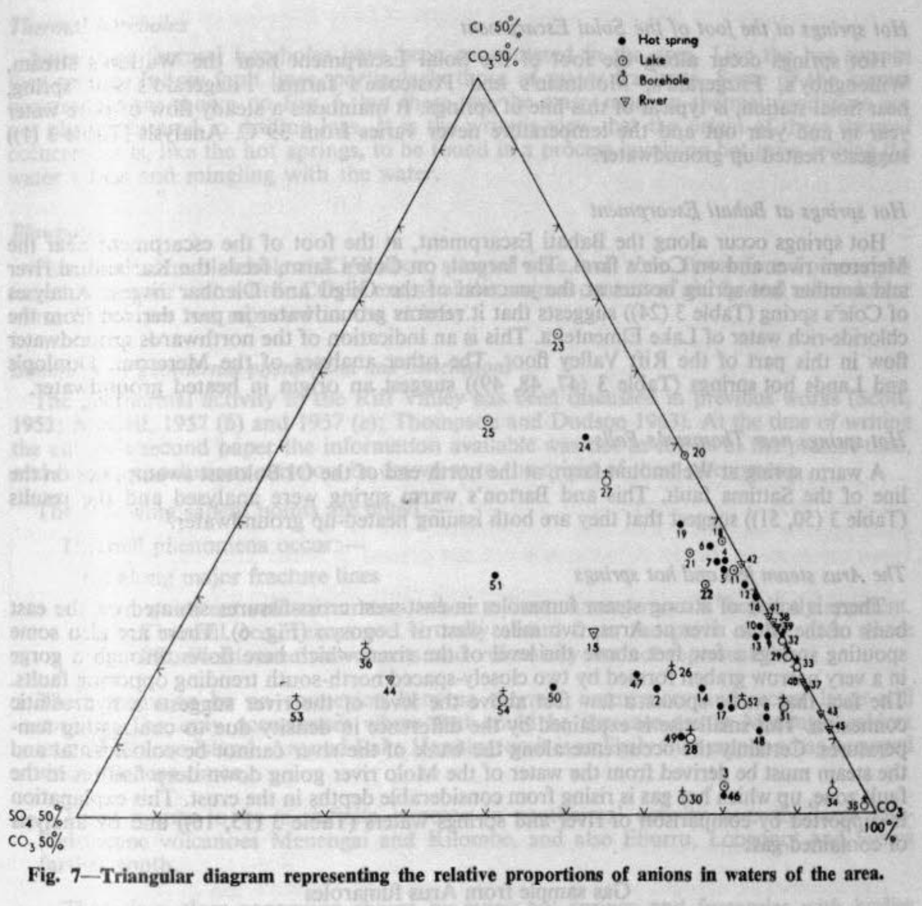


Fig. 7—Triangular diagram representing the relative proportions of anions in waters of the area.

It is probable that the lake, lying as it does in a basin in impermeable lava, is not at its south end in direct connexion with any continuous water body, and is not a "hydrographic window" (Barth 1951, p. 17). The extraordinarily different analysis of the peninsular hot spring from the other lake-side springs supports this view. The mode of derivation of the springs fits in well with Steven's ideas of recirculation (Baker, 1956, p. 56) but Lake Hannington is not in a "sump" of the Rift Valley, and there is continuous removal of the saline water northwards underground.

The analyses show a reflection of the compositional change of the lake waters from south to north in the springs along the lake shore. The salinity of the springs is, as has been noted, always lower than the nearby lake water, and they mostly carry appreciable carbonate as well as bicarbonate. The analyses do not suggest any appreciable juvenile water content.

Hot Springs at Emsoss

Hot springs emerge at the foot of the escarpment discharging on to the surface of the fragmented lava plateau which lies to the east of Lake Hannington. These springs, which are on the continuation of the line of springs along the south shore of Lake Hannington, have a temperature of 37°C.

Farther along the foot of the Emsoss and Legisianana escarpments on the Sertonji plain a borehole (No. 138) struck water at 52°C, indicating that a thermal zone runs right along the line of this major escarpment. The analysis of the Emsoss spring (Table 3 (2)) suggests a source in heated groundwater.

Hot springs at the foot of the Solai Escarpment

Hot springs occur along the foot of the Solai Escarpment near the Watkin's stream, Willoughby's, Fitzgerald's, Moolman's and Postcoke's farms. Fitzgerald's hot spring, near Solai station, is typical of this line of springs. It maintains a steady flow of pure water year in and year out and the temperature never varies from 39°C. Analysis (Table 3 (1)) suggests heated up groundwater.

Hot springs at Bahati Escarpment

Hot springs occur along the Bahati Escarpment, at the foot of the escarpment near the Mereroni river and on Cole's farm. The largest, on Cole's farm, feeds the Kariandusi river and another hot spring occurs at the junction of the Gilgil and Oleobar rivers. Analyses of Cole's spring (Table 3 (24)) suggests that it returns groundwater in part derived from the chloride-rich water of Lake Elmenteita. This is an indication of the northwards groundwater flow in this part of the Rift Valley floor. The other analyses of the Mereroni, Dunlop's and Lands hot springs (Table 3 (47, 48, 49)) suggest an origin in heated groundwater.

Hot springs near Thomson's Falls

A warm spring at Wellmount farm, at the north end of the Ol Bolossst swamp, lies on the line of the Sattima fault. This and Barton's warm spring were analysed and the results (Table 3 (50, 51)) suggest that they are both issuing heated-up groundwater.

The Arus steam jets and hot springs

There is a line of strong steam fumaroles in east-west cross-fissures situated on the east bank of the Molo river at Arus, two miles west of Logosyo (Fig. 6). There are also some spouting springs a few feet above the level of the river, which here flows through a gorge in a very narrow graben formed by two closely-spaced north-south trending opposing faults. The fact that water spouts a few feet above the level of the river suggests a hydrostatic connexion. This small rise is explained by the difference in density due to contrasting temperatures. Certainly the occurrence along the bank of the river cannot be coincidental and the steam must be derived from the water of the Molo river going down deep fissures in the fault zone, up which hot gas is rising from considerable depths in the crust. This explanation is supported by comparison of river and springs waters (Table 3 (15, 16)) and by analysis of contained gas:—

Gas sample from Arus fumaroles

	H_2	CH_4	N_2	O_2	A	CO_2
% Vol.	0·04	0·14	51·9	13·3	0·62	34·0

Anal. A. E. R. E. Harwell

This analysis indicates a mixture of air and carbon dioxide. The Arus fumaroles are situated only some ten miles from the Esageri gas fumaroles which carry 98% warm CO_2 (McCall, 1959), and it seems likely that it is hot CO_2 from juvenile sources that is the primary agent in this thermal occurrence.

The Arus fumaroles show a slight radioactivity anomaly. Such an anomaly has been noted by Barth in Iceland (1950, pp. 29–30). He was unable to come to any conclusion as to whether this radioactivity is related to the source of the thermal energy. A similar minor radioactive anomaly has been noted in the Lake Hannington and Menengai (western) fumaroles.

Ol Kokwe Island

Hot springs are situated on Ol Kokwe Island in Lake Baringo, a few miles to the north of Logumkum, on a very straight north-south trending island shore apparently marking a fault. Analyses of these hot springs (Table 3 (19)) suggest an origin from lake water going down fissures. No juvenile gas was recognized, but there is some doubt as to the validity of the sample analysed, which corresponded with air, since the sample may have leaked air in shipment to the United Kingdom.

Thermal boreholes

Numerous thermal boreholes have been encountered in the area. Like the hot springs they tend to follow fault lines, particularly those of major fractures. Some of the known occurrences are shown on Fig. 6, but there may be many more as thermal conditions are not always entered in drilling logs. It is the writer's view that the origin of these thermal occurrences is, like the hot springs, to be found in a process involving hot gases joining the water tables and mingling with the water.

Blowholes

There is a warm blowhole at Kipkaibon, situated on a fault zone. It was found on analysis to be blowing air with a little CO_2 in excess of the normal content of air. Several other similar warm blowholes are reported in the vicinity.

Summary of geothermal phenomena and conclusions

The geothermal activity in the Rift Valley has been discussed in previous works (Scott, 1953; McCall, 1957 (*b*) and 1957 (*c*); Thompson and Dodson 1963). At the time of writing the author's second paper the information available was not as full as at the present time, and further conclusions can now be drawn as to the origin of these phenomena.

The following salient points are noted:—

Thermal phenomena occur:—

(*a*) along major fracture lines

(*b*) in quiescent volcanic craters, where a linear arrangement is frequently apparent. Thermal occurrences are virtually absent from the parts of the area where Plio-Pleistocene movements and vulcanicity are not represented.

There seems to be no connexion between thermal occurrences and recent lavas still cooling. The only occurrences where that could be the case are in Menengai caldera and Ol Kokwe Island. Around Lake Hannington it is unlikely that eruption has occurred since Pliocene times.

There seems to be a definite increase in geothermal activity near the large Plio-Pleistocene volcanoes Menengai and Kilombe, and also Eburru, Longonot and Suswa farther south.

There is a close connexion shown by many hot springs and fumaroles with bodies of surface water. For example Lake Hannington, where all of the hundreds of springs and fumaroles are on the edge* of or under the lake.

At Arus and Ndolaita the hot springs are on the edge of flowing streams, and the hot springs and fumaroles on Ol Kokwe Island in Lake Baringo show an obvious connexion. Steam, where encountered, is never in great volumes or under high pressure.

CO_2 is undoubtedly emanating from juvenile sources at Esageri where hot gas containing 98% CO_2 occurs in a borehole at 500 feet (McCall 1959) at a pressure of over 60 lb. per square inch.

CO_2 of juvenile origin is present in steam fumaroles at Arus and at Lake Hannington.

The content of 95% Nitrogen together with a little CO_2 and argon in fumaroles on Menengai indicates a supply of hot juvenile gas. The presence of methane and hydrogen in gases analysed is also significant.

There is no evidence of juvenile water in the area.

All analyses in Table 3 are compatible with meteoric sources and the high pH values indicate an absence of juvenile water except as a negligible content (Barth, 1950, p. 39).

*The resemblance to the occurrences around the edge of the caldera lake Taupo in New Zealand is striking (Grange, 1937). There the hot springs are believed to be derived from much meteoric water mixed with a little juvenile steam.

The steam fumaroles and geysers and hot springs of Lake Hannington are believed to be derived from lake water going down fissures and being returned after meeting hot gases, dominantly CO_2, as steam mixed with gas. Some admixture with groundwater may have occurred. The Arus and possibly the Maji ya Moto occurrences are also believed to be derived from surface bodies (rivers) in the same way, though groundwater may be involved to a considerable extent at Maji ya Moto. The remainder of the thermal occurrences are apparently derived from hot gases mingling with groundwater bodies. The conclusion reached is that hot juvenile gas—CO_2 (more rarely nitrogen) plus traces of argon, methane and hydrogen—is emanating over a wide area in the Rift Valley, being to some extent concentrated around the large trachyte volcanoes which are known to be underlain by syenitic magmatic bodies. Syenite is abundant in boulders on Kilombe, Menengai and Longonot. Part of the syenitic magma is probably still in the process of cooling, and throwing off the gas as residual volatiles. Syenite shows a comparative absence of pneumatolitic phases, indicating a high residual volatile content in contrast with the acid magma of Elba which is supposed to be still cooling under Lardarello and giving off great volumes of steam (McCall, 1957 (*b*), p. 49). The alternative that the cooling pluton under the Rift Valley is in a last *mofette* stage cannot however be entirely rejected. The restriction of fumaroles and other thermal occurrences to fault zones is due to the fact that elsewhere the hot gases dissipate owing to the lack of channels of rapid access to the surface levels of the crust.

The conclusions reached on the present area agree closely with those of Thompson and Dodson (1963) in the Naivasha area, and the gases analysed in that area showed a closely allied juvenile suite with CO_2 and N_2 dominant, and hydrogen and methane significant minor components. Boron or boric acid are not present in either area except as traces.

Comparison of the geothermal occurrences with other well known areas leads to the conclusion that the definition of Allen and Day (1934, pp. 2275-2283) for hot springs in the Yellowstone Park—"circulating groundwater of surface origin heated and augmented by steam in a superheated state rising from an underlying magma through deep cracks in the earth's crust"—must be modified in this area. The thermal agent in this case appears to be hot juvenile gases, mainly CO_2, with little or no juvenile steam.

The gas content fits in well with other occurrences of juvenile gas in solfataric areas. Allen and Day (op. cit.) suggest the content of a deep juvenile gas in such an area as CO_2 98·26%, H_2S 0·66%, H_2 0·11%, CH_4 0·11%, N_2+ A 0·86%. Jagger (1945) however believes the main components of such a gas to be H_2, CO_2, N_2 and A. Carbon dioxide is also the main component of juvenile gases at Lardarello and in New Zealand.

The presence of nitrogen in such a high percentage in fumarole gas in the very centre of Menengai crater poses the question as to whether the composition of juvenile gas may not vary very rapidly from the volcanic centre to the peripheral areas, and also show variation according to the type of magma involved. The nitrogen in Menengai was collected in the centre of the caldera while high carbon dioxide percentages come from peripheral areas some miles from any volcanic centre. This exactly reverses the condition described by Barth (1950, p. 38) from the basaltic field of Iceland, a relationship which suggested to him that the very high percentages of nitrogen in the peripheral area were not indicative of juvenile origin. The nitrogen:inert gas proportion was found to be equivalent to that of air, and a source in the atmosphere was suggested. The writer however is of the opinion that the nitrogen in Menengai fumarole gases must be of juvenile origin. It is difficult to imagine any process which would extract the entire oxygen content from atmospheric gases.

VI.—GEOPHYSICS

1. Seismology

The Gregory Rift Valley is one of the minor seismic zones of the earth, in which earthquakes of shallow focus occur on a limited scale. Minor shocks are fairly frequent in the area under discussion, being most commonly felt at Solai and Subukia. Lt.-Col. S. Reeder, whose house at Solai is situated on a narrow fault block within a hundred yards of the bounding fault, has felt several such shocks in recent years. The shocks are described as resembling a train going across a viaduct and seem to approach from the north-east, that is from the direction of the Laikipia Escarpment. The frequent experience of shocks at Milton's Sidings is not surprising since this locality is characterized by faults which have moved in very recent times.

Only one major earthquake has been recorded within the area, and this, the Laikipia earthquake of 6th January 1928, was felt and caused damage as far afield as Rumuruti, Thomson's Falls and Eldama Ravine. The epicentre calculated from readings of seismographs all over the world was calculated as Lat. 0°20′N. (±.05′) 36°22′E. (±·05′) (Tillotson 1937 p. 72). However the greatest effect was felt in the Lariak Forest, rather to the west of this point, and the shock was more probably centred on some point on the Laikipia Escarpment, the cause being a late adjustment on this complex fault zone. Damage was noted to buildings throughout this section of the Rift Valley, particularly at Subukia and Solai where stone buildings fared the worst, mud-brick buildings tending to crack but stay upright. Lake Hannington is said to have turned black (possibly an exaggeration, but also possibly due to upheaval of bottom muds). At Subukia large fissures opened (Fig. 8) and the land surface was disrupted in a manner suggesting normal faulting on a steep plane.

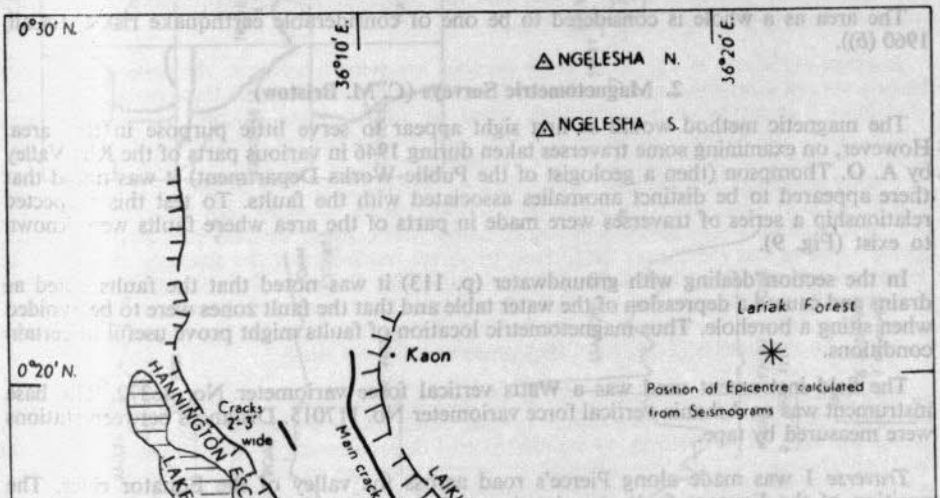


Fig. 8—Sketch map of the distribution of cracks formed by the 1928 Laikipia earthquake in relation to its calculated epicentre.

The earthquake had an intensity of 7·0 on the Richter scale, and the depth of focus abnormally shallow (Tillotson, 1938 p. 315). An earthquake of this magnitude would have destroyed a modern city of high buildings, but in a developing farming area the damage was considerable but not catastrophic in terms of loss of life and property.

Both the writer and Bristow have recently noted new earthquake cracks along the Laikipia Escarpment indicative of minor adjustments still continuing.

As a result of the Laikipia earthquake the Subukia river was diverted underground. Interference with water supplies and the destruction of boreholes are likely to be among the more serious effects of any future earthquakes, besides damage to life and buildings. The area immediately west of Nakuru town is very unstable and within the last few years fissures have on occasion disrupted the railway services. However, not all the fissuring in this area is due to seismic causes (Pulfrey, 1951), some being due to underground waters.

The area as a whole is considered to be one of considerable earthquake risk (McCall, 1960 (*b*)).

2. Magnetometric Surveys (C. M. Bristow)

The magnetic method would at first sight appear to serve little purpose in this area. However, on examining some traverses taken during 1946 in various parts of the Rift Valley by A. O. Thompson (then a geologist of the Public Works Department) it was noted that there appeared to be distinct anomalies associated with the faults. To test this suspected relationship a series of traverses were made in parts of the area where faults were known to exist (Fig. 9).

In the section dealing with groundwater (p. 113) it was noted that the faults acted as drains and caused a depression of the water table and that the fault zones were to be avoided when siting a borehole. Thus magnetometric location of faults might prove useful in certain conditions.

The field instrument used was a Watts vertical force variometer No. 46372. The base instrument was an Askania vertical force variometer No. 117015. Distances between stations were measured by tape.

Traverse 1 was made along Pierce's road across the valley of the Equator river. The position of the Equator fault at point A was known with fair certainty and a magnetic anomaly was recorded along the known line of the fault. The traverse was continued across the valley in order to determine whether the small gorge in which the river flowed would have any effect on the readings taken in its vicinity. It did not. However on extending the traverse up the other side of the valley a strong anomaly was obtained which suggested that there was another fault at point B, to some extent confirmed on examining the aerial photographs of the area.

Traverse 2 was taken near Thomson's Falls with the intention of testing a known fault for an anomaly and also to determine whether a buried valley filled with alluvium produced any effect on the magnetic readings taken in its vicinity. The fault produced a strong anomaly at point A on the traverse and the buried valley appears to have caused a reduction in values obtained in its vicinity. At point B a small anomaly was found which may correspond to another fault.

Traverse 3 was taken at a topographically similar site to No. 2. This traverse however indicates that the centre of the buried valley (point B) does not coincide with the centre of the present valley (point C), a fact suspected before the curve was taken. At point A solid rock was seen at the surface. The area of the traverse at D shows a series of peaks and lows which correspond to a disturbed zone known to exist at this point.

Traverse 4 was made from the south end of the large dam on Kinghorn's farm in a southerly direction as far as Ol Bolossat Forest. No anomaly was found between the dam and the road, but south of the road a strong anomaly was found which corresponds to the position of the Equator fault.

Traverse 5 was made from the Ndaragwa road, near the Moridjo Forest, to the foot of the Sattima scarp. There is a strong fluctuation in values from the start of the traverse near the top of the scarp to just above the foot of the scarp.

