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GEOLOGY OF THE NAIROBI AREA

DEGREE SHEET 51, NE QUARTER
(with coloured geological map)

by

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MAP

Geological map of the Nairobi area.
Degree sheet 51, NE Quarter. Scale 1:125,000 at end

PREFACE

This report is another in a series of quarter degree geological sheet descriptions that, regrettably, have been awaiting publication for several years. Field work was completed in 1967 and the geological map published soon afterwards.

The task of preparing the report for publication has been part of a UK-funded project under which geologists of the British Geological Survey have worked alongside Kenyan counterparts of the Editorial Section of the Mines and Geological Department. A major aim of this project is to reduce publication delays in the future so as to ensure the rapid application of geological data to the search for, and controlled development of, Kenya's mineral, groundwater and energy resources.

A significant part of the report is a detailed description of a sequence of Cainozoic volcanic rocks and their development in relation to the Eastern Rift Valley. Although couched in terms that may be no longer acceptable to modern volcanologists, the rock descriptions have much relevance to the economic potential of the Nairobi area.

The best potential is for building stone, particularly in the vicinity of the city of Nairobi, while other promising deposits include diatomaceous earth, bentonite, limestone and ceramic clays.

C Y O Owayo
Commissioner of Mines and Geology

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Chief Geologist

June 1991

ABSTRACT

This report describes an area of approximately 1,200 square miles (3,108 km^2) in the Central Province of Kenya, bounded by latitudes 1°00' and 1°30' S and by longitudes 36°30' and 37°00' E. Physiographically the area may be divided into four units: the lava plains in the east and south; the Kikuyu highlands; the Rift flank and Kedong valley; and the Ngong hills.

The Nairobi area covers part of the eastern flank of the Great Rift Valley and its geological history has been dominated by widespread volcanic activity of Cainozoic age. Lavas, welded tuffs and other pyroclastics cover nearly the entire area and overlie a foundation of poorly-exposed, folded and metamorphosed Precambrian rocks of the Mozambique Belt. Superficial deposits are of Pleistocene and Recent age. All the volcanic rocks have undergone extensive faulting on more than one occasion during the formation of the Rift Valley.

Economic deposits of importance include building materials, diatomite, bentonite, limestone and clay.

Acknowledgements

It would be impossible to mention by name all individuals who helped the author during the survey. In particular, however, he would like to thank the Commissioner of Mines and Geology for the use of transport during a short period in 1967 and the Director of the National Parks for much assistance during mapping of the Nairobi National Park. Thanks are also due to the Senior Geologist, Ministry of Works, and to his staff for access to borehole records and to the many householders and landowners in Nairobi who permitted the author to examine, and collect rock specimens from, their gardens and properties.

1 INTRODUCTION

The area described in this report comprises the north-east quarter of degree sheet 51 (Kenya) and sheet 148 of the Directorate of Overseas Surveys. It is bounded by latitudes 1°00' and 1°30' S and by longitudes 36°30' and 37°00' E and has an area of approximately 1,200 square miles (3,108 km^2).

Most of the field work was carried out in interrupted periods from 1961 to 1963 and during January 1967, and was accompanied by a building materials survey of the same area (Joubert, unpublished).

Topographic data were taken from contoured 1:50,000 maps (SK 11, sheets 148/1 - IV, Edition 6). Air photographs were employed in the field and aided map compilation.

The Kenya-Uganda railway and the Mombasa-Nairobi-Uganda main road pass south-east to north-west across the area and are the principal lines of communication. A branch railway line to Nanyuki and the main road from Nairobi to the north are also major routes. From Nairobi a series of good bus routes radiate to all parts of the country including Mombasa and the coastal region, Namanga in northern Tanzania, Nyeri and Nanyuki on the slopes of Mt. Kenya, Kisumu on Lake Victoria and Kitale at the foot of Mt. Elgon on the Uganda border. The area is well-served with roads and tracks, most of which are passable even during the heaviest rains. Nairobi, as well as being at the intersection of the east-west route to central Africa and the Cape to Cairo road route, is also served by an international airport. A network of internal air services links all the principal centres of Kenya and East Africa.

Because of the altitude, the climate in the area is perhaps one of the finest in the world. Rain falls mainly in the periods October-December and March-May at the change of the monsoons and increases from the plains at Athi River to the Kikuyu escarpment. Table 1, based on the 1966 records of the East African Meteorological Department, shows rainfall recorded at different places in the area. The stations have been divided into groups of three. The first group lies on the Rift shoulder, the second in the centre of the area and the last group in the east. In each group the stations are arranged from north to south. It will be seen that there is an increase in precipitation from the plains at Athi River towards the Kikuyu escarpment, although the statistics do not reveal the considerably lower rainfall within the Rift. Temperature statistics, supplied by the Meteorological Department, are given in Table 2.

Because of the nature of the underlying volcanic rocks and the relatively high rainfall, compared with other parts of the country, the area west of the meridian of Nairobi is fertile and well served by streams.The higher parts of the area are densely forested. Some of the most important crops grown include coffee, tea and sisal while mixed farming is important in some areas.

West of the Nairobi Hill escarpment the land once supported extensive, luxuriant or semi-deciduous woodland, but little remains due to intensive cultivation. It is here that both coffee, on the lower slopes, and tea, on the higher ground, are grown. In contrast, the area to the east of a line Thika-Nairobi-Ngong is either grassland or *Combretum* savannah where sisal flourishes in the drier conditions. The transition, from montane forest on the Ngong hills to the semi-desert conditions of the Kedong valley within a distance of 20 miles (32 km), is striking.

To the south of Nairobi lies a National Park, rich in wildlife and an important tourist attraction within easy access of the city.

Table 1 Rainfall statistics in the Nairobi area

Station	Height above m.s.l. (feet)	Years of records	Days of rain in 1966	Total in 1966 (mm)	Yearly average (mm)
Uplands, Lari Forest Station	7921	58	92	1201	1399
Limuru District office	7491	8	124	1447	1497
Ngong (P.C.'s office)	6700	55	58	705	829
Githunguri	6560	25	140	1243	1316
Kiambu (D.O.'s office)	5796	57	63	781	1058
Nairobi (Ministry of Works)	5450	39	68	952	906
Gatundu	5600	26	78	897	1138
Ruiru Tatu Estate	5100	28	81	805	879
Athi River Station	4949	54	30	533	609

Table 2 Temperature statistics in the Nairobi area (°F)

Station	Height above m.s.l. (feet)	Years of records	Max. recorded temp.	Mean of annual max.	Mean of annual min.	Mean recorded temp.
Limuru Old Station	7350	9	82.0	66.4	50.1	35.0
Lower Kabete Reformatory	6000	16	92.3	74.5	52.2	37.0
Nairobi Station	5495	42	91.0	76.8	55.9	39.0
Athi River Station	4949	4	-	77.0	55.0	-

The area forms part of the eastern slopes of the Great Rift Valley (also known as the Gregory, or Eastern Rift) and rapid, deep incision by innumerable, easterly-flowing streams has resulted in many excellent outcrops and rock sections. With rapid urbanisation of this part of Kenya numerous quarries for a variety of materials have been in operation for a number of years providing further useful exposures. Deep weathering of the volcanic rocks however gives rise to an extremely thick soil cover on the watersheds which masks many critical sections.

2 PREVIOUS GEOLOGICAL WORK

The German professor, Suess (1892) was the first to summarise the geology and structure of the Eastern Rift Valley, from Malawi in the south to the Dead Sea in the north.

In 1893, Gregory (1896) made his first journey through Kenya and returned in 1919 for a second safari to selected areas. His contributions to the geology of the country were published two years later (Gregory, 1921). In this important account he described lavas from the present area, naming and designating the Kapiti Phonolite as the oldest unit of his major volcanic series. Other lavas recognised include the trachytes, agglomerates and building stone of the Nairobi metropolitan area and the basic lavas of the Ngong volcanic centre. Miss Neilson identified and described a number of the specimens collected. Gregory also reports the finding of a Miocene shell, *Clementia cf ungeri* Rolle (fam. *Veneridae*) on the surface at Kabete; a common shell, frequently found in northern Miocene areas of Africa and thought to have been carried by travellers from the coastal limestone regions. This is likely since a former slave route, the railway and the first road from the coast to the interior passed through Kabete now situated on the western outskirts of the capital. As a result of his two journeys to Africa, Gregory made a significant contribution to early knowledge of East African geology in numerous papers dealing with various aspects of the Rift Valley and its environs.

A riebeckite trachyte and a phonolitic trachyte collected by the Schöller expedition from the western edge of the Kikuyu reserve were described by Kunzli (1901) in his account of the volcanic rocks of the Eastern Rift Valley. Prior, of the Mineral Department of the British Museum, later examined a large number of rocks from British East Africa, including Kapiti Phonolite and phonolitic quartz trachytes, collected from the present area by Gregory. He recognised various subdivisions of a Phonolitic Series (Prior, 1903 p 234) and compared many of the lavas with those of other African territories. Walker (1903) and Collie (1912) both passed through Nairobi and briefly commented on the geology of the area and in 1905 Maufe, then of the Geological Survey of Great Britain, made a geological survey along the railway from Mombasa to Kisumu. In his report, published in 1908 (pp 31-40), he gives a brief *resumé* of the geology of Nairobi and north-westwards along the railway line to Kijabe. Like other early authors he describes the principal rock types and comments on the nature of the faulting on the east flank of the Rift Valley above the Kedong.

An account of the Geology of East Africa by Krenkel (1925) describes a volcanic succession based on the work of Maufe and Gregory (1921, pp 248 and 250) and reference is made to specific rock types from the Nairobi area.

During the period 1920-1925 Sikes, then Director of the Public Works Department, conducted underground water surveys in the Nairobi area and the results of his observations and findings are embodied in three accounts (1926, 1934 and 1939). It was his description of the grid-fault structures that led to the name 'Sikes grid' for the style of the late faulting that occurs in the western portion of the present area and in the Rift region. These early geological accounts were followed by further hydrological investigations by staff of the Ministry of Works involving detailed examination of boreholes that were being drilled in the rapidly-growing Nairobi. This work was incorporated in a Technical Report by Gevaerts (1964).

Wayland, formerly Director of the Geological Survey of Uganda, made a survey of materials in Kenya, including the Nairobi area, for use as building stone and in the manufacture of bricks and tiles, limes and cements. His report was issued in 1926 by the Imperial Institute.

Bailey Willis in his study of the Gregory Rift Valley (1936, pp 266-267) divided the Rift region int several basins, one of which, the Kedong basin, forms the western margin of the area. Though not structurally distinct trough, but part of a continuous depression, it is physiographically separate fro the Naivasha basin to the north. He also drew attention to the Kikuyu scarp, the warped peneplain i the neighbourhood of the Nairobi area (*cf* Saggerson and Baker, 1965) and to the Sikes grid whic has affected the volcanic rocks of the Rift Valley region (Bailey Willis, 1936 pp 271-275).