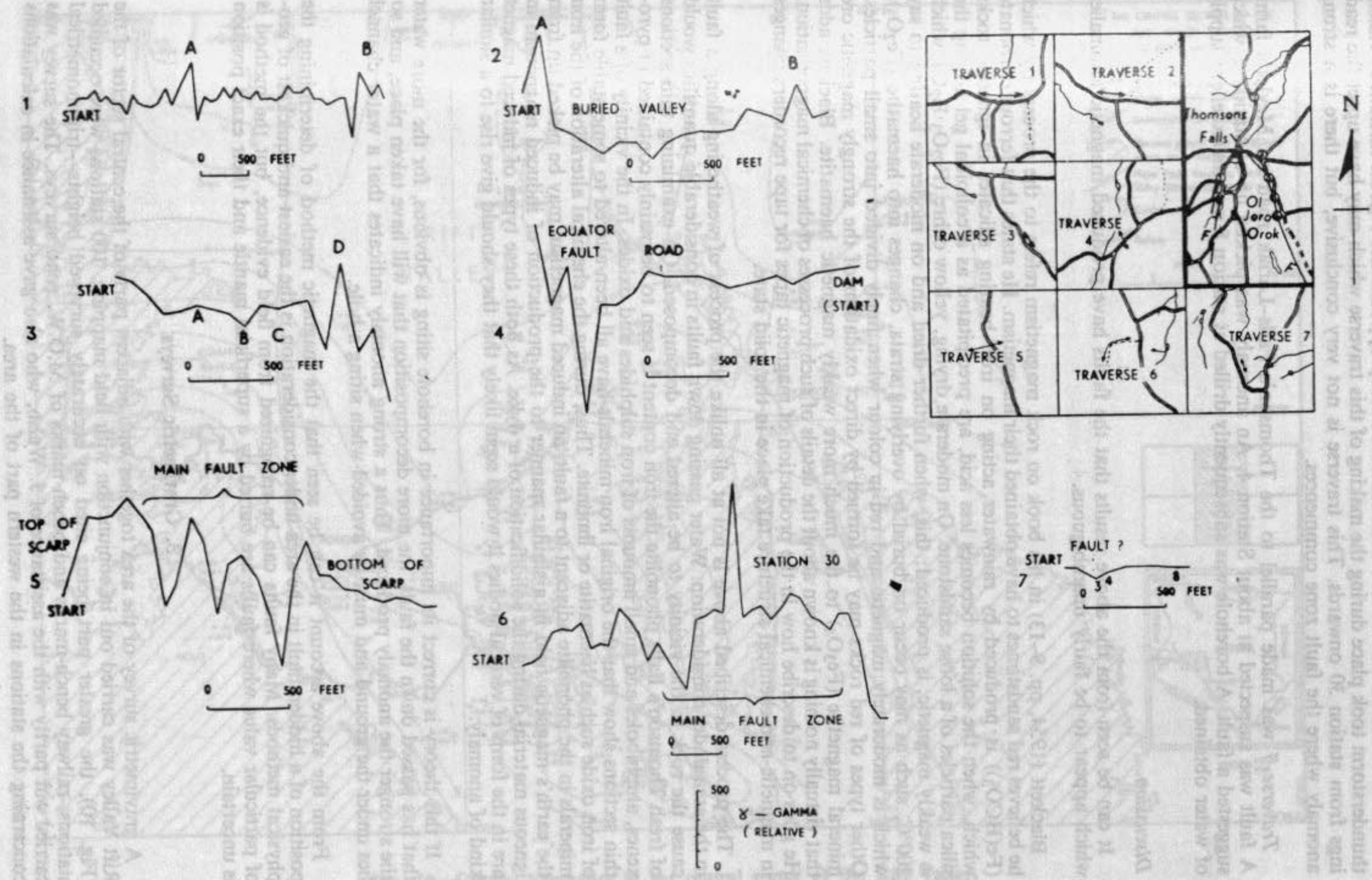


Fig. 9—Recordings obtained in magnetometer traverses across fault zones.

Traverse 6 was also made down the Aberdare scarp opposite the Ngobit turnoff. A violent thunderstorm took place during the making of this traverse which may have upset the readings from station 30 onwards. This traverse is not very conclusive, but there is a strong anomaly where the fault zone commences.

Traverse 7 was made parallel to the Thomson's Falls–Lariak road on Meyler's farm. A fault was suspected at about Station 4. An anomaly was picked up at station 3 which suggested a fault. A borehole was subsequently drilled at station 8 and an excellent supply of water obtained.

Discussion

It can be seen from the above results that the faults have produced magnetic anomalies which appear to be fairly unambiguous.

Blackett (1954, pp. 9–13) in his book on rock magnetism refers to the process by which he believes red sandstones to have obtained their magnetism. He states that ferrous carbonate ($Fe(HCO_3)$) is produced by rainwater acting on iron bearing silicates in igneous rocks which, when the solution becomes less acid, are precipitated as a colloidal gel among the silica particles of a loose sandstone. On moderate drying, yellow ochre ($Fe_2O_3 \cdot H_2O$), which is weakly magnetic, is produced: this, when further dried and on moderate heating to say 200°C, such as may occur on burial by overlying strata, changes into haematite (Fe_2O_3), which is moderately magnetic and red in colour when finely divided into small particles. Other types of red rocks may be formed by direct oxidation of the strongly magnetic ore mineral magnetite (Fe_3O_4) to the much more weakly magnetic haematite. Blackett adds that virtually nothing is known about the details of such processes of chemical magnetisation. He goes on to describe how in the production of magnetic tapes for tape recorders changes in magnetic and chemical structure take place in the solid state.

The process described above is not at all unlike the process of weathering along a fault in the area under consideration. Water passing down faults in considerable quantities would cause the rock in the vicinity to be altered and decomposed. On examining thin sections of fresh Thomson's Falls phonolite the iron content is seen to be mainly contained in pyroxenes, amphiboles and small amounts of iron sulphides and oxides. In the vicinity of a fault thin sections show that the original iron minerals have all been altered to some stable form of iron oxide such as haematite or limonite. Thus, during the chemical alteration of the iron minerals in the phonolite adjacent to a fault, an induced magnetism may be picked up from the earth's magnetic field in a similar manner to the production of induced magnetism in igneous material during the solidification of a dyke. As both these types of induced magnet are in the form of vertical bodies it would seem likely that they should give rise to a similar kind of anomaly.

If this theory is correct its importance in borehole siting is obvious, for the more water that has passed down the fault, the more decomposition that will have taken place, and so the stronger the anomaly produced. Thus a strong anomaly indicates that a water channel lies under the ground and must be avoided when siting a hole.

From the above account it can be seen that the magnetic method of determining the position of a hidden fault in the area under consideration is the easiest and quickest of geophysical methods. Many faults can be recognized from field evidence, but the method is of particular value where faults are buried by a superficial mantle and their exact position is uncertain.

3. Gravimetric Surveys

A gravimetric survey of the area together with adjacent parts of the central sector of the Rift Valley was carried out in conjunction with field mapping. 100 stations were occupied (Fig. 10), the greater part being sited on accurately surveyed heights—trigonometrical stations, railway bench-marks and bench marks of M.O.W. road surveys. The survey was carried out partly with the assistance of J. Walsh, who also gave assistance in calculations concerning the stations in the western part of the area.

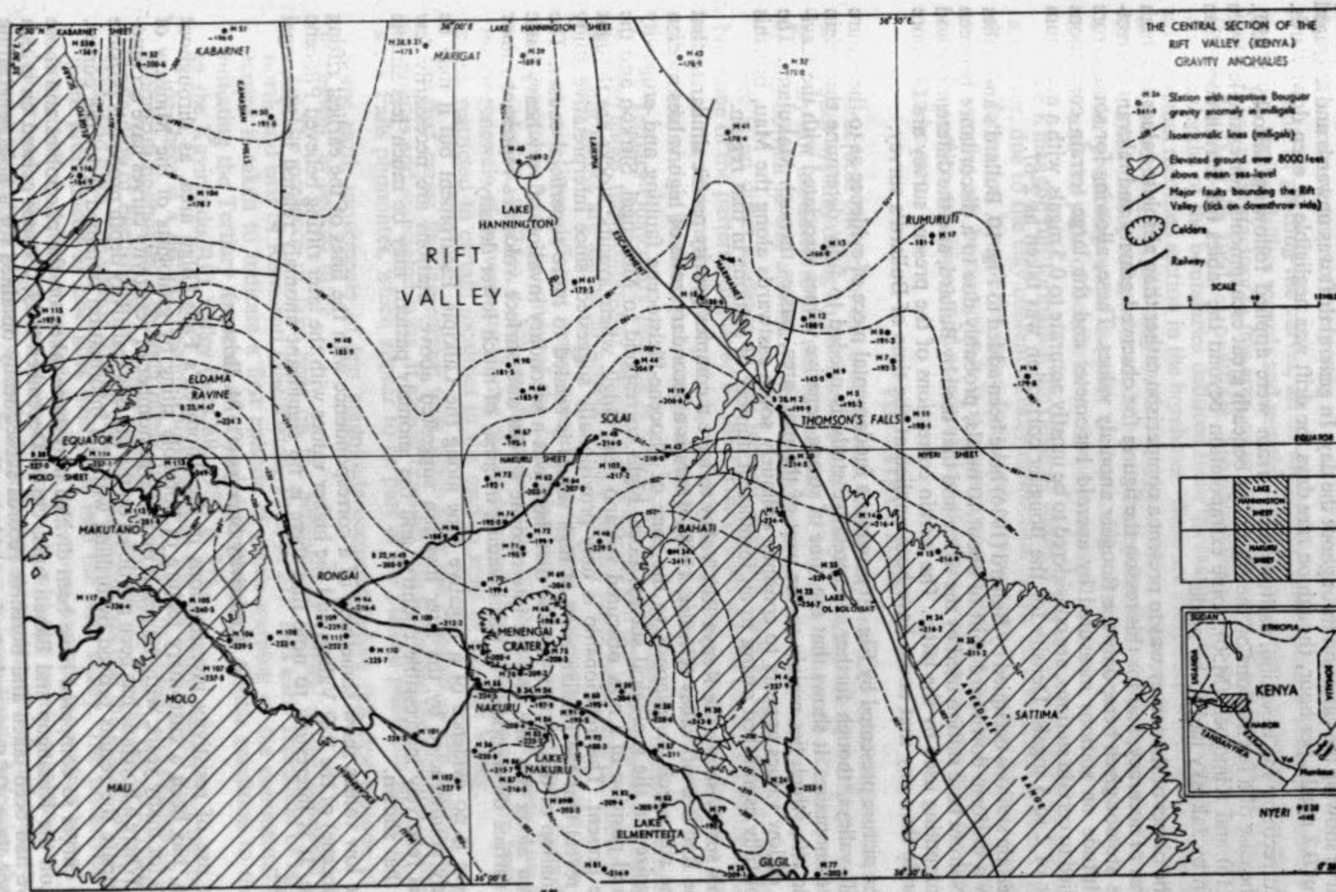


Fig. 10—Gravity anomalies in the central sector of the Rift Valley.

The instrument used was Worden gravimeter No. 104, the portability and robust packaging of which made it ideal in the rugged country covered. Drift corrections were applied by a process of reoccupying stations after intervals of a few hours and thereby calculating a curve showing the variation throughout the day. In general drift was upwards and averaged about 0.2 mgals. per hour, though on rare days the drift was negligible or even downwards.

Corrections for elevation, latitude and terrain were applied following Jakosky (1950). In the case of a few stations on the edge of or beneath great escarpments, for example Nyeru (M116) and Kimojoch (M50), some extrapolation beyond the tables for terrain correction given by Jakosky had to be made.

The object of the survey was to present a comparison rather than absolute values to a high degree of accuracy, and for this reason the figures for observed gravity and relevant corrections are not given here, only the Bouguer anomaly values. These, allowing for some errors in altitude on stations measured by aneroid barometer and the large terrain corrections applied to certain stations, are considered to be mostly accurate to 0.5 mgals, with a maximum error of 2 to 3 mgals. Density for the Bouguer correction was taken as 2·67.

Certain stations occupied by Bullard (1936) have been added to Fig. 10. Bullard's anomalies show a uniform downward shift of about 10 mgals, probably due to a discordance between the Nairobi base station used by the writer and that used by Bullard, and the different method of computing used by the latter. The terrain corrections of the present survey are far more accurate than any that could have been applied at the time of Bullard's survey.

The picture presented by Fig. 10 provides a fundamental piece of evidence as to the nature of rift valleys, though further interpretative study is needed to fully determine the origin of the anomalies. It shows that the zone of strong negative values associated with the Kavirondo rift, which lies mainly to the west of the map area, passes through Makutano. The area of low values appears to continue obliquely south-eastwards along the Mau, but this is not fully established owing to an insufficient number of stations in that region.

This survey shows the Kenya Rift Valley to have a complex gravity profile similar to that of the Red Sea rift valley (Girdler, 1958). There is a secondary zone of high values median to the rift which corresponds to the zone of Pliocene-Pleistocene faulting and eruptivity recognized in the geological survey. Local highs correspond to Menengai, Sirrkon and the inferred position of a now obscured volcano near Gilgil, where syenitic stocks are thought to be present. This relationship is only provisionally suggested, since interpretative study may reveal that the median zone of high values is related to more superficial causes. The explanation of this pattern may be that there was a secondary invasion of very heavy basic magma along this line and the intermediate stocks and surface volcanics represent minor near-surface differentiates of this invading magma, of much lower density.

There is no evidence of a negative zone along the Laikipia Escarpment but it may be entirely counteracted by the later invasion suggested above. Stations are necessarily few in this relatively inaccessible country, and the anomaly pattern may be much less simple than that shown.

The low values show something of a correspondence with the lines of the earliest rifting (? Miocene) of the Rift Valley, and the higher values with the later rifting believed Pliocene in age. It is interesting to note that there is no significant anomaly related to Menengai caldera.

4. Resistivity Surveys (C. M. Bristow)

The use of resistivity investigations in the Thomson's Falls-Gilgil area, as throughout Kenya, has been a customary feature of borehole siting by geologists of the Ministry of Works for many years, with the result that a large number of resistivity curves have accumulated. Where a borehole has been put down on the site of a resistivity depth probe it is possible to compare the results proved by drilling with the information obtained from the curves.

The curves so compared have been divided into those taken on the phonolites and those taken on the Kinangop and Bahati tuffs. Up to December 1959, 29 sites existed on which a curve had been taken and borehole records subsequently obtained for a hole penetrating the phonolites. Of these only twelve yielded sufficiently regular curves to be interpreted by the Mooney and Wetzel (1956) master resistivity curves. In the case of the Kinangop and

Bahati tuffs, 30 curves existed for sites on which boreholes had been drilled, and of these only five yielded sufficiently regular curves for interpretation. (The Kinangop Tuffs have a very high clay content with contained capillary water, and the low resistivity values resulting from this are not easy to interpret).

The result of plotting the curves, all of which were taken using a Wenner electrode configuration, against drillers records and samples taken during drilling, indicated that resistivity methods are unsatisfactory in this area, as in the western part of the area lower down in the Rift Valley (McCall, 1957 (*c*), p. 40–41). The phonolites yielded a very wide range of values, and the depths of the boundaries deduced from the master curves do not show any relation to the actual recorded section in the boreholes. There are exceptions which show some degree of correspondence, but this may be due to chance. It is apparent that resistivity curves in this formation mainly reflect the conditions in the top few feet of dry strata, which is of little interest for predicting water supplies at depth. No correspondence between curve values or shape and the yield of boreholes could be recognized.

In the Kinangop tuff formation the range of values is not so wide, and the average values are lower, due to the clay content already mentioned. Again no correlation between the calculated formation boundaries (on a four layer scheme) with the actual boundaries shown by the samples can be recognized. It is again apparent that the curves tend to reflect only the near-surface conditions, and no correlation of values or shape of curve with the borehole yield can be seen.

VII.—STRUCTURE

The structural pattern of the area shows a complexity probably quite unparalleled in the Rift Valley system, owing to the number and variety of orientation of the faults—a feature probably not unrelated to the nearby junction of two Rift Valleys (the Gregory and Kavirondo) normal to one another. The principal structural elements are shown in Fig. 11.

There is no direct evidence of any tectonic episodes prior to the Tertiary rift-faulting, but some of the patterns displayed by the Tertiary faults may be controlled by the structural trends in the Basement System which, where it emerges from under the Tertiary cover to the north, shows predominant north-north-westerly and north-easterly trends.

The Tertiary-Quaternary faulting is entirely of one type, normal faulting characterized by steep hades, most commonly near-vertical (Plate III) but occasionally as low as 60 degrees. The fault planes are almost invariably slightly curved, many being strongly arcuate.

There are three different major episodes of faulting represented within the area. These are detectable from the study of the field relations, in particular faced or faceted fault scarps (McCall, 1957 (*c*), p. 12), and from the study of contrasting land forms. Two further minor renewals of movements, during the Middle and Upper Pleistocene, have been recognized, restricted to certain localities in the median zone of the Rift Valley.

The first major faulting episode took place after the eruption of the Rumuruti plateau phonolites and associated lavas. It almost certainly also succeeded the eruption of the Thomson's Falls phonolites, which appear to be part of the plateau phonolite succession.

Some earth movements of less magnitude occurred before this first episode of major movement, evidenced in:—

(*a*) The presence of lake beds on the peneplained surface of the Basement System north and east of Rumuruti (Shackleton, 1946, p. 27). This early formation of lacustrine basins is taken to indicate a first episode of gentle warping of the continental surface initiating the Tertiary sequence of crustal deformations, a similar condition to that seen in the Kavirondo Rift Valley (McCall, 1958, p. 81).

(*b*) There is a distinct unconformity between the Samburu basalts and the overlying Rumuruti phonolites. The latter rarely dip at angles of more than five degrees to the east, while dips of twenty-five or thirty degrees are commonly seen in the underlying pile of lavas and tuffs. The section from Kaon westwards suggests that this unconformity becomes more pronounced as one goes westwards into the Rift Valley. The underlying basalts are arched up with increasing intensity as one moves towards the median line of the rift, whilst under Kaon they are nearly conformable with the overlying phonolite. The dip is too high to be a primary volcanic dip and the best explanation would seem to be that there was upwarping along a median zone during or immediately following the basalt eruptions.

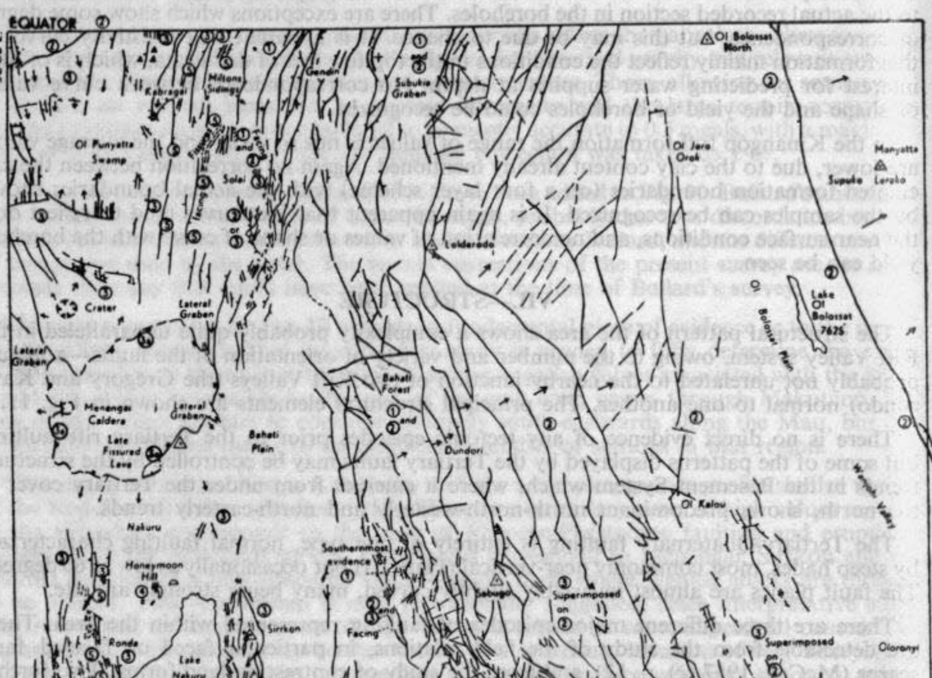
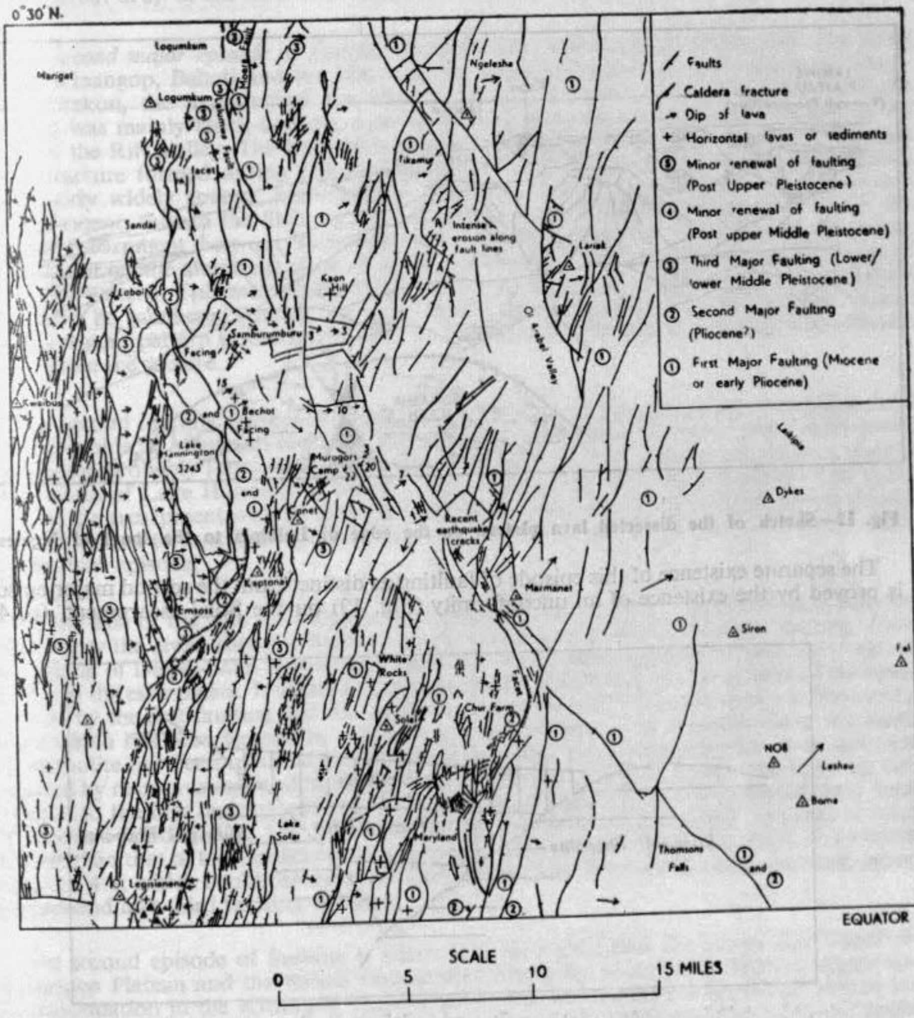


Fig. 11—Structure of the Nakuru-Thomson's Falls-Lake Hannington area.