In 1936, after a visit to Kenya, Shand (1936, p 311) gave his impressions of the Rift Valley and state that it was a prolongation and perpetuation of a volcanic fissure. Later (1937) he described a numbe of rocks collected from the Kedong scarp.

A classification of some rhyolites, trachytes and phonolites from Kenya was given by W Campbe Smith (1931, pp 121-258) and among the many rocks described and analysed were specimens collecte from the Nairobi area. In a later paper (1950), Campbell Smith reviewed the terminology of kenyte with reference to Kapiti Phonolite, comparing the rocks with examples from the Kapiti plains adjace to the present area.

In the nineteen thirties Bowen visited the country and made an excursion into the Rift Valley. H made collections of lavas from various parts of the country and in particular from the Nairobi are His studies of these fine-grained rocks had far reaching effects beginning with his paper, publishe in 1937, in which he first gave his celebrated account of Petrogeny's Residua System illustrating h experimental work with personal observations on East African lavas.

A detailed soil survey of the Nairobi area and environs was initiated by Jones in 1952 and complete by Scott of the East African Agriculture and Forestry Research Organisation (Scott, 1963) wh described a variety of soils developed under a wide range of climatic conditions. Minerals typical metamorphic rocks were noted by Stephen, Bellis and Muir (1956) in soils from the Embakasi are

Subsequently Häkli (1960, pp 99-108) investigated the nature of the alkali-feldspars in certain Ken rocks, and specimens of the Kapiti Phonolite, collected by the Finnish East African Expedition i 1952 from the Stony Athi River, were included in the study.

Numerous other geological investigations have been made in the Nairobi area for a variety of purpose and are mainly recorded in unpublished departmental reports of the Mines and Geologica Department, including those by Shackleton, Binge, Temperley, Joubert, Pulfrey and Saggerson. L S B Leakey, has examined many Stone Age implements from the area though detailed accounts the numerous finds and sites have not been published. Various lavas have been collected from th Nairobi succession and have now been dated.* Other work performed includes palaeomagneti studies by members of the Physics Department of the University College of Nairobi (Mussett *et a* 1964 and 1965). In a recent account of Nairobi, Williams (1967) gives an outline of the geology in i regional setting.

* For more recent age data on rocks from the Nairobi area. see Baker *et al* (1988) (Ed).

3 PHYSIOGRAPHY

Volcanic activity has dominated the geological history of the Nairobi area since Miocene times and has controlled the geomorphological evolution. Apart from a few isolated occurrences of Precambrian and Quaternary rocks the area is composed of volcanic rocks that originated in the Rift region and flowed eastwards on to a warped and partly dissected, pre-Miocene erosion surface, cut across the older crystalline rocks.

Four prominent physiographic units are recognised in the Nairobi area reflecting the volcanic rock types and the tectonic movements which have affected them. They are: the lava plains; the Kikuyu highlands; the Rift flank; and the Ngong hills. The main drainage is consequent upon the regional slope of the volcanic rocks towards the east, while subsidiary internal drainage into the Rift region is confined to the western part of the area. A more comprehensive review of the physiography of the area is given by Morgan (1967).

The lava plains east of a line Ruiru-Nairobi-Ngong are underlain by a succession of lava flows alternating with lake beds, stream deposits, tuffs and volcanic ash. These plains, comprising mainly the Athi plains and the northern section of the Kapiti plains, extend westwards, rising from 4,900 feet (1,493 m) at Athi River, to 6,000 feet (1,829 m) in the faulted region near Ngong. They form gently rolling grasslands with a fairly even surface, broken occasionally by low east-facing scarps that represent the margins of partly eroded lava flows. Gullies and canyon-like gorges, cut into the lavas, have steep walls, such as those along the Mbagathi valley. Further east this valley widens slightly where soft material is being actively eroded.

East of a line Lari-Kandizi the volcanic country is relatively undisturbed by faulting and the innumerable east-flowing streams are consequent upon the prevailing slope of the volcanic rocks. These lavas flowed onto the plains from centres and fissures on the high flank of the Rift region at almost 8,000 feet (2,438 m) near Lari.

Partly due to continued uplift of the Rift region during the late Tertiary and probably early Pleistocene times and mainly due to the continual deposition of lavas and tuffs onto an easterly-inclined surface, the streams which drain the often densely forested Kikuyu highlands have become deeply incised and can be shown to have re-excavated their former courses. This is particularly notable in the streams draining the area north of Githunguri. During part of the volcanic history of the area, ignimbritic lavas and welded tuffs and ash flows poured down the valleys inundating and choking them with volcanic rock which rarely overflowed onto the interfluves. The original valleys filled by these tuff-flows were then re-excavated. Little lateral erosion has taken place and the main work of erosion was concentrated in the streambeds where channelling and corrasion were at a maximum. As a result of uplift, the valleys have steep gradients, are narrow or sharply V-shaped, and show many of the features of young valleys. Because of rapid downcutting and the relatively soft character of much of the younger volcanic rocks, the consequent streams flow in parallel courses and instances of river capture are limited. Gregory (1921, pp 154-155) noted one example near the present day Ruiru dam where the river Kiruchi has captured the head streams of the Mukuyu river and Morgan (1967, p 17) cites another fine example south of the Ngong hills where the river Kiserian has captured several east-flowing streams.

Although most of the streams are permanent in the western half of the area, it is during the heavy rains that they become most active. Headward erosion of gullies and tributaries then becomes common. Many parts of the area receive more than 900 mm of rain *per annum* usually concentrated

during a few months of the year. At these times the load transported by the streams, by erosion of the thick soil cover, may be so great that the rivers become streams of red mud. Waterfalls are common in many stream courses and are due to variation in the resistance of the rocks of the lava-tuff sequence. In some instances steepening of stream gradients has been caused by faulting, a common feature in the western portion of the area where the Rift faults are prominent.

The western part of the area is occupied by the eastern shoulder of the Rift Valley where prominent scarps and fault blocks give a characteristic physiographic expression described in detail by Bailey Willis (1936, p 40). It comprises the central section of the Kikuyu scarp which, starting as a general flexure in the Magadi region near the Tanzania border, gradually rises northwards to a maximum elevation in the Aberdare mountains north of the present area. The simpler structures south of Magadi are replaced northwards by 'grid faulting'; blocks and fault splinters having been tilted at different angles and down-thrown to both east and west. Accordingly the flank of the Rift in the present area is divided into narrow strips which rise to different elevations and which are bounded by nearly vertical fault and fault-line scarps. The faults are often of short lateral length but may extend for many miles along well-defined scarps such as the Ngoirobi-Mrithu fault scarp, three miles west of Limuru. From the Kedong escarpment west of Nairobi the descent to the floor of the Rift Valley is through a sequence of steep faults (Fig 9) arranged *en échelon* (Plate 6). This Rift section has its own internal drainage pattern, is very arid, and contrasts markedly with the remainder of the area. This is due to the intense faulting causing peculiar groundwater conditions and departure from the east-west drainage pattern so well developed to the east of the Rift flank. As Sikes points out (1926, pp 389-390), in place of east-west valleys, carved by erosion along the maximum gradient of the inclined lavas, there is a series of north-south valleys bounded by steep cliffs either on one or on both sides. These long parallel valleys often open out into basins that in earlier pluvial periods were occupied by lakes but now are filled with fluviatile and lacustrine deposits. The well-cultivated area to the east gives place to cliffs and boulder-strewn slopes covered only by scanty vegetation of thorn scrub and tufted grass. The valleys contain no permanently flowing water and any rain rapidly infiltrates the parched, dusty soils.

A number of prominent depressions (swamp pits of Gregory, 1921 p 156) occur within the Rift fault zone west of the longitude of Nairobi. They vary in size from a few scores of feet across to the largest, the Nyakumu depression, approximately one and a quarter miles (2 km) square. Some have been thought to be due to volcanic vent deflation. Detailed mapping, however, shows that these depressions are merely downfaulted lava blocks adjacent to N-S trending faults and fractures, their topographic expressions being little modified by erosion (Plate 2). The underlying lava in the downthrown blocks or strips is responsible for local perched water-tables and hence the development of internal drainage and swamps or lakes in which sediments accumulated. Many such areas, which are often quadrangular in shape reflecting the fault pattern, are undoubtedly derived to some extent by underground seepages. In others the retention of water for long periods, even during periods of drought, indicates that there is little infiltration loss.

The Ngong hills form a distinct topographic unit dominating the Nairobi landscape (Plate 1). They lie immediately south of the Kikuyu highlands astride the Rift scarp and their distinctive basic rocks in contrast to the remainder of the area, indicate that the range represents the eastern half of a faulted and now much eroded, volcano 8,074 feet (2,752 m) high rising more than 4,000 feet (1,219 m) above the floor of the Rift. The western portion has been down-faulted into the Rift and buried beneath a cover of younger rocks. The steep western flank of the hills is in marked contrast to the moderate slope of the east side. Ol Esayeiti, another dissected volcanic mass rising to over 7,000 feet (2,134 m) forms the south-western corner of the area (Fig 9).

4 SUMMARY OF GEOLOGY

The rocks of the Nairobi area mainly comprise a succession of lavas and pyroclastics of Cainozoic age overlying a foundation of folded Precambrian schists and gneisses of the Mozambique Belt. The crystalline rocks are rarely exposed but occasionally fragments are found in agglomerates derived from the former Ngong volcano. For the period between late Precambrian and Tertiary times no geological record exists in central Kenya except that the area is known to have undergone peneplanation on more than one occasion.

Volcanicity is genetically associated with tectonic movements attendant upon rifting. Doming, linear warping and erosion of the sub-Miocene erosion surface had taken place prior to the extrusion of the first lava flows which flooded the eastern plains during mid-Miocene time. Subsequently volcanicity continued intermittently until Recent time, the area being covered by lavas and pyroclastics from fissure eruptions during the development of the Rift Valley. Two central volcanoes, Ngong and Ol Esayeiti, were also active during this period.

These rocks form part of a wider East African alkaline suite characterised by a dominance of soda over potash which distinguishes them from the potash-rich alkaline rocks of the Western Rift Valley. Strongly and mildly alkaline series are recognised. The former series is represented by feldspathoid -bearing phonolites, basanites, tephrites and more basic varieties, while the latter includes feldspathoid-free rocks containing soda-rich amphiboles and pyroxenes. Both series show an increase in silica content with differentiation and include trachytes, rhyolites and obsidians.

All formations are covered by deep soils and gravels of Quaternary age. Within the Rift, loess and lacustrine deposits, some containing diatomaceous beds, reflect major changes in climatic conditions.

Faulting has affected the western part of the area on at least three occasions, resulting in spectacular topography.