0°30'N.
36°00'E.
36°30'E.
EQUATOR
Faults
Caldera fracture
Dip of lava
Horizontal lavas or sediments
Minor renewal of faulting (Post Upper Pleistocene)
Minor renewal of faulting (Post upper Middle Pleistocene)
Third Major Faulting (Lower/lower Middle Pleistocene)
Second Major Faulting (Pliocene?)
First Major Faulting (Miocene or early Pliocene)
Logumkum
Marigat
Sandai
Kwaibus
Lake Hannington 3243'
Bechot
Facing
Samburumburu
Kaon Hill
Ngelesha
Lariak
Ol Arabel Valley
Intense erosion along fault lines
Murogors Camp
Recent earthquake cracks
Kapton
Emsoss
White Rocks
Solai
Chui Farm
Lake Solai
Maryland
Marmanet
Siron
Dykes
Laikipia
Fal
NOB
Lashau
Boma
Thomsons Falls
SCALE
0
5
10
15 MILES

The patterns produced in the first major faulting episode are similar to those of the later episodes, but the faults are rather less numerous or closely spaced than those of the third episode, and the general effect is to produce a series of large eastward-tilted fault blocks, dropping the land surface by a succession of steps to the floor of the Rift Valley (Fig. 12). Some complicated, though rather widely spaced, grid patterns were however effected by this faulting in the Ol Arabel Forest and around Solai trigonometrical beacon. The degree of dissection shown by the scarps of this first faulting is striking (Plate VII). Deep valleys channel the fault scarps, in spite of the absence of any drainage from behind the scarps, and some valleys have been entrenched to depths of over a thousand feet along minor fracture lines formed by faults of negligible throw.

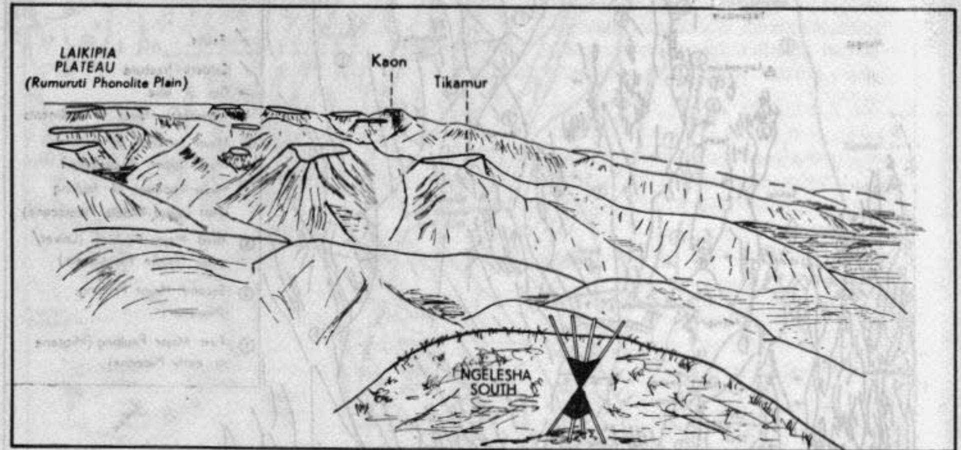


Fig. 12—Sketch of the dissected lava plateau on the edge of Laikipia to the south of Ngelesha.

The separate existence of this episode of faulting as distinct from the second major episode is proved by the existence of an unconformity (Fig. 13) on the Solai escarpment, (p. 45).

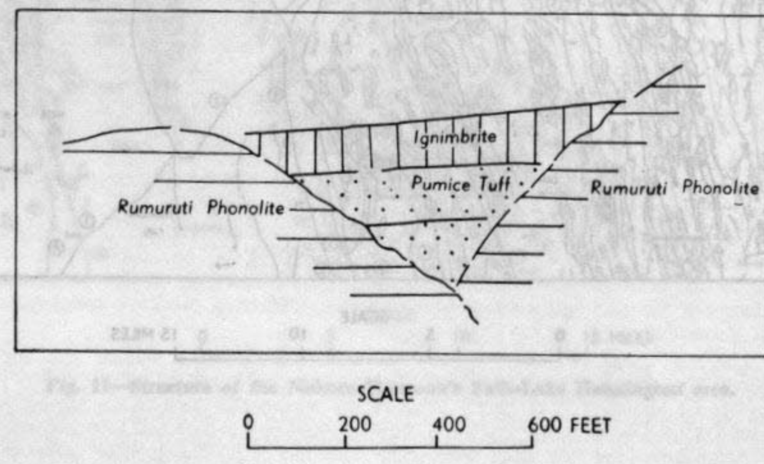


Fig. 13—Sketch of the unconformity of the Bahati tuffs (Pliocene?) on the Rumuruti phonolites (Miocene?) to the south of Tindaress. The tuffs fill a deep cross valley cut in the older phonolites and running down the face of the earlier-formed Solai scarp.

The magnitude of the apparent downward displacement of the Rift Valley floor during this first episode was probably over four thousand feet in the Lake Hannington sector, but appears to diminish southwards. This earliest faulting is completely obscured by later tuffs in the Bahati Forest. The fact that it is not recognized in the Nakuru sector (with the possible exception of the southern part of the Sattima Escarpment where the three thousand feet feature shows considerable dissection (Shackleton, 1945, p. 21)) suggests that the displacements of this first major episode may have been negligible there. It is probable that the Nakuru sector, adjacent to the junction with the Kavirondo Rift Valley, was in the nature of a high standing area unaffected or little affected by the first movements which caused the apparent drop of the floor elsewhere.

The second major episode of faulting occurred after the eruption of the tuffs and lavas of the Kinangop, Bahati and the Mau and the associated major central volcanoes (Menengai, Sirrkon, the hypothetical Kariandusi volcano, Kilombe, etc.). The pattern of the faulting was mainly block-faulting, a series of tilted steps dropping the land surface to the floor of the Rift Valley. The Lake Hannington Escarpment is, however, formed by a single great fracture formed during this second episode. The faults formed during this episode were fairly widely spaced, and complex grid structures do not seem to have developed to any extent, though the flight of steps bounded by north-westerly trending faults in the Bahati Escarpment between Menengai and Lolderodo shows a complication of minor back-faults on the sloping surface of some of the steps, the first stage in the development of a grid pattern. This magnificent flight of thirteen successive steps is a structural feature that may be numbered among the most ideally developed structures in the Rift Valley; such a regular pattern is seldom reached, as horst and graben and back-facing faults usually complicate the picture.

The second faulting episode formed the greater part of the escarpment extending from the north side of Menengai to Loboi, the northernmost section between Loboi and Logumkum being probably formed entirely in the third episode. This escarpment shows a distinct facet south of Lake Hannington below a line of cliffs with well marked screes. The upper part of the escarpment with its screes is believed to have been formed in the second episode of faulting and to have been eroded back from the fault line before the fault moved again in the third episode.

To the east of the lake the Laikipia Escarpment shows an abrupt facet two thousand feet high below the great dissected flight of tilted fault blocks formed by the first faulting. There is a facing of Dispei-Lake Hannington phonolite which extends to only a mile or so east of the lip of the escarpment. It appears that there was an older scarp, the lowest step of the series, formed by the first faulting and the dissected face of the old scarp still shows in the escarpment which has been formed by renewed later movements; it is revealed where the facing of phonolite has been removed by subsequent erosion. This facing structure is in fact complicated by re-excavation, and by the fact that the floor of the Rift Valley was filled up subsequent to the first faulting and the obliterated scarp replaced by a later feature as a result of renewed faulting (Fig. 14). It is notable that the width of this facing structure is much greater than that of the Pleistocene lava facings of Mbaruk and Gilgil. The ratio of the widths is about 4:1, which could represent the ratio of the time intervals between first and second and second and third faulting episodes.

The second episode of faulting is believed to have produced the scarps that bound the Kinangop Plateau and the Bahati Escarpment. The latter escarpment, more complex than its continuation in the Kinangop Escarpment to the south, which is formed of one or two simple steps, runs north-west from Gilgil in a series of steps complicated by horst and graben structure and well developed screes. To the north it passes into the already mentioned flight of thirteen steps below Lolderodo. Near Gilgil disentanglement of this second episode from the complex pattern produced in the third episode is difficult, but it is clear that only a few, if any, of the older faults follow the north-south trend preferred by the later faults. The facing of basalt at Mbaruk (McCall, 1957 (*c*), p. 10–12) clearly places this second episode subsequent to the eruption of the Bahati tuffs, but separated by a considerable erosional interval from the third major episode of faulting which formed the limited facet feature at the foot of the escarpment.

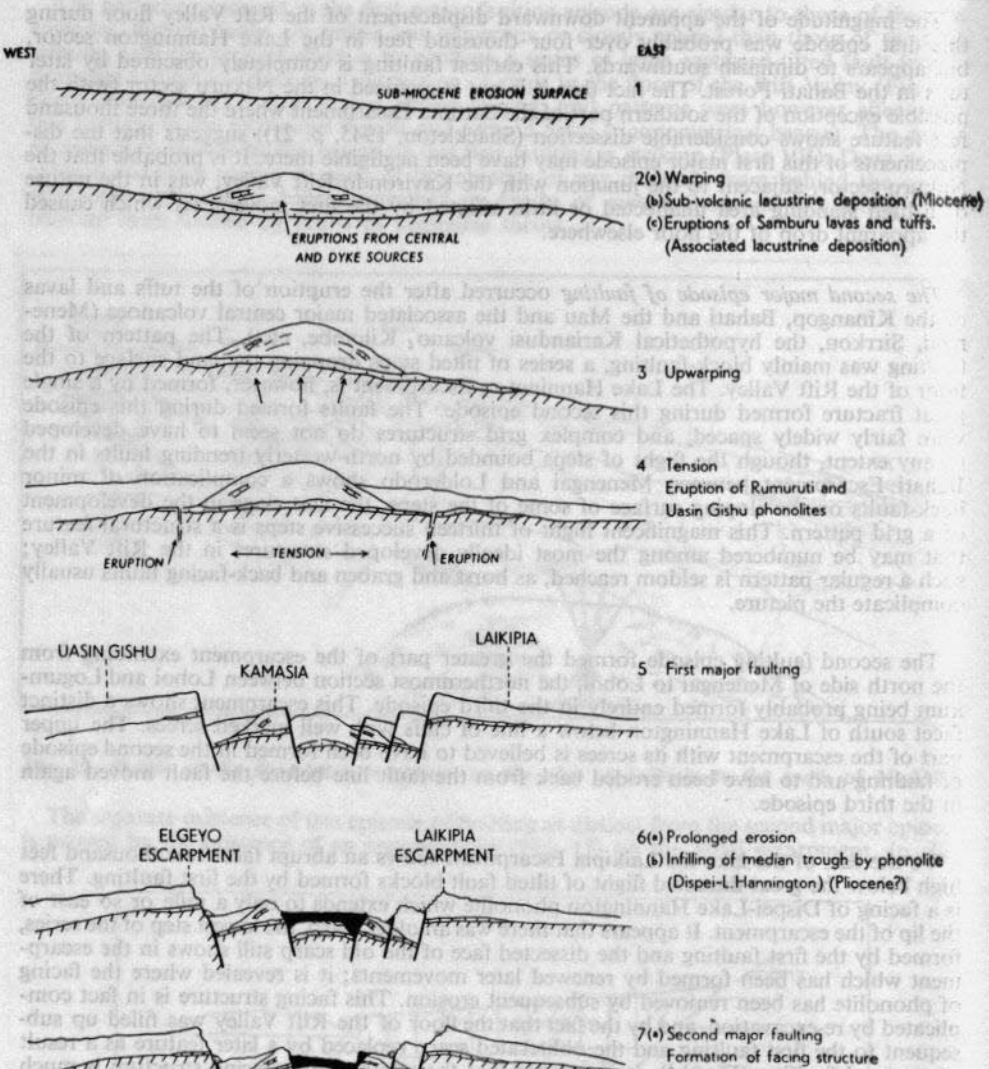


Fig. 14—Diagrammatic representation of the successive stages in the formation of the Rift Valley in the Lake Hannington sector.

The Sattima fault was apparently formed during this second period. At its northern end it displaces the Kinangop tuffs and so cannot be of the first episode; secondly the escarpment shows a rather gentler profile than the fault scarps of the third faulting episode, and in contrast to them is marked by screes along its foot. It is, however, possible that some earlier faulting is represented by the dissected 3,000 foot scarp above the Wanjohi valley.

In the Mau there appears to be a strong tilt of the tuff formation inwards towards the median line of the Rift Valley. The faulting is rather obscure and owing to the soft nature of the yellow tuffs forming the surface rocks the scarps are much dissected. The faulting which affects the tuffs is believed to belong to the second episode, except at the foot of the Mau in the scarps immediately west of Lake Nakuru, where later faulting of the third episode has occurred.

In the Subukia graben to the north of the Lolderodo flight of steps the effect of the second episode of faulting is apparently slight. Tuffs of the Bahati and Kinangop succession fill the graben and there can be no doubt that it was formed prior to their deposition. A minor facet at the foot of the Lolderodo Escarpment, displacing ignimbrites of the Bahati tuff series, probably represents the total renewal of throw on the older lines in this graben. At Chui farm there is a distinct facet at the foot of the Marmanet and Chui Escarpments which increases southwards, and this is believed to represent some renewal of faulting along the earlier formed fault lines during the second episode.

Immediately west of Lake Hannington the apparent downward displacement of the Rift Valley floor during this episode was over 2,000 feet. The actual floor formed after the first faulting episode has in fact been dropped more than 6,000 feet relative to its original level, but is now obscured by later lavas. In the Nakuru sector the flight of steps below Lolderodo lowers the surface of the Bahati tuffs about 3,500 feet vertically. Along the margin of the Kinangop the downward displacement effected by the faults of this second episode was in the order of 2,000 feet. The total displacement on the Mau was about 2,000 feet at Mau Summit and nearer 3,000 feet farther south, but much of this seems to have been effected by a monoclinal warp after the eruption of the Mau tuffs.

The third major faulting episode was of much less magnitude than the two previous episodes. The patterns produced in this series are characterized by very complex and closely spaced grids (Plate VIII). The fault scarps are abrupt cliff features with no appreciable development of screes, but some bouldery material has accrued at the base and enough degradation of the scarp has occurred to allow a sparse bush vegetation to cover all but the sheerest cliffs.

Near Gilgil and in the Elmenteita and the Nakuru lake basins this last major faulting is strongly developed. It shows a tendency to a northerly or north-north-easterly trend, but also follows many oblique trends. It caused rejuvenation along the Bahati, Sabugo and Mayfield fault lines, all of which trend north-north-westerly. This latest faulting dies out towards Kipipiri to the east, and Ol Kalou to the north of Gilgil. To the north of the Nakuru basin it fades away against Menengai and to the west of Lake Nakuru against the Mau scarp. There is a transverse belt of country extending from Njoro through Menengai and Lolderodo to Thomson's Falls which forms a cross-ridge feature, a form of culmination in the Rift Valley floor, in which faulting is completely absent except for the caldera fracture of Menengai, which produces exactly similar fault scarps, and may have been formed in this third episode.

The facing structure at Mbaruk has already been described, and a similar facing on the Gilgil escarpment is illustrated in Fig. 15 (*a*).

To the north of Menengai this third faulting reappears in northerly or north-north-easterly trending fractures and also a series of transverse horst-and-graben and tilted block structures which appear to be concentric fractures related to the Menengai centre.

The faults formed in the third episode run northwards across the earlier formed Emsoss Escarpment, part of the great escarpment bounding Lake Hannington on the south and east. Where they cross this escarpment their throw wanes, increasing again on the northern side. This feature of waning of the grids where they encounter or cross a major transverse fault line running oblique to their trend, is seen over and over again in the area, for example in the Marmanet and Bahati Escarpment. To the north of the Emsoss Escarpment the grids

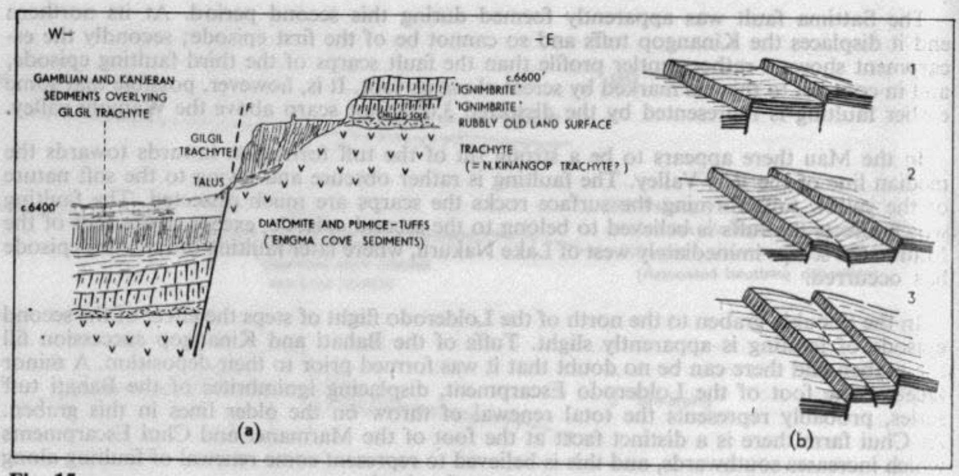


Fig. 15

(a) Section (diagrammatic) of a faced fault scarp involving two successive movements on the same fault plane. Gilgil escarpment.

(b) The progressive stages in the development of a horst and graben structure from an earlier simple block-faulting (ratchet) pattern.

extend in a continuous train to Marigat and Loboi, where they pass under recent sediments of the Baringo plain. The grid faults to the west of Lake Hannington fragmentate a formerly continuous flat-topped plateau of phonolite which at one time appears to have had an even slope at the east. This tilt was probably effected in the second major tectonic episode (Fig. 14). In contrast the Dispei plateau seems to have been level or to have been tilted slightly to the west before fragmentation.

The movements of this third tectonic episode caused an apparent lowering of the Rift Valley floor by only a few hundred feet in the Elmenteita basin and Lake Hannington sector, but in the Nakuru basin the displacement is greater, probably a thousand feet or more. This faulting caused renewed movements on older fault lines along the foot of the Bahati and Lake Hannington-Emsoss Escarpments, but the facet on the former is only some two hundred feet high at Mbaruk, a negligible amount compared with the great throw of the earlier faulting.

The type of structures seen in the grids formed in this third episode are of the same patterns as were produced in the earlier episodes except for the closer spacing of the fractures. In the area west of Lake Hannington are seen typical examples of all the structural styles, unaffected by erosion, and the drawings in Fig. 15 (*b*) taken from actual structures in this locality serve to illustrate the mode of progressive formation of horst and graben structure seen throughout the area.

The essential stages are:—

(*a*) Tilted blocks bounded by a series of curved fractures of steep hade, the blocks tilting away from the fractures. The whole forms a pattern exactly like a ratchet.

(*b*) On the reverse slopes of the tilted blocks backward-facing faults of minor displacement develop. As the intensity increases the surface of the tilted block, now broken into two sections, flattens out and a horst and graben feature is formed, the far wall of the graben being formed by the bounding fracture of the adjacent block.

The late minor faulting involving renewals on the older fault lines has been described previously (McCall, 1957 (*c*), p. 24–25 and Fig. 5). Renewed faulting affects the Kanjeran lake beds of Kariandusi and the tuff cones of Elmenteita and Honeymoon Hill, forming the peculiar median graben transecting the craters (op. cit., p. 22). The conclusion was reached that this median faulting, the throws of which are insignificant compared with the earlier movements, was genetically related to and closely followed the Middle Pleistocene eruptions.

Closely spaced late faults involving some renewals of movements along older lines can also be seen to the west of Lake Nakuru in the Larmudiac valley and the dry valley to the south of it, and on Ronda sisal estate. The faults displace the sediments and tuffs of the Upper Pleistocene (Gamblian) succession and effect an apparent lowering of the floor of the Rift Valley in the Nakuru basin by up to 100 feet. Into this newly formed depression the Gamblian and Makalian sediments of the Nderit and Makalia river sections were deposited.

This line of renewed movement runs north into Menengai along a line of fissures and subsidence craterlets (McCall, 1957 (*a*), p. 67). It reappears to the north of Menengai in Solai, where there are many small knife-sharp fault scarps in the soft Solai tuffs of probable Upper Pleistocene age (Plate V (*a*)). There are some very narrow facing structures composed of these tuffs facing older phonolites to the north-east of Milton's Sidings.

There are no signs of any such late renewal of movement of any consequence to the north of Solai until the vicinity of Marigat is reached. To the north of Marigat administrative post, just beyond the north-west corner of the area, the Kapthurin beds (believed to be of Upper Pleistocene age) and the underlying Dispei-Lake Hannington phonolites are cut by very young fault structures, new faults and renewals of the grid structures formed during the third great episode of faulting. It is this zone which Gregory (1921, p. 109) termed Clapham Junction from its likeness to a succession of railway platforms. Beneath many of the scarp faces, as much as 200 feet high, there is not a trace of fallen boulder material, the bare treeless rock cliff abutting on a smooth boulder-free valley floor.