Early writers assigned various ages to the volcanic rocks. Some thought that many of the formations were Tertiary to Recent but Gregory (1921) believed that the earliest lavas of the Kapitian Series were Cretaceous. Recent age-dating however, indicates that volcanicity began in Upper Miocene times and had almost completely waned by the end of the Pleistocene. It is likely that volcanic activity continued into Recent times in areas to the west; the eruptive periods of this later period being represented by weathered tuff and ash layers within soil profiles. Table 3 gives ages of rocks and minerals from the region determined by Evernden *et al* (1964) . A stratigraphic correlation of the principal strata of the Nairobi and neighbouring areas is given in Table 4.

Table 3 K/Ar ages of rocks of the Nairobi region

Reference	Rock type	Locality	Mineral	Age (M
KA 661	Plateau Trachyte Series	As KA 650 but different flow	Anorthoclase	0.80
MB/26	Limuru Trachyte	Quarry, Limuru 1°07' S, 36°37' E	Sanidine and Anorthoclase	1.55 ± 0.9 1.59 ± 0.9
KA 654	Limuru Trachyte	N end of Ngong hills 1°20' S, 36°35' E	Anorthoclase	1.72
KA 650	Plateau Trachyte Series	Magadi road 1°32'30' S, 36°34' E	Anorthoclase	1.74
KA 652	Orthophyre Trachyte	Nr. Legamunge BH. N of Magadi road 1°32'30' S, 36°27' E	Anorthoclase	2.40
MB/41	Ngong Basanite	S end Ngong hills, 1°27' S, 36°37' E	Whole rock	2.58 ± 0. 2.53 ± 0.
KA 662	Olorgasailie Trachyte	Top of Olorgasailie mtn., 1°43' S, 36°37' E	Anorthoclase	2.70
MB/25	Nairobi Trachyte	Kenyatta Ave, Nairobi 1°18' S, 36°48' E	Whole rock	3.45 ± 0. 3.17 ± 0.
MB/32	Nairobi Stone	Getathuru river Muthaiga, 1°15' S, 36°56' E	Sanidine and Anorthoclase	4.84 ± 0. 5.67 ± 0.
KA 663	Nairobi Phonolite	Beacon ranch quarry 1°23' S, 36°56' E	Anorthoclase	5.2
MB/33	Ol Eseyeiti Tephrite	Loodo Ariak 1°32' S, 36°35' E	Feldspar	5.64 ± 0. 5.85 ± 0.
KA 653	Olorgasailie Phonolite	Loitigoshi 1°38' S, 36°45' E	Nepheline	5.83
MB/27	Nairobi Phonolite	Quarry, Nairobi Airport 1°18' S, 36°55' E	Feldspar	10.22 ± 0 9.74 ± 0.
MB/28	Kapiti Phonolite	Stony Athi river 1°27'30" S, 37°0'30" E	Feldspar Nepheline	12.90 ± 0 13.10 ± 0
KA 651	Kapiti Phonolite	Stony Athi river 1°27'30" S, 37°0'30" E	Nepheline	13.40

Rocks collected by Curtiss, Evernden and Miller, University of California.

Table 4 Correlation of Cainozoic rocks in the Nairobi region

		SOUTH		CENTRAL	NORTH		NORTH-SOUTH
		MAGADI (Baker, 1958 and 1963)	KAJIADO (Matheson, 1966)	NAIROBI (Saggerson, 1968)	KIJABE (Thompson, 1964)	NYERI (Shackleton, 1954)	EASTERN RIFT (Gregory, 1921)
RECENT		Loess, Evaporite Series, Boulder Beds	Soils	Soils, ashes, alluvium loess, gypsiferous beds	Soils and Ashes		
PLEISTOCENE	U	High Magadi Beds		Longonot Trachyte	Trachytes Lacustrine deposits	Moraines and red earths	
	M	Olorgesailie Lake Beds	Olorgesailie Lake Beds	Sediments (Kandizi Valley) Rhyolites, trachyrhyolites and obsidians (with interbedded diatomites)	Pyroclastics Trachytes Kijabe Basalt Welded tuffs	Naromoro Ash	
	L	Pebble beds and sands Oloronga Beds Chert Series Lavas and ashes Ol Doinyo Nyegi Volcanics Orthophyre Trachyte Plateau Trachyte Series Lengitoto Trachyte Ol Keju Nero Basalts Basalts of S Magadi	Orthophyre Trachyte Alkali Trachyte	Upper Trachyte Division: Welded tuffs and pyroclastics Orthophyre Trachyte Limuru Trachytes	Pyroclastics and Laikipian Basalts		Naivashan Series
PLIOCENE		Kirikiti Basalts Lenderut Volcanics Shombole Volcanics Olorgesailie Volcanic Series (Relative ages of Pliocene volcanics in the Magadi area, unknown)	Ol Keju Nero Basalts Ol Esayeti Volcanics Kerichwa Valley Tuffs and Ol Doinyo Narok Agglomerate Olorgesailie Volcanic Series Mbagathi Trachyte Upper Athi Tuffs	Middle Trachyte Division: Tigoni Trachyte, Karura Trachyte, Ruiru Dam Trachyte, Kabete Trachyte, Kerichwa Valley Tuffs Ol Esayeti Volcanics Lower Trachyte Division: Ngong Volcanics, Ol Doinyo Narok Agglomerate, Ololua Trachyte, Nairobi and Kiambu Trachytes, Sediments and Tuffs, Nairobi and Kandizi Phonolites, Mbagathi Phonolitic Trachytes Athi Tuffs and Lake Beds	Sattima Series and Laikipian Lavas Simbara Series	Upper Laikipian Basalts Kenyite, agglomerates Lower Laikipian Basalts Sattima Series and tuffs Thomson's Falls Phonolites Simbara Series	Laikipian Series
MIOCENE			Kapiti Phonolite	Simbara Basalt Kapiti Phonolite	Simbara Series		Doinyan Series Kapitian Series*
PRECAMBRIAN		Basement System	Basement System	Metamorphic rocks of the Mozambique Belt	not exposed	not exposed	Gneisses and schists