Superficial structures. There are many large landslides on the Bahati Escarpment between Mbaruk and Kariandusi. The presence of these structures, some extending about a mile along the fault scarp, has been cited as evidence for a very young age for the greater part of the movement on the Bahati scarp (verbal communication B. N. Temperley). All the other evidence seems to be against such a deduction; the low facet at Mbaruk and Gilgil would seem to rule it out completely. A clue to the cause of these landslides is perhaps found in the fact that many of the blocks of flat lying tuffs and "ignimbrites" have been tilted strongly in this sector and slope appreciably toward Lake Elmenteita. Such an inward slope would tend to provide the inclined planes of slip necessary for the massive "ignimbrites" to slide over the clayey underlying pumice tuffs under the influence of gravity.

The general pattern of the faulting in relation to the Rift Valley as a whole

As a general rule it appears that each successive faulting episode has tended to plough a narrower furrow up the Rift Valley.

To the west of Marigat the Kamasian Hills are bounded by a well dissected scarp, and beyond that the western-most escarpment of the Rift Valley, Elgeyo, is again extremely dissected. The only volcanic rocks exposed west of the Kamasia scarp (Walsh) are the equivalent of the Samburu basalt and Rumuruti phonolite successions together with the Kabarnet trachyte which may be equivalent to the Sipili trachyte. The first faulting recognized in the Lake Hannington sector thus appears to extend right across the fifty mile width of the Rift Valley. The second faulting is seen in this sector only in the two thousand feet displacement on the east side of Lake Hannington (though Walsh traces some movement in the Kamasian Hills due to this second episode). This fault and the grid structures produced in the third major episode, together with the Pliocene lavas, occupy a narrower twenty-mile zone in the centre of the Rift Valley and in fact form a rift valley within the Rift Valley—the structure might conveniently be termed rift-in-rift structure. In addition there is an even narrower zone of faulting later than the Upper Pleistocene (?) deposition of the Kamasia type-area. This occupies a belt not more than a mile wide approximately median to the Rift Valley as a whole. To the north of Lake Baringo this narrow zone of very late movement becomes most marked, running to the east of Lopokino caldera, where a fantastic complexity of recent eruptives and very closely spaced fault scarps disrupting drainage channels occurs. It appears that as the zone of activity narrows and the fault pattern becomes more complicated and closely spaced, the angle of hade of the factures steepens to almost vertical.

The Nakuru sector is less easy to describe than the Hannington sector as there is a markedly triangular overall pattern developed instead of a simple trough. The triangle formed by the Legisianana-Emsoss-Lake Hannington Escarpment, the Bahati Escarpment and the Sattima Escarpment as the base, shows an apex pointing into the confluence of the Kavirondo and Gregory Rift Valleys at Loldiani volcano. The older faulting is not seen in this sector, and the second episode is represented right across the fifty mile width of the Rift Valley from Mau Summit to the Sattima Escarpment. In the south of the area the third episode is represented only in a lateral zone about twenty five miles wide extending from the west side of Lake Nakuru to the Turasha river. It is mainly represented in the basins.

The Rift Valley forms a depressed trench in the continental surface, but modern opinion is trending towards the concept of upward movement of the continental surface accompanied by lag in the rift zone. There are two well-marked planation cycles on the continental surface, the sub-Miocene and end-Tertiary (Upper-Pliocene ?) planations, and the fairly steep gradients they show from the coast inland and their cross-over (morvan) suggests two successive periods of upwarping of the crust. The gradients cannot be primarily the results of a Davisian planation cycle. Cooke (1957, p. 20) states that the lower Miocene lake beds were deposited on a continental surface of fairly low relief which had undergone little warping. The planations are matched by deep sedimentary deposits of Miocene and Pliocene age in the coastal belt, apparently of detritus derived from the rapidly upwarped continental surface. The primary movement in the rift zone could well be this upward warping, which occurred in two distinct stages. The rift faulting could be in the nature of a lag in relation to this upwarping, but there does not seem to be any exact correspondence between the degree of upwarping and the apparent downward displacement of the Rift Valley floor. Further, the extreme downward displacement of the Rift Valley floor in the Lake Hannington sector, estimated at over 6,000 feet, suggests that there was an actual downward movement of the floor. The most significant feature of the structural history of the central sector of the Rift Valley is the fact that the two greatest faulting episodes (which far outweigh any other movements that have occurred) apparently coincide with the termination of the two erosion cycles.

There is a very close geographical connexion between volcanism and faulting, and it is noticeable that the fault movements tend to follow volcanic eruptions, though this is not always the case. The intensity of development of individual tectonic episodes frequently shows a striking variation over only a few miles of the length of the Rift Valley. This contrasts with the evidence of fairly even upwarping which becomes apparent from the study of erosion surfaces to the east of the Rift Valley (verbal communication B. H. Baker).

VIII.—MINERAL DEPOSITS

1. General

(1) Diatomite

Diatomites, waterlain deposits formed from the siliceous skeletons or frustules of microscopic organisms called diatoms, are of common occurrence in the area. They occur in the Samburu Basalts (Miocene ?), the Kinangop Tuffs (Pliocene ?), the Enigma Cove and West Cliff sediments (Lower Pleistocene ?) and in all the later Quaternary lacustrine formations. The only really substantial occurrences containing diatomite of great purity and workable thickness are at Kariandusi and at Kockum and Brown's working on Soysambu Estate, both of Middle Pleistocene age.

Diatoms secrete silica from the water in which they live, and the warm lakes of the Rift Valley during the Tertiary and Quaternary epochs provided a perfect habitat for innumerable millions of these primitive unicellular plants, since there was an abundant supply of amorphous forms of silica in the ash showers which fell into the lakes of those times. This form of silica is most readily soluble in sodium carbonate solutions such as pertain in the Rift Valley saline lakes today, and no doubt pertained throughout Tertiary and Quaternary times, since the Rift Valley volcanics (other than the basalts which are weakly alkaline) are characteristically a sodic suite.

The pure diatomites such as are seen at Kariandusi are truly lacustrine in origin, being formed of innumerable skeletons of diatoms which floated on the lake surface during life, but sank into deeper levels of the lake after death, levels at which little washed-in detritus penetrated to form impure diatomaceous silts. Impure diatomites in the area probably formed in shallow water swamps and pondings in river courses, not necessarily in true lakes.

The commercial grades of diatomite lie in the following ranges (after drying):—

SiO_2	65–95 per cent
Fe_2O_3, Al_2O_3	8–0·2 ,, ,,
CaO, MgO	7–0·1 ,, ,,
K_2O, Na_2O	5–0·0 ,, ,,
H_2O and organic matter	15–4·0 ,, ,,

Physical characteristics are as important as chemical content in determining possible uses, and for high speed filtration purposes a large proportion of long unbroken spicules is required. A rather impure diatomite may fetch a high price it it has certain physical properties.

The mineral is used for:

Insulation.—Lagging of furnaces, kilns, etc.; insulation of refrigerating and air conditioning equipment. This property is based on its high porosity and chemical stability. It is converted into bricks of the natural material with or without a binder.

Building purposes.—Sound insulation; fireproof and vermin resisting coatings.

Absorbent and Stabilizer in the Chemical Industry.—Mainly in preparing Nitroglycerine as Dynamite: certain explosives made from liquid air and gases; sulphuric acid manufacture; ultramarine; sodium silicate manufacture.

Filtration.—Industrial filtration, in particular viscous liquids; sugar manufacture; brewing; water filters.

Filler.—Where lightness and fire-proof qualities are required. Light partitions in buildings and ships; plasters; rubber; asphalt; magnesite compositions; bakelite and casein products; Portland Cement.

Abrasive.—As a mild abrasive.

As is seen from the above list diatomite is one of the most important industrial earths. The great disadvantage is its light weight, on account of which transport charges become very high since carriers take shipments on a basis of bulk, not weight.

The Kariandusi deposit

This deposit was first reported by Hobley in 1909. Samples, together with others from Subukia (near White Rocks) were analysed as follows:—

	Kariandusi		*Subukia*	
	A.	B.	A.	B.
SiO_2 (total)	69·28	67·68	56·92	55·26
SiO_2 (soluble) ..	61·20	61·50	33·65	31·50
K_2O	1·49	1·12	1·47	0·84
Na_2O	2·43	1·79	2·00	2·48
CaO	0·77	1·43	0·46	1·15
MgO	0·86	0·73	0·32	0·61
Fe_2O_3	3·33	2·78	3·91	3·90
Al_2O_3	6·47	6·99	19·57	19·40
MnO	—	—	—	—
TiO_2	Tr	Tr	Tr	—
Loss on Ignition (H_2O)	15·10	17·40	16·10	16·49
Total	99·73	99·92	100·75	100·13

Anal. Imperial Institute, London.

Production started in a small way about 1940, to supply local soap and sugar industries and the Indian market. Pulfrey (1944) examined the deposits and gave the following succession:—

	ft.	in.
Soil and yellowish subsoil	2	3
Diatomite (Sample 1)	2	3
Siltstone (yellowish in upper part)	0	1
Dark grey tuff	0	3
Diatomite (Sample 2)	0	4
Banded grey tuffs with a thin yellowish band at the top	2	0
Diatomite, variable thickness somewhat flexed (Sample 3)	0	6
Rather coarse dark tuff, probably redeposited. Variable thickness	0	2
Banded grey tuffs, coarse and fine with irregular upper surface	2	1
Diatomite, somewhat ironstained on joints and at base (Sample 4)	1	5
Grey tuffs, upper inch diatomaceous	1	11
Diatomite, variable thickness	0	6
Banded grey tuffs and redeposited tuffs: some bands gravelly with pebbles up to ¾ inch diameter	3	6
Main diatomite, with irregular tuff intercalations in the upper foot of thickness. Base not seen. Sample 5— Top to 5 feet; „ 6— 5 „ 8½ „; „ 7— 8½ „ 16 „; „ 8— 16 „ 22½ „; Another twelve feet was exposed in a shaft at the east of the working	34	6
Average dip noted 10° SW. Total	51	9

The E.A. Diatomite Syndicate later proved a thickness of over 100 feet in the main band. Pulfrey noted that the best diatomite is in the main band. Difficulty of quarrying is increased by the thick overburden, and the presence of later sediments banked unconformably against the diatomite.

Samples collected by Pulfrey (listed above) were partially analysed as follows:—

	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	10* %
Loss on ignition	6·99	6·55	8·32	7·00	6·19	5·86	5·33	5·35	5·51
SiO_2	80·33	83·06	71·06	71·68	82·66	81·77	83·55	85·20	84·19
Fe_2O_3	—	—	—	—	—	—	—	2·80	3·04
TiO_2	—	—	—	—	—	—	—	·30	·20
Al_2O_3	—	—	—	—	—	—	—	4·63	4·67
CaO	—	—	—	—	—	—	—	·28	·36
MgO	—	—	—	—	—	—	—	·13	·28
Alkalies as Na_2O	—	—	—	—	—	—	—	1·45	1·74
								100·14	99·99

*Quartered sample, composite of 5+6+7+8 Anal: A. F. R. Hitchens.

In a further report Pulfrey (1944, second report) described the results of mineralogical and palaeontological examination of his eight samples.

Density.—He found the apparent block density to vary, with one exception, between 25 and 33 lbs. per cubic foot. This corresponded with the acceptable range for commercial diatomites viz. 25–37½ lb. cu. ft. No. 4 showed a much higher block density (49½ to 60). Apparent powder densities were also in close correspondence with the usually accepted commercial values.

Grading.—Most of the material passed through a 200 mesh sieve. In the upper part of the main band however, up to 9.6 per cent remained, being too coarse. This was the pumice material mentioned in the section.

Residual Material was determined as:—

Fine-grained:—alkali felspar; soda plagioclase; volcanic glass (some pumiceous); iron ore grains; augite; quartz; agate; small clots of diatoms; nepheline; felsite; spores or seeds; chlorite; vegetable matter; apatite grains.

Coarse-grained:—pumice; diatom clots; calcareous fragments (often tubular); tuff fragments; vegetable fibres; large felspars.

Micro-Palaeontology.—The diatoms recognized are given in Table 4 which also includes diatomaceous beds in nearby Gamblian deposits (9).

TABLE IV

Sample No.		Sponge spicules	*Melosira*	*Pinnularia* (large)	*Pinnularia* (small)	*Eunotia*	*Cocconeis*	"Large" Circular forms	Small Circular forms	Minute Circular forms	*Diploneis*	*Navicula*	long slender *Eunotia*	Diatom detritus
1.	Main Diatomite Band	few	predominant	few	—	occ.	occ.	occ.	—	—	—	—	—	abundant
2.		occ.	many	few	some	not uncommon	occ.	occ.	—	—	—	—	—	abundant
3.		occ.	uncommon	—	common	fairly common	—	—	occ.	—	fragments	occ.	—	abundant
4.		occ.	uncommon	—	occasional	few	occ.	—	f.c.	common		—	—	abundant
5.		rare	many	few	—	few	—	f.c.	—	occ.	—	—	few	abundant
6.		—	very common	few	—	—	—	f.c.	—	occ.	—	—	occ.	abundant
7.		—	very common	few	—	rare	—	—	uncommon	—	—	—	occ.	abundant
8.		—	very common	few	—	rare	—	—	occ.	—	—	—	f.c.	abundant but less than in 5, 6 and 7
9.	Gambian	—	some	few	occ.	some	—	—	some	—	—	—	—	abundant

occ. = occasional.
f.c. = fairly common.

Mineral composition.—The suggested mineral composition based on the analysis of sample 8 was given as:—

Soluble Silica	75·77 per cent
Volcanic Glass	13·08 „ „
Kaolin	8·89 „ „
Ilmenite	0·57 „ „
Haematite	1·30 „ „
Calcite	0·36 „ „
	99·97

The silica content of sample 8 calculated on an ignited basis is 89·9 per cent. This is a highly satisfactory figure since the general standard for a crude diatomite is 87 per cent on an ignited basis.

In 1946 E.A. Diatomite Syndicate took over the deposit and made plans for greatly enlarged operations. The present plant consists of a hammer mill, followed by several cyclones for eliminating pumice and obsidian sands.

Barnard (1950) published a brief description of the deposit, including a very good photograph of the workings and a microphotograph of the typical diatom flora. The reserves were then estimated at over 1,500,000 tons.

Drilling with a Banka drill was tried but found unsatisfactory, and after seven holes had been drilled an alternative method of pitting by well-sinking teams produced better results, depths as great as 186 feet being reached. Some prospecting by means of adits was also carried out. The results of prospecting are shown in Fig 16. (adapted from a map and sections drawn by G. C. Barnard in 1950).

The prospecting revealed that in the area covered, about one-sixth of the known north-south extent of these diatomitic beds, the ore was situated in six main blocks. Two of these (5, 6) are residual inliers in the Upper Pleistocene (Gamblian) riverine silts and are not continuous with the main body. These blocks include reserves of diatomite with little pumice waste, and are suitable for opencasting.

The bulk of the ore is in the area east of the river, where the ore is divided into two bands, the upper thin band being of diatomite of a hard type with some clay content, suitable for cold tiles and furnace brick.

The main band has a thickness of over 100 feet in the quarry. It is lacking in stratification, but shows rapid lateral variation in composition, colour, density and texture and its greatest thickness appears to follow a narrow north-south line from the quarry through Pits 6 and 13, and probably southwards to Pit 11. In the main band wastage (pumice, volcanic glass, and diatomite mixed with them) is estimated at 33%. Of the diatomite 15% is of super-grade and 85% normal grade. The effects of faulting are negligible throughout the area prospected.

Along the line of the north-south fence, which limits the area of operation to the east, boreholes proved some diatomite under a thick channel filling of later silts. No prospecting has been carried out to the south of the area shown on Fig. 16, but there is reason to believe some good ore with little overburden exists there.

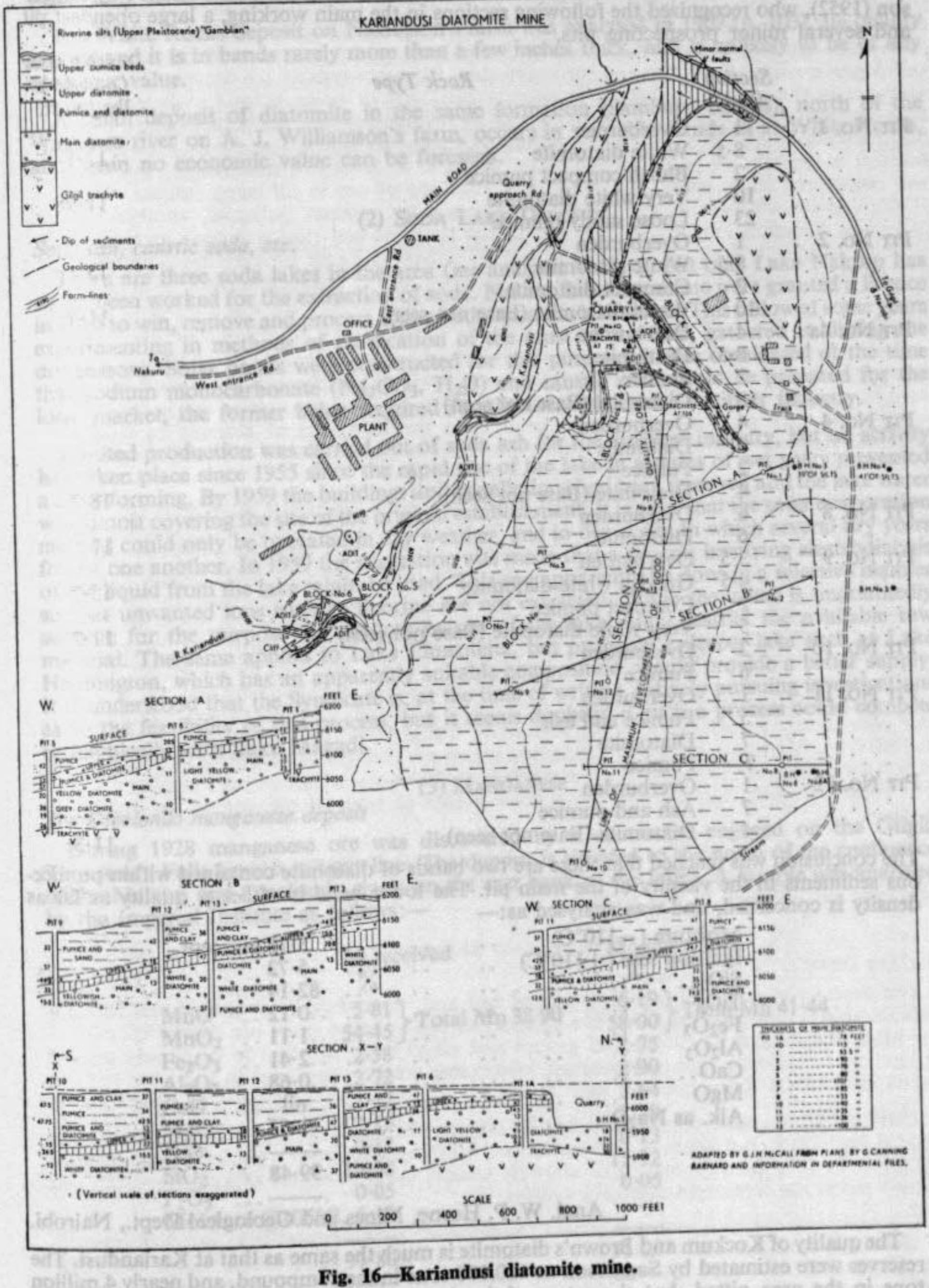


Fig. 16—Kariandusi diatomite mine.

Kockum and Brown's deposit (Soysambu Estate)

The only other deposit in the area of any significance is situated on a gentle grassy slope in open country east of the disused Elmenteita Station. The deposit was examined by Saggerson (1952), who recognized the following sections in the main working, a large opencast pit, and several minor prospecting pits.

	Section (feet)	*Rock Type*	*Density tests* (*powder*) lbs./cu.ft.
Pit No. 1	1	Overburden	
	8·5	White diatomite	12·1
	2	Bluish compact pumice	
	10	Very white diatomite	11·98
	23	Loose sandy pumice	
Pit No. 2	1	Overburden	
	8·5	White diatomite	15
	2	Compact diatomite	
	10	White diatomite (Base not seen)	11·7
Pit No. 4a	4	Overburden	
	8·5	Diatomite	
	2	Pumice	
	10	Diatomite (Base not seen)	
Pit No. 4	4	Overburden	
	8	Diatomite	
	2	Pumice	
	4	Diatomite (Base not seen)	18·3
Pit No. 8	6	Overburden	
	6	Diatomite	17
Pit No. 9	3·5	Overburden	
	4·5	Greyish white diatomite	15·7
	2	Compact pumice	
	5	Very white diatomite (Base not seen)	11·2
Pit No. 10	2	Overburden	
	6	Pumice	
Pit No. 11	1	Overburden	
	5	Pumice and ash	
	7	Diatomite	17·6
	?	Pumice	
Pit No. 12	1	Overburden	
	7	Ash and pumice	
	4	Diatomite (Base not seen)	11·3

The conclusion was reached that there are two bands of diatomite contained within pumiceous sediments in the vicinity of the main pit. The lower band is of better quality as far as density is concerned, and was analysed as:—

Moisture (−110°C)	5·78 per cent
Ignition loss (+110°C)	5·72
SiO_2	82·14
TiO_2	0·12
Fe_2O_3	1·11
Al_2O_3	2·41
CaO	0·68
MgO	nil
Alk. as Na_2O	1·52
	99·48

Anal. W. P. Horne, Mines and Geological Dept., Nairobi.