xxx Faulting – – – Erosion ~ ~ ~ Major Unconformity

*Beginning in the Upper Cretaceous according to Gregory

5 PRECAMBRIAN ROCKS OF THE MOZAMBIQUE BELT

Crystalline rocks, of Precambrian age and belonging to the Turoka Group,* are exposed in the vicinity of Leopard Cliffs and southwards to the valley of the Kitengela where the volcanic cover has been removed by erosion.

These small, highly weathered outcrops of foliated, metamorphic rocks consist of layered, fine-grained schists and coarse gneisses that have been invaded by pink quartzofeldspathic pegmatites. Biotite-garnet-epidote gneisses, hornblende gneisses and quartz-feldspar gneisses were all identified at the locality. Variations in strike and dip of these rocks are due to generally small-scale folds. Lineations which plunge at approximately 14°-21° to the south-west are 'b' lineations and are considered to be related to NE-SW fold trends (see Chapter 8) that have been recognised in neighbouring areas (Saggerson *et al*, 1960).

Near the southern border predominant biotite gneisses, frequently migmatitic, crop out in the valley of the Kitengela. Similar rocks also form isolated exposures two miles (3.2 km) to the north where they occur in shallow stream courses or as float on interfluves. The structures revealed in these rocks indicate N-S trending folds. These markedly different fold trends in the two sub-areas described are typical of a large part of southern Kenya which is underlain by Precambrian rocks that have been subjected to at least two phases of deformation.

A period of erosion prior to the deposition of the overlying volcanic rocks is indicated by exposures on the south bank of the Mbagathi River near Leopard Cliffs where a thin layer of gneissic rubble separates Precambrian and volcanic rocks and clearly is derived from the gneisses by weathering. Elsewhere, evidence from boreholes at Nairobi station and near Athi River township (*eg* BH 1937 *c* 37°00' E, 1°24' S) ** indicates that clays, sands and detritus immediately overlie the crystalline rocks. That the lavas and sediments of Tertiary age were deposited upon an undulating surface cut across the crystalline foundation rocks is suggested by differences in elevation above sea-level of the unconformity at different localities. At Leopard Cliffs it lies at approximately 5,100 feet (1,554 m), in the Athi River at a point four miles (6.4 km) north-east of Athi River Station (just beyond the eastern boundary of the present area) it lies at just under 4,900 feet (1,494 m), and it was penetrated at about 2,750 feet (838 m) above sea-level in a borehole at Nairobi station. The presence of crystalline rocks at about 4,985 feet (1,519 m) above sea-level in a borehole BH 2655 at the railway *landhies*, *** 3.5 miles (5.6 km) south-east of Embakasi station, and at approximately 300 feet (91 m) below the present surface on Wattle Blossom Farm, five miles (8 km) north-west of Athi River township, reveals the presence of former topography in this area. Sikes (1939, p 14) also reports crystalline rocks at about 4,950 feet (1,509 km) above sea-level in a borehole near the Nairobi National Park between Nairobi and Mbagathi.

Lavas extruded at the Ngong volcanic centre now exposed (in the Ololua area) in a tributary of the Kandizi river, at a point three miles (4.8 km) east of Ngong township, contain fragments of hornblende and quartz-feldspar gneisses indicating that crystalline metamorphic rocks were penetrated at depth during the formation of the Ngong vent. The occurrence is interesting in that no other lavas or

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* The age of phlogopite in crystalline limestone from Turoka. 30 miles south of the present area, indicates an age of 505 ± 25Ma for the latest metamorphic events affecting these rocks (Author)

** Borehole numbers are allocated by the Water Development Department. Nairobi (Author)

*** Railway siding (Ed)

fragmentary deposits were noted containing megascopic fragments of Precambrian rocks. Soil samples from the Embakasi area, however, were found by the author to contain kyanite and other typical metamorphic minerals suggesting that some of the volcanic material of the Nairobi area, which on weathering gave rise to the Recent soils, had during their eruption incorporated pieces of crystalline Basement. Stephen *et al* (1956) also found that the soils near Embakasi contain the metamorphic minerals sillimanite, kyanite, staurolite and garnet.

The pre-Tertiary basement is concealed throughout most of the area by large accumulations of mainly Pliocene volcanic rocks. No evidence of earlier sedimentation is present, the only events recorded being the cyclic peneplanations of the crystalline foundation in early Tertiary time.

6 CAINOZOIC VOLCANIC AND ASSOCIATED ROCKS

The geological history of the Nairobi Area has been dominated by volcanic activity whereby a thick succession of alkaline lavas and associated tuffs began accumulating in mid-Miocene time and continued into at least the upper Pleistocene. Practically the entire Nairobi area is covered by these volcanic rocks derived from the Rift Valley region and estimated to amount in volume to more than 250 cubic miles (1,042 km^3) and covering an area of nearly 1,200 square miles (3,000 km^2). Part of a more extensive late Cainozoic (Pliocene-Recent) petrographic province, they extend from Ethiopia in the north to Tanzania in the south.