The quality of Kockum and Brown's diatomite is much the same as that at Kariandusi. The reserves were estimated by Saggerson as 120,000 tons in the compound, and nearly 4 million tons in the area pitted, but the extent of the deposit was not known, and the possibility of a thicker band situated as at Kariandusi at a slightly greater depth was never investigated.

Subukia diatomite deposits

Two deposits of probable Miocene age are known from Subukia, besides much yellowish white tuff, often mistakenly reported as diatomite.

The White Rocks deposit on Nicholson's farm was analysed in 1909 (p. 103). Its quality is poor and it is in bands rarely more than a few inches thick, and is unlikely to be of any economic value.

A small deposit of diatomite in the same formation (Samburu basalts), north of the Wasagess river on A. J. Williamson's farm, occurs in very thin bands as at White Rocks, and again no economic value can be foreseen.

(2) Soda Lake Deposits

Soda ash, caustic soda, etc.

There are three soda lakes in the area (*see* analyses Table 3) but only Lake Nakuru has so far been worked for the extraction of soda. Nakuru Lake Syndicate were granted a licence in 1952 to win, remove and process soda goods upon the lake shore. This followed some years experimenting in methods of purification of the crust of the lake, gathered in during the dry seasons. Solar ponds were constructed for this purpose. It was considered at the time that sodium monocarbonate (Na_2CO_3, H_2O) and caustic soda could be prepared for the local market, the former being required for the local phosphate-fertilizer industry.

Limited production was carried out of soda ash for the fertilizer industry, but no activity has taken place since 1955 since the rapid rise of the lake in a series of wet years prevented a crust forming. By 1959 the buildings and installations had been removed and the lake water was almost covering the site of the original establishment. It is clear that the solar evaporation method could only be operated in dry weather, and in dry cycles in which several dry years follow one another. In 1959 the suggestion was made that a process involving electrodialysis of the liquid from the lake might be used. This can apparently be done in a selective manner so that unwanted ions such as fluorine are not extracted. While the water is undoubtedly suitable for the purpose the shallow nature of the lake might restrict the available raw material. The same applies to Lake Elmenteita, but probably a deeper lake such as Lake Hannington, which has an apparently suitable composition, would provide a better supply. It is understood that the Syndicate is, at the time of writing, actively pursuing investigations as to the feasibility of this process, but it seems doubtful if such a process could compete economically with Lake Magadi.

(3) Manganese

The Oleolondo manganese deposit

During 1928 manganese ore was discovered by a contractor engaged on the Gilgil-Thomson's Falls branch railway line. The deposit is situated to the north of the confluence of the Melawa and Oleolondo rivers on the east bank of the latter. A sample was analysed by the Imperial Institute as follows:—

	As received %		Moisture free %	
MnO	5·81	Total Mn 38·90	6·19	Total Mn 41·44
MnO_2	54·45		58·00	
Fe_2O_3	2·58		2·75	
Al_2O_3	2·72		2·90	
CaO	3·42		3·64	
MgO	2·15		2·29	
NiO	0·12		0·13	
SiO_2	14·38		15·32	
P_2O_5	0·05		0·05	
Moisture @105°C.	6·12		—	
	91·80		91·27	

Ba, Co, Pb, Cu absent — Combined water not determined

The sample was identified as pyrolusite with some psilomelane and possibly some manganite. It was not found worth working this deposit due to the long rail-haul before shipment. In 1942 interest revived under wartime conditions and Dr. R. M. Shackleton (1942) reported on the deposit. He considered the deposit to be derived from replacement of a diatomite bed by irregular bodies of ore. The diatomite forms part of a series of lake beds which include tuffs, silts, gravels, marls and diatomite. These beds, which are part of the sub-aqueous tuff deposits within the Kinangop tuff succession, dip eastwards at 2-3 degrees. The manganese ore is distributed irregularly through a thickness of some three feet below a layer of diatomite. It forms about 20% of the rock by volume and it is easily picked and cleaned. Soil indications of ore extend for some 60 yards to the north and south, but the same horizon is exposed 70 yards to north-east where it is devoid of manganese. The deposit was considered to be small, not more than 100 tons of ore in all being present. Hitchen (1942) considered that the ore might also contain the mineral polianite, another variety of MnO_2. Beneficiation tests carried out at the time showed that screening and calcining at 300°C could produce ore containing over 75% MnO_2. Later prospecting supported the limited extent suggested by Shackleton, and only 44 tons of manganese were won from the mine before it was considered exhausted. This was used locally for war purposes, and the last stocks left in the mine were used by Kenya Glassworks Ltd. some ten years later.

Leakey (in the course of correspondence) referred to the sediments as of Kamasian age, a dating originally given by Solomon (Leakey, 1931), and Pulfrey (1956) agreed that they were presumably Pleistocene. It is clear however from the mapping carried out in the present survey that they are much older sediments than the Kanjeran of Kariandusi (formerly known as Kamasian) and in all probability the Pliocene age attributed to the Kinangop tuffs by Shackleton (1945, p. 6) is correct for these deposits.

Interest in the deposit revived from a purely academic viewpoint in 1959, when a very high molybdenum percentage (2300 p.p.m. in pyrolusite, 1700 p.p.m. in psilomelane) was discovered in manganese ore. The much degraded working was revisited by the writer, who noted that the sediments nearby seem to be rather less diatomitic than suggested in the earlier report, replacement of stratified tuffs seeming at least equally important in the ore formation, relic fragments of unreplaced tuff being visible in some of the ore. The mineralization is seen to accompany intense silicification of the sediments with the formation of massive banded chert, often stained with limonitic iron ore. The high molybdenum content, typical of ores related to alkaline intrusions or carbonatites, is explained (McCall, 1960 (*a*)) by the theory that the manganese is concentrated by secondary processes from "ignimbrites" and tuffs closely associated with the sediments. These pyroclastic rocks are known to be derived from Menengai and other volcanoes, which are thought to be the surface expression of syenitic complexes. Support for this method of derivation of the ore is found in the fact that these tuffs and "ignimbrites" often show a film or crust of manganese on weathered surfaces.

The likelihood of any large body of ore being found in this area is remote, and if such a deposit was discovered the economic potential would be dubious, in view of transport problems and distance to any market.

(4) Building Materials

Building Stone

The excavation and dressing of blocks of tuff and "ignimbrite" or welded tuff forms a considerable industry in the area. The quarries of the building stone are mostly centred in the Mau, Bahati and Kinangop tuff groups and allied tuffs, believed to be closely related in age, on the eastern side of Menengai, with some smaller workings in the later tuffs in the vicinity of Ol Kalou and Ol Joro Orok.

There are ample reserves of material as far north as Milton's Sidings, Subukia Post Office and Ol Joro Orok, but north of the line formed by these three points (which by coincidence corresponds with the equator) there are only sparse, small outcrops of suitable rock, and farther north the formation disappears altogether.

The best material for dressing is coarse "ignimbrite" with characteristic flattened lenticles of glass and obsidian. The welded tuffs of the type known as claystone, a much finer rock, also dress well. The yellowish tuffs, which are formed by the decomposition of "ignimbrites" and the more compact pumice tuff, are easy to quarry and cut but crumble after only a few years, and disintegrate rapidly if there is any vibrating machinery nearby.

Ballast

Hard rock for railway ballast and roadstone has a patchy distribution in the area. In the large area covered by tuffs in Bahati Forest, Ol Kalou and Oleolondo there is no very suitable rock available, a fact which caused a problem during the reconstruction of the main road from Gilgil to Thomson's Falls. Elsewhere the phonolites and trachytes provide ample material highly suitable for this purpose. The principal quarries are a mile west of Gilgil, on the east and south slopes of Menengai on Ronda Sisal estate, on the north-west corner of Lake Nakuru, and on a horst near the Larmudiac river in the extreme west of the area. In the north of the area there are many small quarries in the Rumuruti and Thomson's Falls phonolites.

Pumice

Pumice for use in building is quarried on the southern slope of Menengai. There are ample reserves to supply any demand that may arise, but the demand is likely to be only local since similar quarries near Naivasha can supply the Nairobi market from a much nearer point.

TABLE V

B/H No.	Owner	Depth (feet)	Water Struck (feet)	Rest Level (feet)	Tested Yield (g.p.h.)
	SOUTH BARINGO				
84	A.D.C. S. Baringo Ngendalel	203	190	140	2,100
94	A.D.C. S. Baringo Sertonji Plain?	88	nil	nil	nil
120	A.D.C. S. Baringo Ol Kokwe	100	65	44	1,520
138	A.D.C. S. Baringo Sertonji Plain	369	360	360	60 (at 52°C)
C 284	A.D.C. S. Baringo Sertonji Plain	215	nil	nil	nil
C 285	A.D.C. S. Baringo Kisinana	365	336	336	1,200
C 583	A.D.C. S. Baringo Sertonji Plain?	600	nil	nil	nil
C 2484	A.D.C. S. Baringo Replacing C 285	400	365	335	880
	SOLAI NORTH				
C 298	Lake Solai Sisal Estate	197	13–25	13	3,000
C 299	Lake Solai Sisal Estate	201	120–145	13	2,700
C 303	Lake Solai Sisal Estate	200	—	14	2,500
C 828	Kiora Estate	250	130–240	109	900
C 2271	Allison	350	180–320	50	5,000
C 2272	Allison	189	110–189	55	2,400
C 2940	Nicholson Bros.	370	205–240, 282, 330–360	188	2,000
	SUBUKIA				
C 1747	Maryland Estate	460	86–435	98	1,200
C 2252	A. D. P. Thomas	500	300–450	70	170
C 2253	A. D. P. Thomas	440	300–400	25	170
C 2303	Mackenzie Estate	460	250–430	65	2,000
C 2311	G. Simpson	321	260–300	180	1,500
C 2360	T. L. Nicholson	400	200–250, 350	150	2,800
C 2605	T. L. Nicholson	375	220	196	3,000
C 2939	Vale Estate	623	180, 225–290, 583–623	330	2,700
	OL BOLOSSAT PLAIN				
C 43	E. H. G. Augerard	296	244	90	2,400
C 45	Wainwright	292	282	81	3,000
C 383	Wainwright	390	247, 274, 341	72	650
C 743	W. Delap	145	100	40	1,840
C 750	W. van de Merwe	230	225	80	333
C 751	S. J. Odendaal	140	136	10	1,000
C 753	H. Rooken Smith	414	412	396	840
C 754	Mrs. D. Griffin	412	408	400	630
C 755	H. Barradell	546	540	150	4,170
C 871	B. J. Mouton	269	240	210	250
C 873	J. S. Blanche	105	60	40	375
C 959	Mrs. I. Norman	501	330, 480	310	208
C 1031	N. B. van Deventer	417	—	—	nil
C 1155	Rhiwerja Ltd.	477	113, 455	252	1,000
C 1193	A. T. Holmberg	251	230	161	300

TABLE V—(*Contd.*)

B/H No.	Owner	Depth (feet)	Water Struck (feet)	Rest Level (feet)	Tested Yield (g.p.h.)
	OL BOLOSSAT PLAIN—(*Contd.*)				
C 1517	P. Klynsmith ..	612	—	—	nil
C 1891	J. S. Blanche	210	53, 189–210	49	1,400
C 1902	H. N. J. van Rensberg	206	175	27	1,810
C 1943	W. Baumann ..	150	98	39	500
C 2073	J. L. Schofield ..	600	590	580	750
C 2100	J. M. Schutte ..	547	370	354	730
C 2151	F. G. MacConnell ..	600	—	—	nil
C 2250	J. van Landsberg	444	93, 246, 436	288	1,200
C 2268	H. J. de Bruin	560	500, 540	324	1,200
C 2290	H. P. de Bruin	490	340	250	540
C 2295	H. P. de Bruin	373	230, 350	234	900
C 2307	H. P. de Bruin	360	—	—	nil
C 2331	H. P. de Bruin	505	320, 480	320	300
C 2344	C. J. van Straaten ..	416	380	252	710
C 2389	I. M. Malan ..	407	—	—	—
C 2390	I. M. Malan ..	432	73, 380	310	1,610
C 2800	Tremaine ..	246	20, 170, 195	10	3,000
C 2817	M. R. N. MacPherson	350	60, 316	85	800
C 2825	A. C. Greling..	250	70	19	?
C 2872	Mrs. D. J. Ewen	239	60, 180	68	50 ?
C 2948	Armitage ..	150	—	50	Good
C 2949	Armitage ..	160	—	—	Artesian
C 2950	Armitage ..	Shallow	—	—	Good
C 2951	D. A. D. Olivier	250	70, 220	6–70	8,000
C 2952	Younghusband	238	—	37	90
C 2953	J. H. Joubert ..	194	?	193	?
C 2954	Odendaal ..	270	50, 250	150	750
C 2955	Odendaal ..	?	?	20	Good
C 2956	Barradell ..	380	?	?	Good
C 2957	Mouton ..	76	25, 60	25	1,400
C 2958	van Landsberg	?	?	?	?
C 2959	van Landsberg	?	?	?	?
C 2960	van Blerk ..	428	100	?	250
C 2961	Roux-Nel ..	400	380, 400	125	?
C 2962	Absalom ..	150	?	100	Good
C 2963	Botha ..	247	80, 230	70	Good
C 2964	Roux-Nel ..	400	380–400	125	?
	THOMSON'S FALLS				
134	J. H. Joubert ..	66	38	30	10
136	J. H. Joubert ..	40	48	20	10
145	J. B. Philips ..	112	85	26	300
C 64	Seth Smith ..	348	?	222	83
C 65	Seth Smith ..	392	?	250	125
C 66	Crampton ..	156	?	120 ?	833
C 109	Dr. Meikeljohn	503	?	?	400
C 118	R. R. Herttens	435	?	248	25
C 226-D	Capt. Luxford	260	230	0	880
C 355	G. H. Elliot ..	410	78, 272	23	52
C 1031	N. B. van Deventer	417	?	?	nil
C 1299	F. P. Booth ..	450	180	100	240
C 1381	Dixon Estates	700	280	100	110
C 1400	A. T. Holmberg	240	220	114	670
C 1515	H. Retief ..	500	200	85	15
C 1899	J. C. Kean ..	442	210, 400	127	675
C 1953	K. Coates ..	255	208, 250	82	250
C 2218	E. V. Hart ..	700	112, 550, 670	60	400
C 2285	G. M. Trent ..	540	27, 240, 360, 500	175	1,200
C 2381	R. Meyler ..	523	268 467–505	78	1,200
C 2401	B. C. King ..	346	—	—	nil
C 2405	B. C. King ..	237	—	—	nil
C 2691	R. C. Long ..	250	230	Artesian	850
C 2708	F. P. Booth ..	270	244	161	200
C 2816	E. C. Gibson ..	60	60	18	1,000
C 2854	E. L. Williams	314	140, 260	130	1,880
C 2858	R. E. Meyler ..	350	54, 135 165, 343	40	2,000
C 2968	Bormann ..	150	?	70	?
C 2969	Wilcox ..	113	?	13	?

TABLE V—(*Contd.*)

B/H No.	Owner	Depth (feet)	Water Struck (feet)	Rest Level (feet)	Tested Yield (g.p.h.)
	RUMURUTI (WEST)—OL ARABEL				
C 37	Ndurumu Ltd.	484	218	151	600
C 913	G. de P. Colville	800	301, 520, 785	150	208
C 951	G. de P. Colville	550	508	?	29
C 1217	Kerr and Icely	363	350	323	1,500
C 1224	L. E. Smith	400	170	?	2
C 1895	G. de P. Colville	782	250	207	200
C 1977	L. A. McIntyre	540	415, 512	260	2,100
C 2144	J. Joubert	800	100, 390, 405, 765	143	192
C 2190	P. J. Van Dyk	800	305, 510	?	?
C 2574	Ndurumu Estate	910	872	240	620
C 2833	Tucker	923	248, 840	280	2,112
C 2904	Lariak Estate (abandoned)	386	80	40	20
	GILGIL - OL KALOU - DUNDORI				
C 417	Ruben and Katzler	607	562, 569, 586, 598,	455	1,200
C 570	E. R. Newbiggin	475	380	100	1,440
C 804	Ol Kalou T.C.	336	260	140	1,670
C 870	R. H. Hallows	343	300	260	400
C 872	Ol Kalou Country Club	364	260	160	730
C 1019	H. F. P. Rutter	724	553, 711–717	545	810
C 1032	H. F. P. Rutter	580	540	?	?
C 1043	R. R. Forrester	700	—	—	nil
C 1358	E. M. Wraith	680	515, 672	490	1,000
C 1361	R. R. Forrester	833	723, 810	620	610
C 1379	E. B. Hoyle	420	120, 350, 400	120	1,300
C 1924	P. J. Prinsloo	525	470	410	500
C 1951	E. E. Smit	492	383–450	365	400
C 1952	A. J. Korf	460	398, 443–459	367	1,500
C 2033	C. Hauschild	422	280	250	1,530
C 2039	W. B. Hallowes	600	—	—	nil
C 2061	E. Spencer-Williams	413	85, 380	70	2,600
C 2076	E.A.R. & H.	738	?	396	1,500
C 2077	E.A.R. & H.	680	?	314	1,400
C 2097	P. J. Williams	603	450, 580	396	430
C 2109	W. B. Hallowes	300	280	140	2,600
C 2110	H. A. Hall	431	353, 418	331	3,000
C 2160	R. Franklin	617	442, 482–495	438	950
C 2210	Lyon	470	176, 449	(142) 170	2,200
C 2296	L. N. Tryon	320	188, 270, 300	100	2,500
C 2322	S. Gotha	460	420	374	1,620
C 2332	K. Strauss	397	385	185	1,620
C 2388	Gilgil Township	880	476, 796, 835	797	1,200
C 2697	J. B. Maree	550	250, 520	100	2,500
C 2753	Rubona Farm Ltd.	700	410	410	20
C 2773	Rubona Farm Ltd.	530	240	240	50
C 2775	Rubona Farm Ltd.	330	220, 301	139	900
C 2966	Enslin	410	260–280, 350	180	500
C 2967	Ulyate	400	?	?	2,500

2. Groundwater

The positions of all the boreholes in the area, 270 in number, are shown in Fig. 6. Those in areas covered by the previous hydrological report (McCall, 1957 (*c*)—Geology and Groundwater Conditions in the Nakuru Area) are not further discussed here, and details of the remaining boreholes are summarized in Table 5. The account that follows is the joint work of the author (the western parts of the map area), C. M. Bristow (the eastern parts) and Bristow and B. N. Temperly (the south-eastern part).

South Baringo.—The following details of geological sections in this sub-area are available:–

Borehole 84 Soft unconsolidated formation 0 to 203 feet.

Borehole 120 Soft unconsolidated formation 0 to 100 feet.

Both these holes lie in a graben known to be deeply infilled with sediments including diatomite and volcanic soils.

Borehole C 2484	0–30 ft.	Soil and lava boulders
	30–45 ft.	Yellow and cream coloured pumice tuff (boulder?)
	45–80 ft.	Red soil and boulders
	80–255 ft.	Successive flows of fine non-fissile lavas of the Dispei-Hannington series, with divisions between the flows marked by weathering and vesicularity at 150, 210, 225 and 305–345 feet.

The water appears to have been encountered between 305 and 345 feet. The figure given by the driller for striking water in C2484 is probably not correct as it was struck at 335 feet (coincident with the rest level) in C285, drilled at the same spot, and one must assume that the water lies in the weathered zone between two flows, with a free air space above it up to 305 feet where the rock is impermeable. The aquifer appears to be the fourth weathered zone between the lava flows, and only part of it lies below the hydrostatic level.

No other samples are available for the boreholes in South Baringo.

Solai North.—The three boreholes on the Sisal Estate, situated to the north of Lake Solai, encountered nothing but soft sediments. From the study of borehole samples the following sections have been deduced for the other boreholes:—

Borehole C828	0–7 ft.	Soil
	7–64 ft.	Fresh phonolite (Rumuruti phonolite-Wasagess sub-division).
	64–130 ft.	Weathered phonolite of the same type.
	130–240 ft.	Basalt (fine felspar-phyric, the top of Samburu series).

The first water was struck between the phonolite and the basalt, and the second probably at a break in the series of thin basalt flows. There is however no sample from below 240 ft. to confirm this.

Borehole C2271	0–140 ft.	Red soil, boulders of Rumuruti phonolite (Wasagess sub-division)
	140–160 ft.	Whitened fissile phonolite of the same type
	180–200 ft.	Basalt (top of the Samburu lavas—fine vesicular felspar-phyric basalt)
	200–220 ft.	Basalt(?)
	220–275 ft.	White sediment with rounded lava fragments
	275–280 ft.	Weathered lava
	280–290 ft.	Fresh basalt
	290–300 ft.	Diatomite
		(No samples beyond 300 ft.)

Water was struck on the boundary between the Rumuruti phonolite and the Samburu lavas. As in C828 the supply from the upper aquifer was not sufficient and drilling had to be continued. Lake beds including diatomite have been recognized in the Samburu formation, and they probably increase in importance towards the centre of the Rift Valley. A good aquifer was located at 320 ft. in one of these pervious layers.

Borehole C2940 showed the following section:—

0–170 ft.	Clayey sediments—whitish to yellow, red staining
170–282 ft.	Phonolite, dark compact, non-fissile, very fresh (Tvp_3)
282–370 ft.	Fissile grey lava, many weathered fragments, porphyritic. Phonolite (Tvp_1?)

Three aquifers were encountered, the first and lowest in lava and the middle one at 282 ft. at an old land surface apparently marking the boundary between two lava groups of widely differing ages.

Subukia.—Samples from borehole C2360 show phonolite down to 250 ft. No samples are available for the bottom 150 ft. section of the hole. The water supply at 200 ft. was struck in a weathered zone in phonolite. Samples from C2605 showed a 370 ft. section in Rumuruti phonolite, water being struck within the lava formation. The Maryland borehole (C1747) is interesting in that it penetrated riebeckitic phonolite of the uppermost (Iguamiti) division of the Rumuruti phonolite throughout the 460 ft. of its depth. Water was struck first in fresh phonolite and secondly in a weathered zone in the phonolite.

The Section of borehole C2311 derived from a study of the samples is:—

0–80 ft.	Clay, soil, lava fragments
80–100 ft.	Fissile phonolite
100–120 ft.	Lava fragments and soil
120–200 ft.	Basalts (including vesicular and felspar-phyric types)
200–280 ft.	Fine textured lava (basalt?)
280–300 ft.	Tuff mixed with lava
300–321 ft.	Whitish clay with lava fragments

The main water supply was struck in a tuff intercalation in the Samburu basalts. A higher aquifer at 260 ft. was in a series of thin lava flows.

Borehole C2939 shows a section as follows:—

0–10 ft.	Red soil
10–140 ft.	Yellow and brown clay and decomposed tuff (Tvf_1)
140–150 ft.	Weathered lava
150–290 ft.	Series of rapidly alternating basalt flows (Tvb_1). Some degree of weathering seen in reddening of lava fragments.
290–320 ft.	Basalt and light tuff with small angular felspar grains.
320–330 ft.	Vesicular basalts
330–420 ft.	Olivine basalts, purplish red weathering
420–440 ft.	Compact purplish black fissile lava.
440–452 ft.	Yellowish tuff
452–532 ft.	Yellowish and brownish tuff
532–550 ft.	Brownish tuff and clay
550–610 ft.	Thin basalt flows, mostly fine textured. Some vesicular basalt (Tvb_1), Red weathered horizons.

Groundwater in the eastern half of the area

Most of the numerous boreholes in the eastern parts of the area have been successful but drilling failure has at times occurred in places which appeared quite favourable at first sight. The pattern of groundwater behaviour which has emerged from this investigation is of considerable complexity.

Phonolites.—The phonolites are usually extremely impermeable. There are three principle types of aquifer in the phonolites:—

(*a*) Fissures in the phonolite. From a study of borehole logs and records of water struck, it appears that most of the water obtained by boring in the phonolites comes from this source. The fissures may be in the form of jointing or fault-movement cracks. The phonolite often shows a poorly developed columnar structure, particularly well seen at the base of the waterfall at Thomson's Falls. Fissures developed on faults are common but only yield useful amounts of water in zones where the faulting is poorly developed, since extensive faulting causes the water table to be appreciably lowered in the fault zone.

(*b*) Porous old land surfaces. In general the old land surfaces in the phonolites are not good aquifers. Most of the old land surfaces are composed of earthy and clayey material and due to their fine grain do not yield much water. Sometimes however more coarsely divided sandy material is struck which yields useful amounts of water.

(*c*) Altered phonolite. In places the phonolite has been deeply decomposed. Although some of the alteration is due to weathering near the surface and by percolating groundwater, it is also apparent that certain deep zones of alteration must be due to more potent factors. The writer believes that this alteration is either due to decomposition of the lava by the movement of late stage solutions or to steam rising from a lake or swamp over which the lava flowed. These altered zones, of which there is evidence in the vicinity of Rumuruti, are frequently quite porous and yield appreciable quantities of water.

In some parts of the area where phonolites are exposed unaffected by rift faulting the boreholes have had to be deepened to between 600 and 900 feet. The depth to the water table is, however, known to be about 200 ft. It appears that the depth of substantial water supplies in this part of the area is governed by the depth to a zone sufficiently porous to yield a good supply, rather than the depth to the water table. To the east of the Thomson's Falls-Maralal road sub-artesian conditions are common, presumably caused by water flowing out from the Aberdare Range. To the west of this road there is some faulting causing a general depression of the water table, and boreholes have frequently to be sunk to depths of almost a thousand feet in the area north and west of the road.

Kinangop and Bahati tuffs.—Most of the rocks in this succession are impermeable or poorly permeable. The aquifers are not extensive and are very variable. The principal kinds are:—

(*a*) Gravels and sands. These are the principal aquifers in the series. As the lenses of gravels and sands are not extensive, the yields are correspondingly low.

(*b*) Porous tuffs and lapilli tuffs. These are of sporadic occurrence and behave in a similar manner to the gravels and sands.

(*c*) Solution cavities in tuffs. These are excellent aquifers, but are not widespread.

(*d*) Fissured "ignimbrite". Sometimes water is struck in joint fissures in the massive "ignimbrite" flows.

Superficial deposits overlying the tuffs

As these deposits are thin and laterally variable little water is found in them. However there are exceptions:—

(*a*) Gravels and sands of the Ol Bolossat plains. Near the Ol Bolossat swamp good supplies of water are obtained at shallow depths from these gravels and sands.

(*b*) Murrams mantling high ground. Wells sunk in the deep soils and weathering mantle in the vicinity of Dundori yield small amounts of water.

One feature of the rocks in the area is their impermeability. The phonolites probably owe this to the massive unjointed nature of the very thick flows which make up the formations. At Thomson's Falls a single lava flow with a thickness of at least 280 feet has been recognized. The Kinangop and Bahati tuffs owe their impermeability to the preponderance of "ignimbrites" and decomposed clayey pumice tuffs. This impermeability may necessitate drilling to a considerable distance below the water table before striking a good supply of water from a sufficiently permeable layer.

The recharge of the aquifers is mainly from local sources, by percolation of rainfall downwards through fissures until a porous stratum is reached, though in certain cases the recharge is derived from surface water bodies. Ol Bolossat lake and swamp recharges the ground around it to some extent, but as it is perched on a clay bed the amount of recharge is not great. In the vicinity of Dundori and Oleolondo the rivers and streams run in valleys aligned along faults. Here the fault zones influence the groundwater strongly, each fault acting like a rubble-filled drain and causing a trough-like depression of the water table along its length. Hence the rivers and streams lose water in the fault zones and do not directly feed the aquifers other than through these zones. A fault-aligned depression is seen along the line of the Ol Joro Orok fault, evidence for its existence being seen in the records of borehole C2100. The same applies along the line of the Oleobar fault (Borehole C417). Perhaps the best example of this depression of the water table along fault zones is seen at Solai, where C2122 was drilled to seven hundred feet in a fault zone, whereas nearby boreholes have been drilled to depths of only a hundred and fifty to four hundred feet.

Water moves through the fault zones into flat lying aquifers and through these away from the areas of high ground. In the area under discussion this movement would appear to be mainly northwards, into the low country around Lake Baringo. Evidence for considerable movement of groundwater along faults may be seen in the Mayfield scarp, where tuffs showing well developed solution cavities are exposed. These cavities could only have developed when the scarp now exposed was deeply buried and formed part of a water channel. Other comparatively young fault scarps show similar features, notably the Sabugo fault scarp.

Through the area mapped there is clear evidence of perched aquifers in the occurrence of abrupt lowering of rest levels recorded during the drilling of certain boreholes. Sub-artesian conditions are not very widespread in the area examined, being confined to the area east of the Sattima scarp and parts of the Ol Bolossat plains (e.g. borehole C2949). In the course of drilling a borehole the water table is frequently encountered at a comparatively high level, but due to the poor degree of permeability of most of the water bearing formations little water enters the hole. In the course of baling out the drilling sludge the water level in the borehole will be appreciably lowered, and the impression is gained that there is no water supply. On reaching a more porous stratum the water enters the borehole rapidly, filling it up to level of the water table, and as the pressure on the water in the aquifer is derived from the head of water over a large area the water level is maintained unless too strongly pumped.

Ol Bolossat plain.—To the east of the Sattima scarp, the Simbara basalts (possibly with members of the Sattima series) provide excellent aquifers. The water table slopes gently northwards parallel to the ground surface at a depth of about 100 feet below the main valleys. Near the Sattima scarp many of the shallow aquifers probably become vadose,* due to the rapid draining of water into the fault zone from the old land surfaces through the numerous channels in the fault zone, eventually to feed the surface and subsurface water bodies of the Ol Bolossat plain. The hydrology of the Ol Bolossat plain is illustrated diagrammatically (Fig. 17 (*b*)). Springs fed from the vadose aquifers on the Sattima scarp flow over the porous fault zone into Ol Bolossat swamp and lake, losing an appreciable amount of their flow underground on the way. On the west side of the plain water from the Simba river passes over the Ol Joro Orok fault, losing water on the way. The river then sinks into the ground and probably reappears as springs at Barton's farm (Barton's springs probably also receive

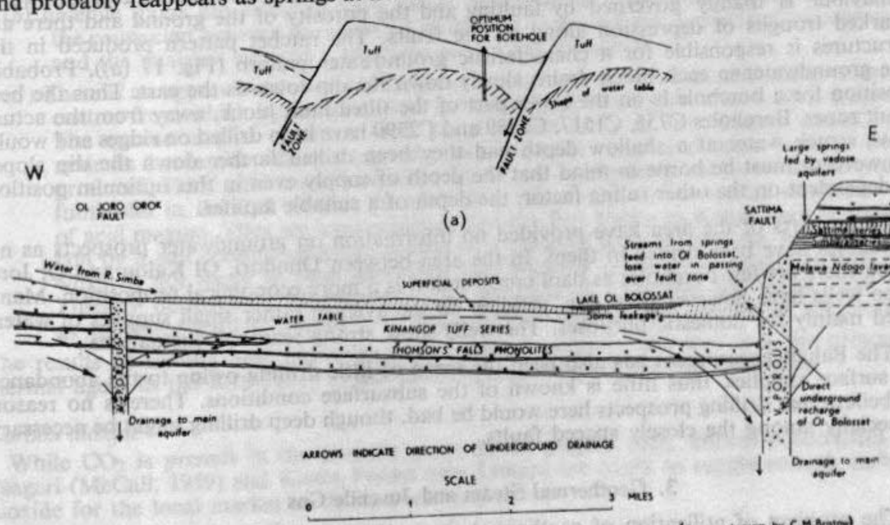


Fig. 17
(a) Diagram illustrating the shape of the water-body and ideal position for drilling in the "ratchet" topography near Ol Joro Orok and Ol Kalou.
(b) Diagram illustrating the hydrology of the Ol Bolossat plain.

*With a free air surface above the water.

ncrements from the stream near Olivier's farm) and at a point 2½ miles north-east of Ol Joro Orok. The stream through Absalom's farm also contributes some water to the swamp and lake. All the above mentioned streams are dry for part of their courses. The water reaches Ol Bolossat swamp and lake via shallow perched aquifers in the superficial deposits mantling the plain. On reaching the lake the water either evaporates or leaks away through the bottom of the lake, very little surface water finding its way northwards to Thomson's Falls. The water which leaks from the perched aquifer connected to the lake is joined by other water derived from general soakage over the Ol Bolossat plain and this feeds into the main water table below the Ol Joro Orok and Sattima faults which cause a depression of the main water table along their length.

It is clear that Ol Bolossat lake loses an appreciable amount of water by processes other than evaporation as it is perfectly fresh. Very recent measurements show that the evaporation from the lake and swamp is so high as to indicate considerable direct sub-surface increment, besides the amounts that can be measured in the known feeder springs. Water analyses are given below for both the lake and a borehole drilled to 250 feet below it. It seems quite possible that the less saline borehole water could be concentrated by simple evaporation to yield a composition akin to that of the lake water, CO_2 being lost at the same time.

	Lake	*Borehole*
pH value	9·0	7·5
Alkalinity (Carbonate) (Calculated as $CaCO_3$)	160 p.p.m.	Nil
Alkalinity (Bicarbonate) (Calculated as $CaCO_3$)..	275 p.p.m.	140 p.p.m.
Total Hardness as $CaCO_3$	47	41
Sulphate (As SO_4)	Trace	Trace

In the north of the Ol Bolossat plain, near Thomson's Falls and Ol Joro Orok, drilling has been carried out mainly in the Thomson's Falls phonolites. On the Nanyuki road a mile to the east of Thomson's Falls there are however numerous boreholes and wells sunk in the decomposed material along the line of the Sattima fault zone. It appears that this fault zone yields copious supplies, contrasting with other fault zones already described which yield poor supplies.

Gilgil, Ol Kalou, Dundori.—In the area between Oleolondo and Dundori the groundwater behaviour is mainly governed by faulting and the porosity of the ground and there are marked troughs of depression along all the faults. The ratchet pattern produced in the structures is responsible for a characteristic groundwater pattern (Fig. 17 (*a*)). Probably the groundwater in each block drains slowly down the dip towards the east. Thus the best position for a borehole is on the lower part of the tilted fault block, away from the actual fault zones. Boreholes C755, C1517, C2389 and C2390 have been drilled on ridges and would have struck water at a shallow depth had they been drilled farther down the dip slope. However it must be borne in mind that the depth of supply even in this optimum position is dependent on the other ruling factor, the depth of a suitable aquifer.

Large parts of the area have provided no information on groundwater prospects as no boreholes have been drilled in them. In the area between Dundori, Ol Kalou and Ol Joro Orok there are few boreholes as dam construction is a more economical proposition. Many deep wells have however been dug, yielding on the average rather small supplies of water, used mainly for domestic purposes. The wells show strong seasonal fluctuations.

The Bahati Escarpment has also been the scene of little drilling owing to the abundance of surface supplies, thus little is known of the subsurface conditions. There is no reason to believe that drilling prospects here would be bad, though deep drilling might be necessary especially among the closely spaced faults.

3. Geothermal Steam and Juvenile Gas

The problem of utilization of geothermal steam has been discussed in a paper read to the International Geological Congress in Mexico (McCall 1957 (*b*)) and also by Thompson and Dodson (1963). In the former work comparison is made with the world-famous occurrence at Lardarello in Tuscany (Mazzoni, 1954). The conclusion was reached that there is no evidence that such great volumes of steam were present under the Rift Valley; evidence of high pressures was scanty, and the absence of an impermeable cap formation and the broken nature of the rift zone made a great build up of reservoirs of steam within a reasonable distance of the surface unlikely. Thompson and Dodson considered that most of the water ejected from the steam jets in the Naivasha area was meteoric, basing their conclusion on the lack of chemical constituents usually present in juvenile water.

The opinions of the writer and of Thompson and Dodson has been queried by Dr. C. S. Hitchen in a written communication to the Commissioner of Mines. Dr. Hitchen considered that there was a parallel between the Rift Valley and the occurrence at Wairakei, New Zealand (Hamilton, 1955), and as consultant to Messrs. Balfour Beatty and Co. initiated drilling near Hell's Gate, Naivasha. The borehole encountered high temperatures (400°C) at 300 feet but no appreciable quantities of steam. The writer does not accept the existence in the Rift Valley of any parallel to Wairakei. The Wairakei occurrence, which has been utilized to work a small experimental power station, is in the nature of a freak. It owes its existence to a permeable formation of a thickness of several hundred feet, fully saturated. The temperature at a depth of 1000 feet is 230°C, but the pressure of the overlying column of water greatly raises the boiling point so that the water at this depth is held there without boiling off. A borehole or tube-well will, of course, cause a sudden drop to atmospheric pressure, and a violent ebullition will ensue, and this ebullition can be utilized to operate the power plant. In the Rift Valley water tables occur for the most part immediately above impervious horizons and the water bodies are rarely more than a few feet deep. Thus the necessary water head to provide the type of occurrence at Wairakei is not likely to be encountered. Hamilton himself (p. 43) considers this type of occurrence as of limited potential and that in New Zealand they have yet to penetrate several thousand feet below the impermeable ignimbrite to see if steam power on a scale comparable with Lardarello is trapped there. The gas content in the steam at Wairakei is small, but CO_2 accounts for 90% of the content, and hydrogen, methane, ethane and hydrogen sulphide are present in traces. This gas content shows some resemblance to the juvenile gas in the Nakuru area in the predominance of CO_2. The volcanic suite exposed in the Rotorua-Taupo graben is however rhyolitic not trachytic, and no exact parallel is perhaps to be expected.

The following features of geothermal steam occurrences in the area are of importance in considering possible utilization.

(a) Hot juvenile gases (mainly CO_2) occur in fault zones. This is particularly well seen at Esageri (McCall, 1959).

(b) Juvenile gases are admixed with steam where, as at Lake Hannington and Arus, the connexion between the situation of surface water and the geothermal occurrences and the analyses support a meteoric source for the steam.

(d) There is an apparent relationship between geothermal occurrences and major volcanic centres from which pyroclastic rocks containing syenite boulders have been erupted. The syenite magma contrasts with the senescent body of acid magma thought to underlie Lardarello where great volumes of juvenile steam and some boric acid are produced. Boric acid is not known to be present in anything but traces in the steam fumaroles in the Rift Valley. Pneumatolitic phases are not so typical of syenite as of acid magma. Thus we have evidence that the Rift Valley in Kenya may be underlain by a still cooling senescent pluton or a chain of separate plutons, but of a type which is not likely to have generated vast volumes of steam comparable with the Tuscany occurrence. Alternatively, the presence of CO_2 and not steam may be, as suggested earlier, related to a final mofette stage in the cooling of the pluton.

The results of drilling near Naivasha would seem to support the idea that the principal thermal agent in the Rift Valley is hot juvenile gas, mainly CO_2, and not steam.

Carbon dioxide

While CO_2 is present in the juvenile gases of the present area, known occurrences at Esageri (McCall, 1959) and Kerita Forest near Limuru are likely to supply enough carbon dioxide for the local market in the foreseeable future.

Helium and Argon

A search was made for Helium in response to a demand from the U.K. Atomic Energy Authority. The only trace found was at Ol Kokwe Island, Lake Baringo, in a gas sample which however appeared to consist largely of air.

Argon is present in traces in the juvenile gases, but is of no economic value.

IX—REFERENCES

Allen, E. T. and A. L. Day, *1934—"Hot Springs of the Yellowstone National Park" Carnegie Institute, Washington, Pub. 466.

Baker, B. H., 1958—"The Geology of the Magadi area". Report No. 42, Geol. Surv., Kenya.

Barnard, G. C., 1950.—"Diatomite and its Production in Kenya." Mining Magazine, Vol. 82, pp. 271–274.

Barth, T. F. W., 1950.—"Volcanic Geology, Hot Springs and Geysers of Iceland." Carnegie Institute, Washington.

Blackett, P. M. S., 1954.—"Lectures on Rock Magnetism." Jerusalem.

Bristow, C. M., 1962.—"Geology of the Katmaian Volcanics of the Upper Oramutia Valley, Kenya." *Geol. Mag.*, Vol. XCIX, pp. 153–163.

Bullard, E. C., 1936.—"Gravity Measurements in East Africa." *Phil. Trans. Roy. Soc.*, London. Series A. No. 757, Vol. 235, pp. 445–531.

Cole, S. M., 1954.—"The Prehistory of East Africa." Pelican Books.

Cooke, H. B. S., 1957.—"Observations Relating to Quaternary Environments in East and Southern Africa." Annex. to Vol. LX., *Proc. Geol. Soc., South Africa.*

Cotton, C. A., 1944.—"Geomorphology." Christchurch, New Zealand.

———, 1952.—"Volcanos as Landscape Forms." (Second edition), Christchurch, New Zealand.

Flint, R. F., 1959 (*a*).—"On the Basis of Pleistocene Correlation in East Africa." *Geol. Mag.* Vol. XCVI, pp. 265–284.

———, 1959 (*b*).—"Pleistocene Climates in Eastern and Southern Africa." *Bull. Geol. Soc. America*, Vol. 70, pp. 343–373.

Fuchs, V. E., 1934.—"Geological Work of the Cambridge Expedition to the East African Lakes 1930–31." *Geol. Mag.*, Vol. LXXI pp. 97–112.

———, 1950.—"Pleistocene Events in the Baringo Basin." *Geol. Mag.* Vol. LXXXVII, pp. 149–174.

Girdler, R. W., 1958.—"The Relationship of the Red Sea to the East African Rift System." *Quart. Journ. Geol. Soc.*, Vol. CXIV, pp. 79–105.

Grange, L. I., 1934.—"Rhyolite Sheet Flows of North Island, New Zealand." N.Z. Journal of Technical Science, Vol. 16, pp. 57–67.

———, 1937.—"The Geology of the Rotorua-Taupo Subdivision." Bull. 37, Geol. Surv. of New Zealand.

Gregory, J. W., 1896.—"The Great Rift Valley." London.

———, 1900.—"Contributions to the Geology of British East Africa." *Quart. Journ. Geol. Soc.*, Vol. LVI, p. 205–222.

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

Hamilton, W. M., 1955.—"Geothermal Energy—Report on Wairakei Occurrence, New Zealand." N.Z. Electrical Journal, Feb. 1955, pp. 36–44.

Hitchen, C. S., 1942.—"Brief Report on the Occurrence of Manganese in the Gilgil District." Unpublished report, Mines and Geological Department, Nairobi.