In the present area, the extent of the lava flows beneath the cover of Limuru Trachytes, as deduced from boreholes, is given in Fig 1 and a stratigraphic classification in Table 4. Volcanism began with the extrusion of the Kapiti Phonolite which has been dated at 13 Ma confirming the evidence by numerous authors (*eg* Saggerson and Baker, 1965) that this lava was extruded onto a dissected erosion surface which had developed across nearly the entire East African region before the onset of Miocene time. Violent volcanic activity was restricted to a number of centres within the Rift region during the Pleistocene and fragmentary deposits derived from them are now represented by weathered pyroclastics interstratified within the lava succession and in the deep red soils.

Although the mass of lava thins appreciably in an easterly direction individual flows have a generally constant thickness. The eastern limits of many of the flows are marked by erosional scarps forming the terminal walls of the more resistant lava sheets. Maximum accumulations can be expected adjacent to the Rift zone and are likely to be in excess of many thousands of feet as a result of down-warping of the sub-Miocene erosion surface into the Rift. With the exception of the Ngong volcano and its satellites Ol Esayeiti and Ngoroi, no vents were discovered and it must be concluded that the bulk of the material was derived from fissure-type eruptions, the centres of dispersion being located in the Limuru-Kikuyu region between the two major volcanoes of Ngong and Niandarawa, 50 miles (80 km) to the north of Ngong. It seems significant that the eruptive products of these volcanoes, almost entirely of basic composition, are restricted in their occurrence yet provide the greatest topographic expression.

The lavas are predominantly phonolitic and trachytic in character, the pyroclasts being dominantly f trachytic. The accumulations of basaltic and nephelinitic rocks, associated with the now eroded Ngong volcano, have rarely been reported from the hundreds of borehole records, except in the north-east where thin flows of Tertiary basaltic lava have clearly been derived from the area of the present Aberdare range. The large volume of trachytic and phonolitic lavas and their associated ash-flow deposits imply the presence of large masses of eruptible magma of acid composition.

1 Kapiti Phonolite

Wherever the contacts of the Kapiti Phonolite are seen, the unit underlies associated volcanic rocks and consequently must be the oldest lava of the succession, forming the lowest division of Gregory's Kapitian Series (1921, p 193). This has been confirmed by numerous borehole sections which reveal that the sub-volcanic floor over which the Kapiti Phonolite was extruded was irregular and cut in Precambrian rocks.To the west of an arcuate ridge of crystalline rocks, from Ol Doinyo Sapuk through the Mua hills southwards to Konza, a valley, now occupied by the Kapiti Phonolite, extended in a northerly direction from latitude 1°22' S, longitude 36°57' E through Athi River and thence north-westwards towards the Kahawa region, a descent of more than 1,000 feet (305 m) in 35 miles (56.3 km). A low spur projecting into the valley is represented by the occurrence of