Holtedahl. O. and J. A. Dons, 1952.—"Geologisk Kart over Oslo og Omegen." Norske Videnshaps Akademi i Oslo.

Jaggar, T. A., 1945.—*"Volcanoes Declare War" Honolulu."

Jakosky, J. J., 1950.—"Exploration Geophysics." Los Angeles. (2nd Edition).

Johannsen, A., 1938.—"A Descriptive Petrography of the Igneous Rocks." University of Chicago Press.

*Not consulted in the original.

King, L. C., 1951.—"South African Scenery." (Second edition) Edinburgh.

Leakey, L. S. B., 1931.—"The Stone Age Cultures in Kenya Colony." Cambridge.

———, 1936.—"Stone age Africa." Oxford and London.

———, 1950.—"The Lower Limit of the Pleistocene in Africa." Proc. Int. Geol. Congress XVIII Session, London, Part IX pp. 62–65.

McCall, G. J. H., 1957 (*a*).—"The Menengai Caldera. Kenya Colony." Proc. Section I, XXth Int. Geol. Congress, pp. 55–69.

———, 1957 (*b*).—"Natural Steam as a Possible Source of Power in the Rift Valley of Kenya." Proc. Section 1. XXth Int. Geol. Congress, pp. 47–54.

———, 1957 (*c*).—"Geology and Groundwater Conditions in the Nakuru Area." Technical Report No. 3, Ministry of Works (Hydraulic Branch), Kenya.

———, 1958.—"The Geology of the Gwasi Area." Report No. 45, Geol. Surv. Kenya.

———, 1959.—"Report on the Carbon Dioxide Occurrence at Esageri." Unpublished report, Mines and Geological Dept., Nairobi.

———, 1960 (*a*).—"The Oleolondo Manganese Deposit." Unpublished Report Mines and Geological Department Nairobi.

———, 1960 (*b*).—"Report on the Risk of Earthquakes in East Africa." Unpublished Report, Mines and Geological Department, Nairobi.

———, 1962.—"Volcanic Rocks of the Oramutia Section, Central Kenya." *Geol. Mag.*, Vol. XCIX, pp. 475–476.

———, 1964.—"Kilombe Caldera, Kenya." *Proc. Geol. Assoc.*, Vol. 75, pp. 563–572.

McCall, G. J. H., B. H. Baker and J. Walsh, 1965.—"Late Tertiary and Quaternary Sediments of the Kenya Rift Valley." Paper read at Symposium No. 29, Wenner-Gren Foundation for Anthropological Research, Vienna.

Mansfield, G. R. and C. S. Ross, 1935.—*"Welded Rhyolitic Tuffs from South-eastern Idaho." *Trans. Am. Geophys. Union*, *16*, pp. 308–321.

Marshall, P., 1932.—*"Notes on some Volcanic Rocks of the North Island, New Zealand" N.Z. Journal of Science and Technology, *13*, pp. 198–200.

———, 1935.—*"Acid Rocks of the Taupo-Rotorua Volcanic District." Trans. Royal Society of New Zealand, *64*, pp. 323–366.

Mazzoni, A., 1954.—"The Steam Vents of Tuscany and the Lardarello Plant." Bologna (2nd Edition).

Mooney, H. M., and W. W. Wetzel, 1956—"The Potentials about a Point Electrode and Apparent Resistivity Curves for a Two-, Three- and Four-layer Earth." University of Minnesota Press.

Nilsson, E., 1929.—"Preliminary Report on the Quaternary Geology of Mount Elgon and some parts of the Rift Valley." *Geol. Fören. Förhandl.*, Vol. 51, pp. 253–261.

———, 1932.—"Quaternary Glaciations and Pluvial Lakes in British East Africa." Thesis, Stockholm Univ.

———, 1935.—"Traces of Ancient changes of Climate in East Africa." Sartryck un Geografiska Annaler, Stockholm, pp. 1–21.

———, 1938.—"Pluvial Lakes in East Africa." *Geol. Foren. Forhandl.* Vol. 60, pp. 423–433.

———, 1940.—"Ancient Changes of Climate in British East Africa and Abyssinia." Avtryck Geografiska Analer, Stockholm, pp. 1–79.

Perret, F. A., 1935.—"The Eruption of Mt. Pelée, 1929–1932." Carnegie Institute, Washington.

Prior, G. T., 1903.—"Contributions to the Petrology of British East Africa." *Min. Mag.* Vol. XIII, pp. 228–263.

Pulfrey, W., 1944.—"Report on the Examination of the Kariandusi Diatomite Deposits, Cole Estates, Gilgil." Two Unpublished reports. Mines and Geological Dept., Nairobi.

PLATE IX.

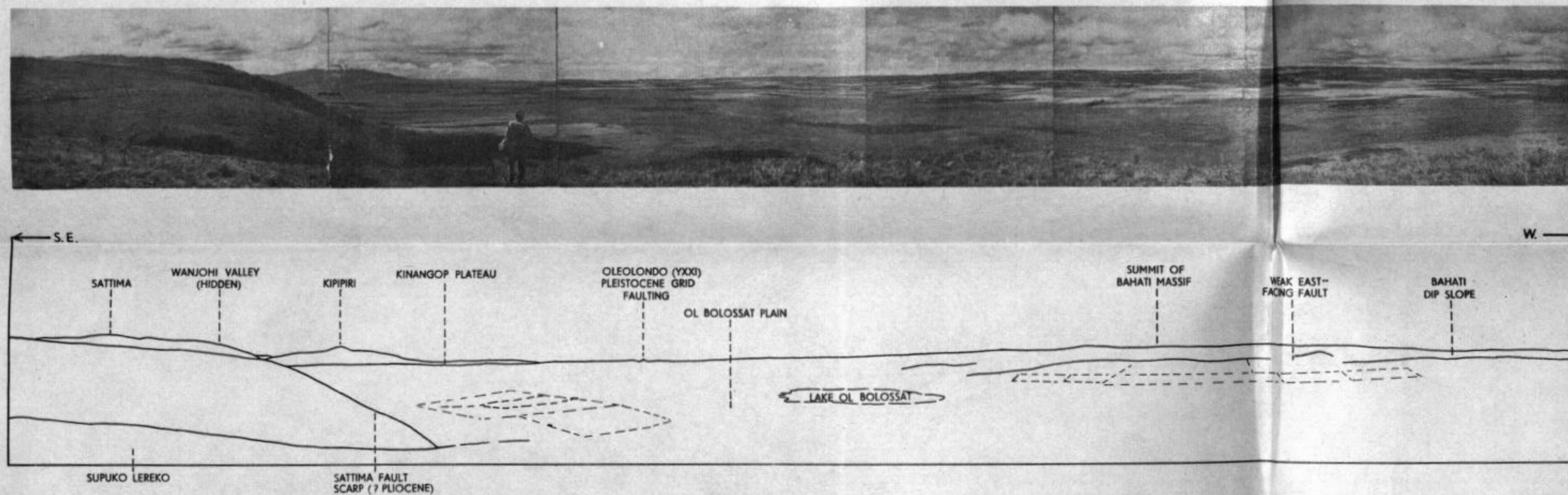
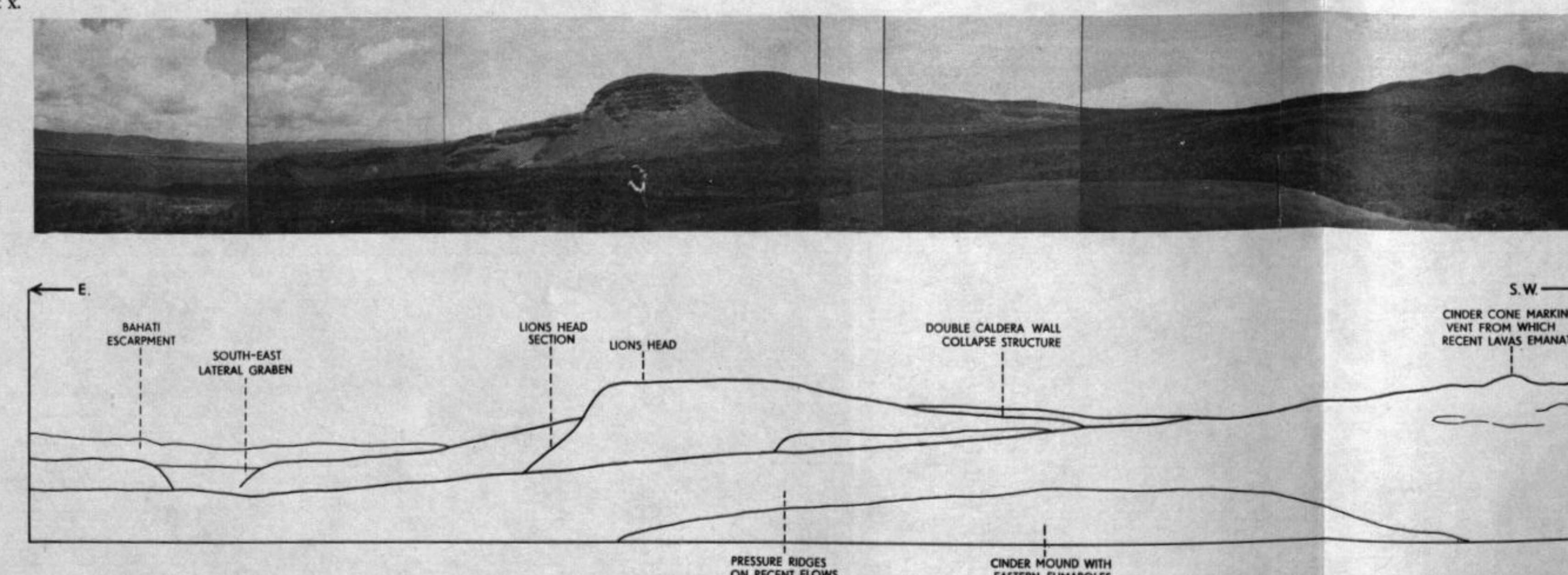
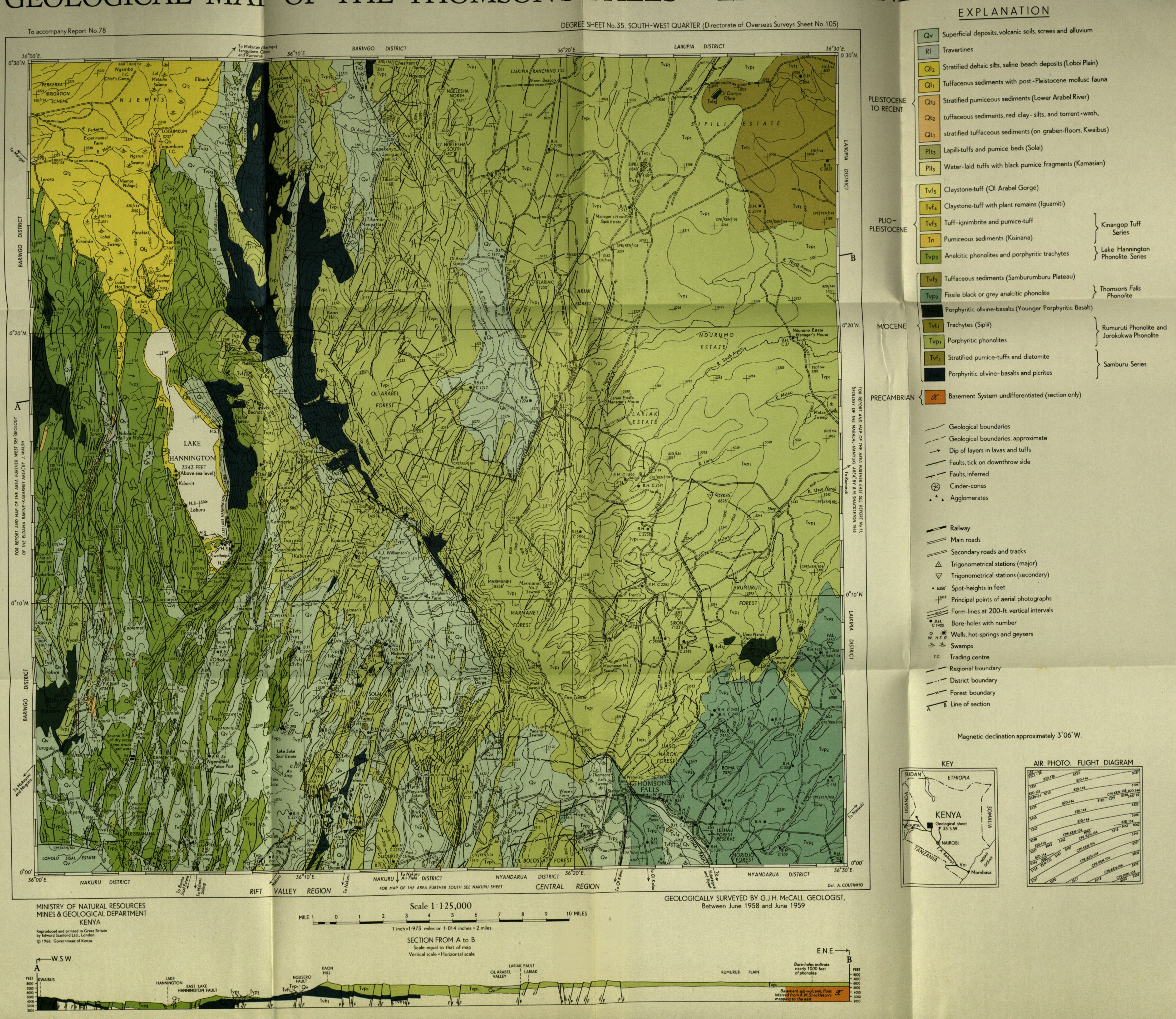


PLATE X.



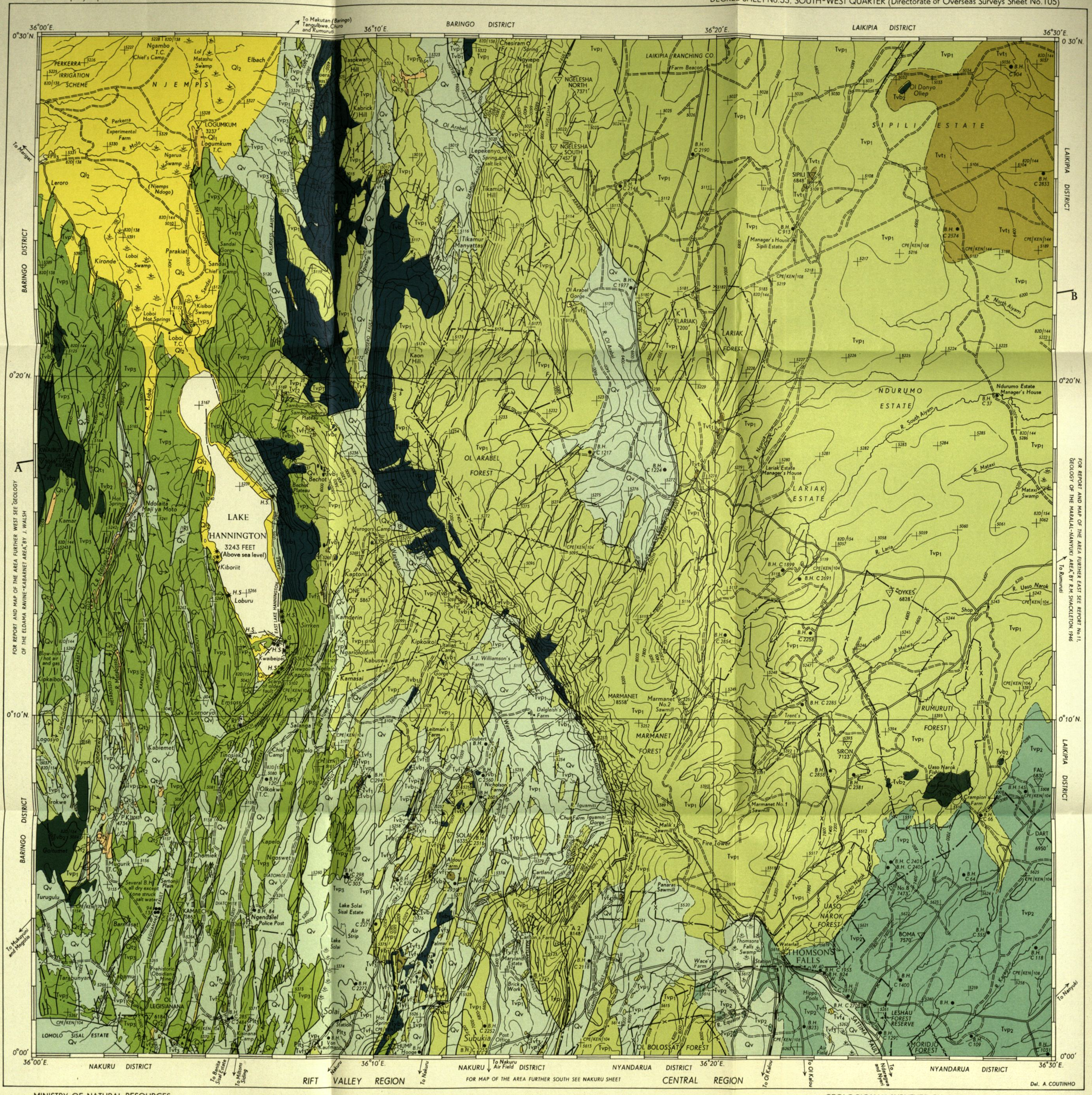
GEOLOGICAL MAP OF THE THOMSON'S FALLS - LAKE HANNINGTON AREA



GEOLOGICAL MAP OF THE THOMSON'S FALLS - LAKE HANNINGTON AREA

To accompany Report No. 78

DEGREE SHEET No. 35, SOUTH-WEST QUARTER (Directorate of Overseas Surveys Sheet No. 105)



EXPLANATION

PLEISTOCENE TO RECENT

- Qv — Superficial deposits, volcanic soils, screes and alluvium
- Rl — Travertines
- Ql₂ — Stratified deltaic silts, saline beach deposits (Loboi Plain)
- Ql₁ — Tuffaceous sediments with post-Pleistocene mollusc fauna
- Qt₃ — Stratified pumiceous sediments (Lower Arabel River)
- Qt₂ — tuffaceous sediments, red clay-silts, and torrent-wash,
- Qt₁ — stratified tuffaceous sediments (on graben-floors, Kwaibus)
- Plt₃ — Lapilli-tuffs and pumice beds (Solai)
- Pll₃ — Water-laid tuffs with black pumice fragments (Kamasian)

PLIO-PLEISTOCENE

- Tvf₅ — Claystone-tuff (Ol Arabel Gorge)
- Tvf₄ — Claystone-tuff with plant remains (Iguamiti)
- Tvf₃ — Tuff-ignimbrite and pumice-tuff — Kinangop Tuff Series
- Tn — Pumiceous sediments (Kisinana) — Kinangop Tuff Series
- Tvp₃ — Analcitic phonolites and porphyritic trachytes — Lake Hannington Phonolite Series

MIOCENE

- Tvf₂ — Tuffaceous sediments (Samburumburu Plateau)
- Tvp₂ — Fissile black or grey analcitic phonolite — Thomsons Falls Phonolite
- Porphyritic olivine-basalts (Younger Porphyritic Basalt)
- Tvt₁ — Trachytes (Sipili) — Rumuruti Phonolite and Jorokokwa Phonolite
- Tvp₁ — Porphyritic phonolites — Rumuruti Phonolite and Jorokokwa Phonolite
- Tvf₁ — Stratified pumice-tuffs and diatomite — Samburu Series
- Porphyritic olivine-basalts and picrites — Samburu Series

PRECAMBRIAN

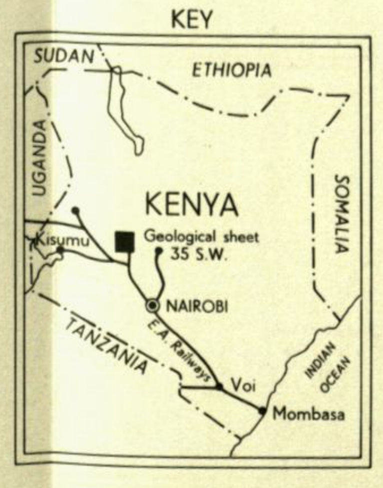
- X — Basement System undifferentiated (section only)

Geological boundaries
Geological boundaries, approximate
Dip of layers in lavas and tuffs
Faults, tick on downthrow side
Faults, inferred
Cinder-cones
Agglomerates

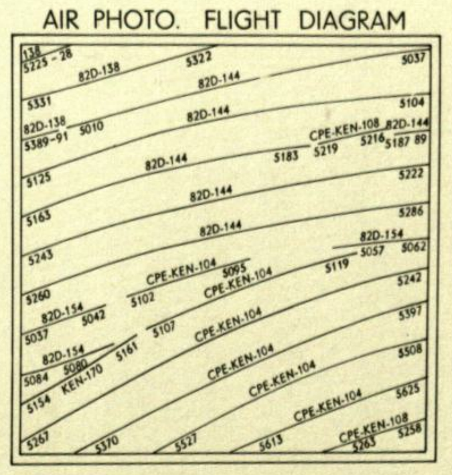
Railway
Main roads
Secondary roads and tracks
Trigonometrical stations (major)
Trigonometrical stations (secondary)
Spot-heights in feet
Principal points of aerial photographs
Form-lines at 200-ft. vertical intervals
Bore-holes with number
Wells, hot-springs and geysers
Swamps
Trading centre
Regional boundary
District boundary
Forest boundary
Line of section

Magnetic declination approximately 3°06'W.

KEY



AIR PHOTO. FLIGHT DIAGRAM



MINISTRY OF NATURAL RESOURCES
MINES & GEOLOGICAL DEPARTMENT
KENYA

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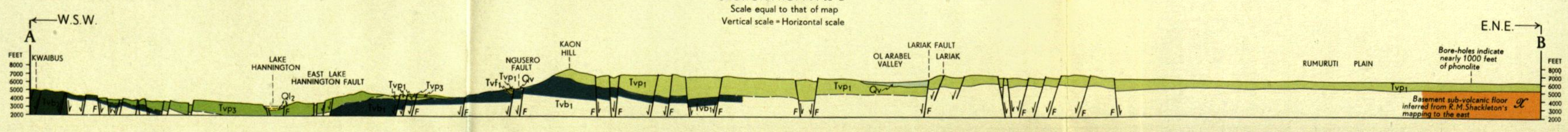
Scale 1:125,000

MILE 1 0 1 2 3 4 5 6 7 8 9 10 MILES

1 inch = 1·973 miles or 1·014 inches = 2 miles

GEOLOGICALLY SURVEYED BY G.J.H. McCALL, GEOLOGIST, Between June 1958 and June 1959

SECTION FROM A to B
Scale equal to that of map
Vertical scale = Horizontal scale



GEOLOGICAL MAP OF THE NAK

To accompany Report No. 78

MINISTRY OF NATURAL RESOURCES
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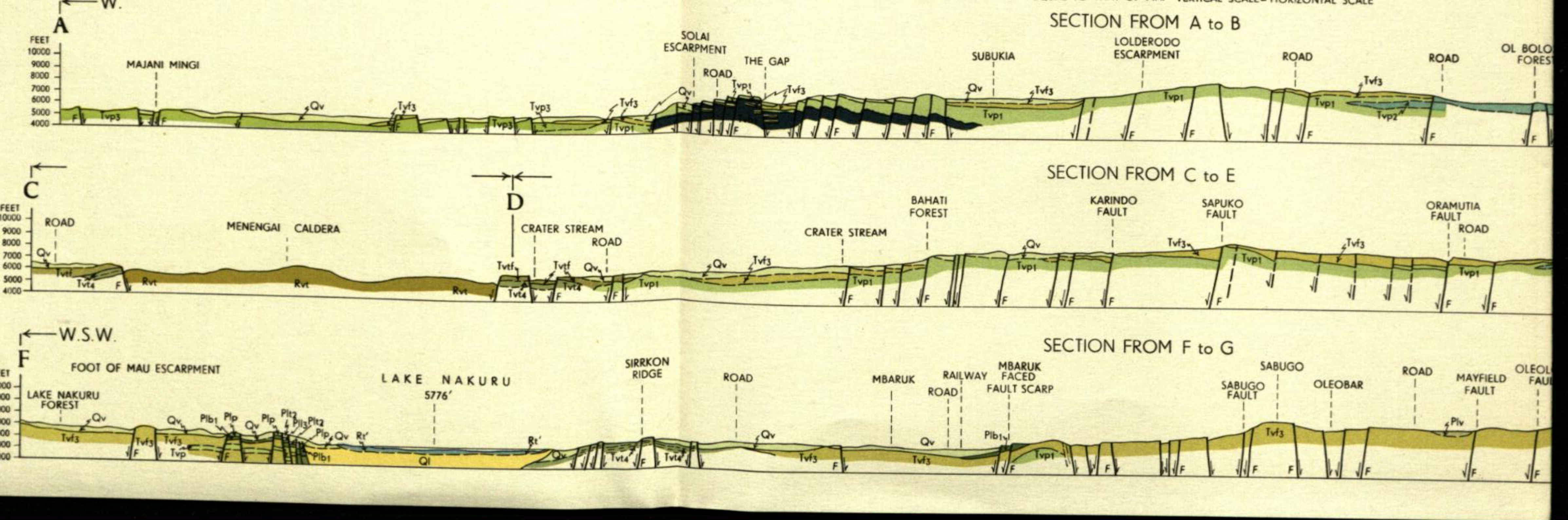
Scale 1:125,000

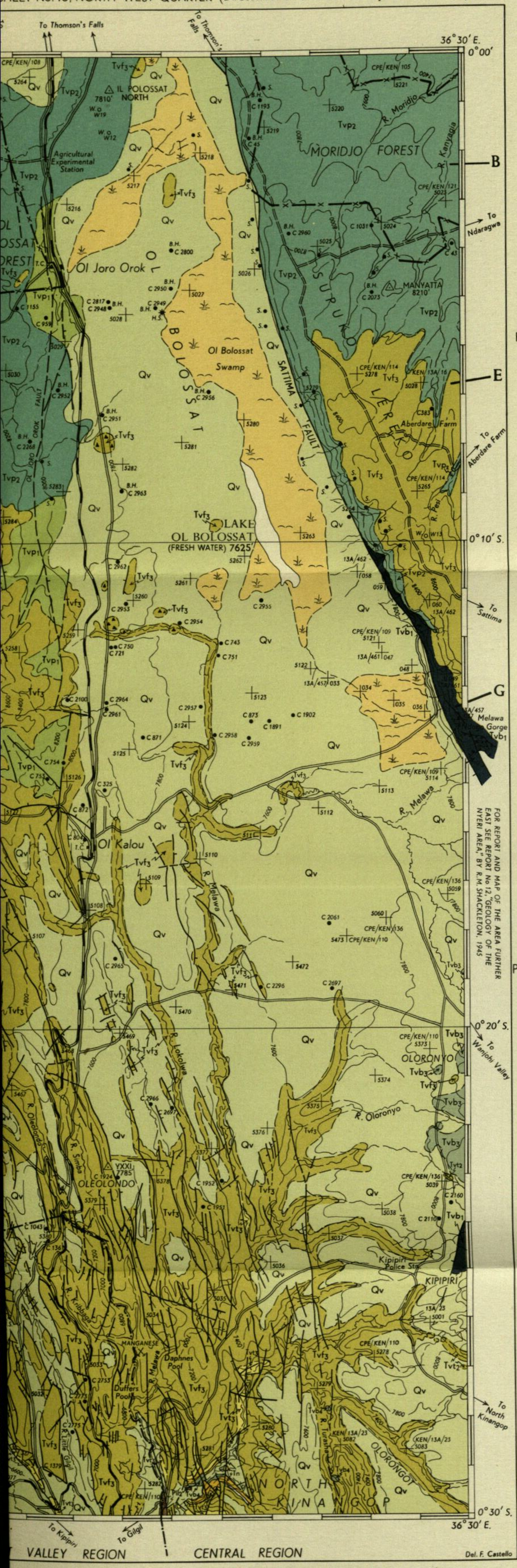
1 inch=1·973 miles or 1·014 inches=2 miles

SCALE OF SECTIONS EQUAL TO THAT OF MAP VERTICAL SCALE=HORIZONTAL SCALE



URU AREA

SHEET No.43, NORTH-WEST QUARTER (Directorate of Overseas Surveys Sheet No.119)



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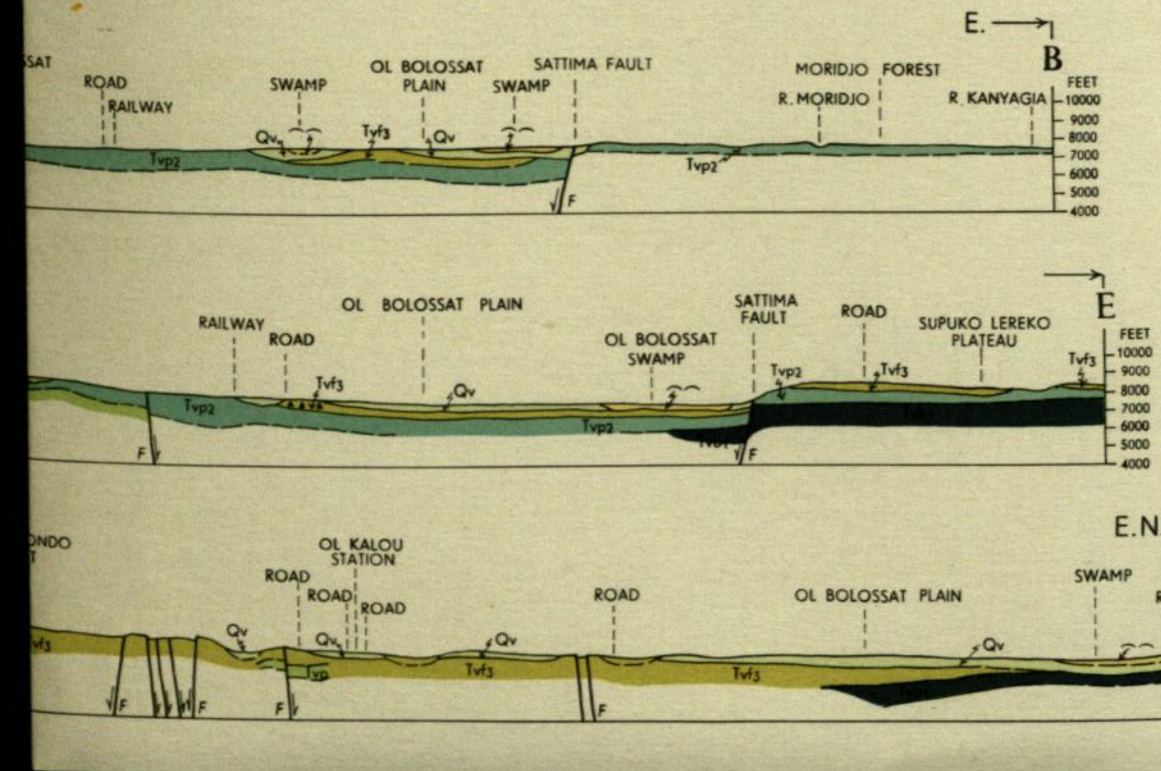


EXPLANATION

RECENT

- Alluvium in lake and swamp basins
- Qv — Superficial deposits, volcanic soils
- Rvt — Trachyte flows, glassy, ropy, and blocky (Upper Menengai Series) also cinder cones
- Rvb — Olivine-basalts, tongue-shaped flows and cinder cones (Lake Elmenteita)
- Rt' — Trona impregnated silts bordering Soda-Lakes
- Ql — Gravels, tuffs and diatomaceous silts (Makalia River Beds)

Slight Unconformity

UPPER PLEISTOCENE

- Plv — Late valley fillings including tuffs unconformable on Bahati Tuffs
- Plt3 — Reddish-brown unstratified lapilli tuffs (Solai Tuff)
- Plt2 — Unstratified lapilli tuffs with green welded tuffs (Larmudiac Tuff)
- Pll3 — Gravels, silts, diatomaceous silts, pumiceous beds and graded tuffs, part lacustrine, part fluviatile (Larmudiac Beds, Gamblian silts of Kariandusi)

Slight Unconformity

MIDDLE PLEISTOCENE

- Plb2 — Older faulted vesicular olivine-basalts of Elmenteita
- Plt1 — Agglomeratic tuffs forming tuff-rings at Elmenteita (Honeymoon and Crescent Hill)
- Pll2 — Kanjeran lake beds of Kariandusi and Soysambu, graded pumice tuffs and diatomite

Unconformity

LOWER PLEISTOCENE

- Pll1 — Lacustrine sediments and graded tuffs (Ronda Hill)
- Plh2 — Trachytes and phonolitic trachytes (Gilgil)
- Plp — Phonolites (Ronda)
- Plb1 — Porphyritic olivine-basalt (Mbaruk Basalt)
- Plh1 — Porphyritic trachyte

Unconformity

PLIOCENE

- Tvtf — Welded vitreous tuffs and ignimbrites (Menengai)
- Tvf3 — Vitric pumice tuffs, ignimbrites and welded tuffs with lacustrine sediments, graded tuffs, diatomites { Mau Tuffs, Bahati Tuffs, Kinangop Tuffs
- Tvt4 — Phonolitic trachytes (Menengai)
- Tvt3 — Quartz-trachytes (N. Kinangop), fragmental trachytes (Kariandusi)
- Tvp3 — Phonolites and subordinate trachytes, trachyte-breccias (Koishiram)
- Tn — Lacustrine sediments, mainly graded tuffs (Turasha Lake beds)
- Tvb4 — Olivine-basalts (Turasha Basalt)

Unconformity

Pliocene-Miocene boundary (?)

- Tvb3 — Vesicular olivine-basalts (Oloranyi Basalt ≡ Laikipia Basalt)
- Tvt2 — Phonolites and trachytes (Sattima Lavas)

MIOCENE

- Tvp2 — Fissile black or grey analcitic phonolite (Thomson's Falls Phonolite)
- Tvp1 / Tvp — Rumuruti Phonolite (Tvp1); Slaggy phonolites N. of Ol Kalau (Tvp)

Local Unconformity

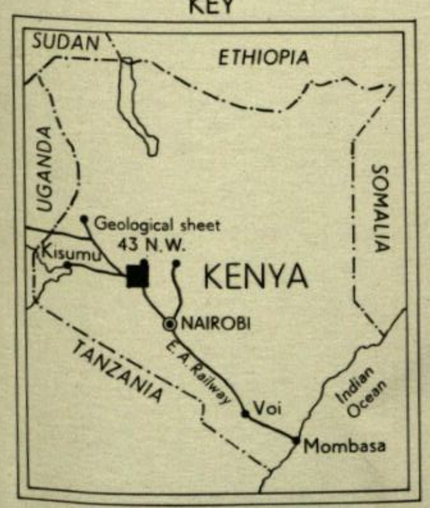
- Tvb1 — Olivine-basalts
- Tvf1 — Graded pumice-tuff intercalations
- Tvb1 — Olivine-basalts
- Tvf1 — Graded pumice-tuff intercalations
- Tvb1 — Olivine-basalts

} Samburu Series ≡ Simbara Basalts

- Geological boundaries
- Geological boundaries, approximate
- Dip of layers in lavas and tuffs
- Faults, tick on downthrow side
- Faults, inferred
- Fissures and joints
- Caldera walls
- Volcanic craters
- Cinder cones
- Edges of Recent lava flows
- Agglomerates
- Mine, working
- Mine, abandoned
- Swamps
- Railway
- Main roads
- Secondary roads
- Trigonometrical stations
- Principal points of aerial photographs
- Form-lines at 200-ft vertical intervals
- Bore-holes, with numbers
- Wells, springs, hot springs
- Trading centre
- Regional boundary
- Forest boundary
- Line of section

Magnetic declination approximately 3° 06′ W.

KEY



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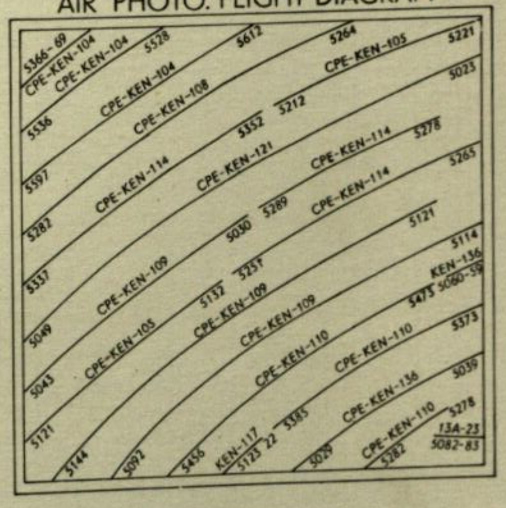

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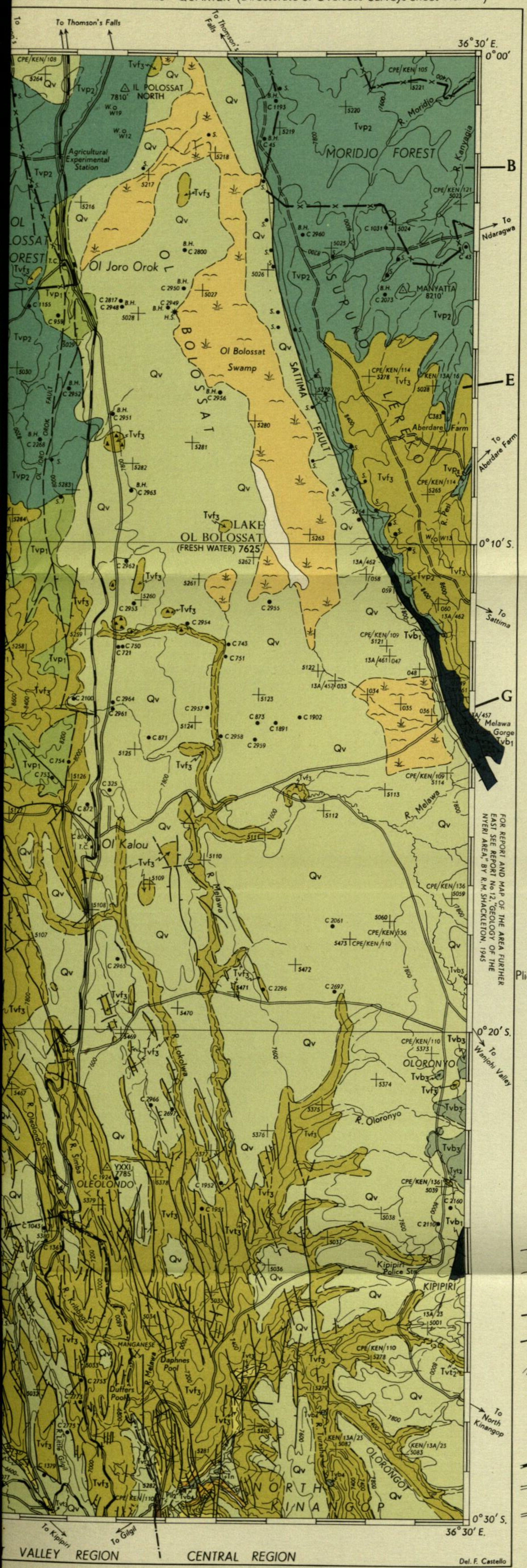

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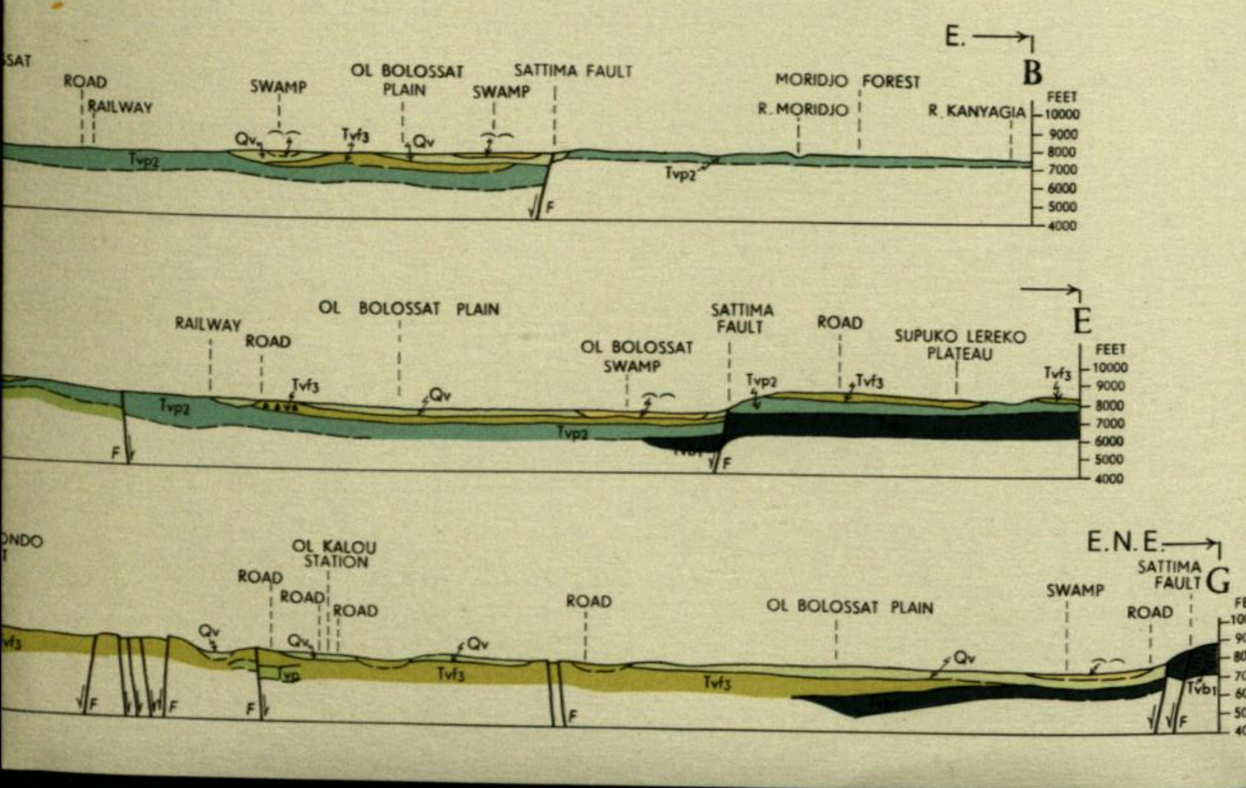

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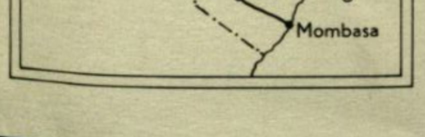

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