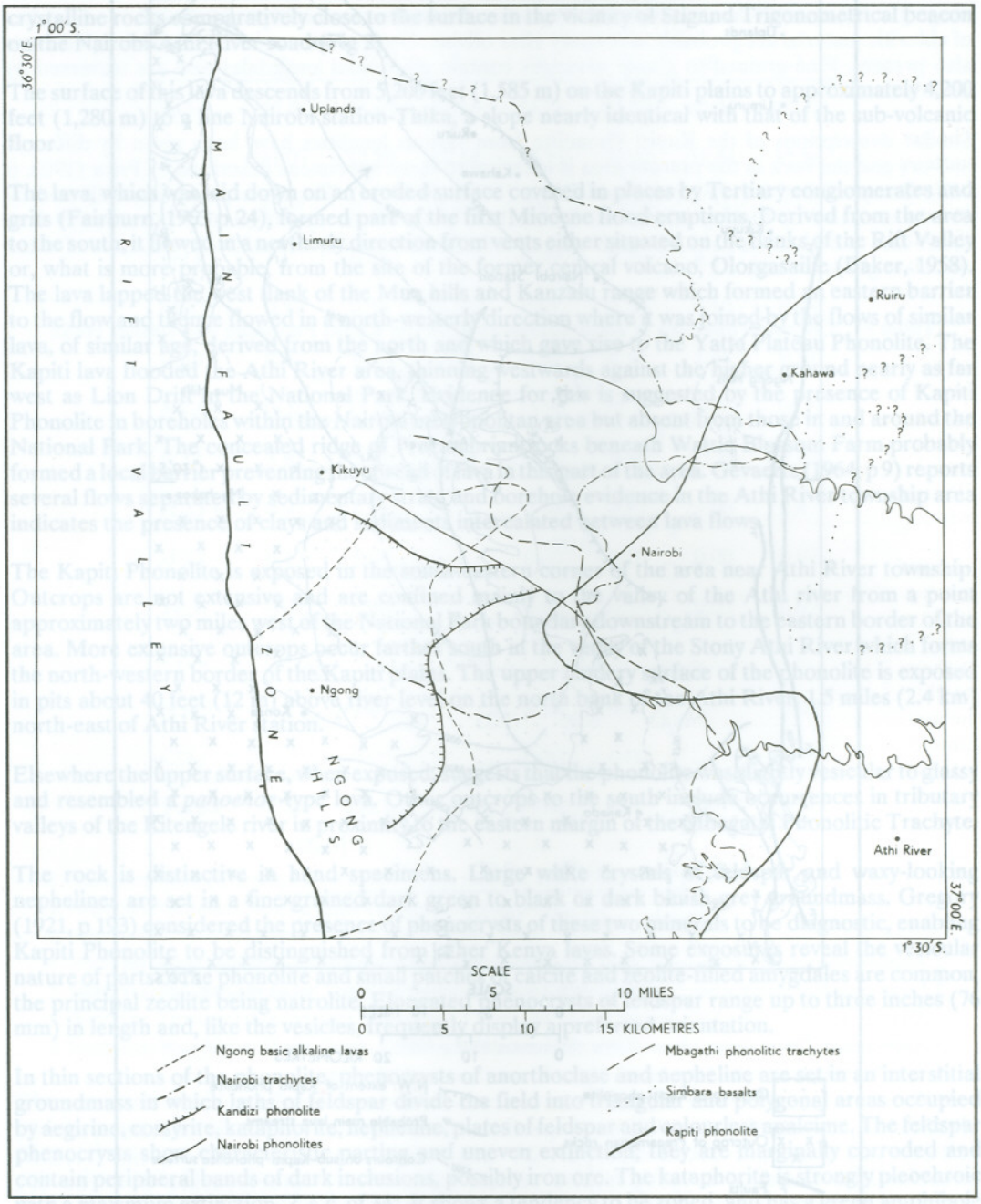


Figure 1 Map showing the extent of early lava flows in the Nairobi area

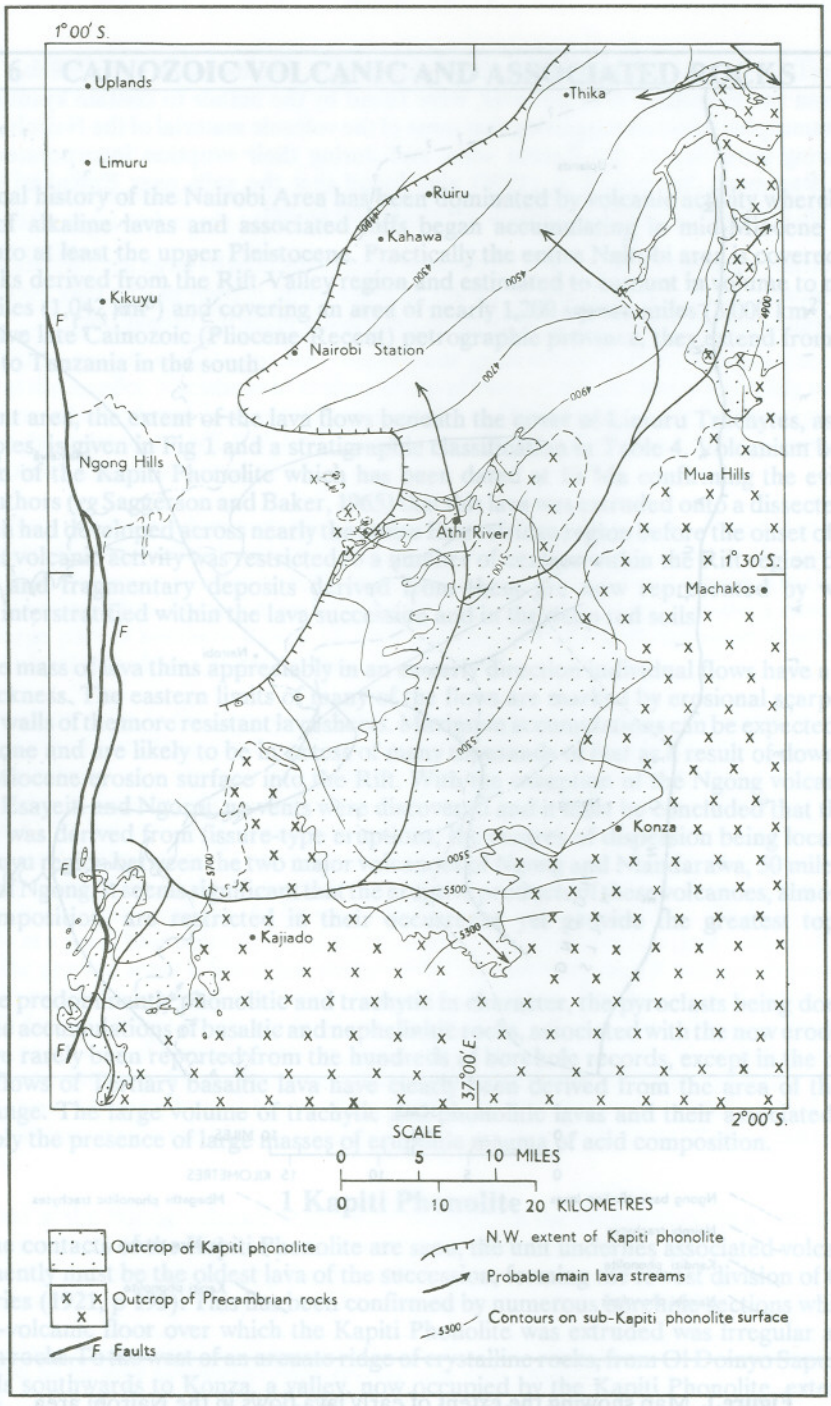


Figure 2 Diagram to show the sub-lava surface in the Nairobi area and the former extent and flow direction of the Kapiti Phonolite

crystalline rocks comparatively close to the surface in the vicinity of Stigand Trigonometrical beacon on the Nairobi-Athi River road (Fig 2)

The surface of this lava descends from 5,200 feet (1,585 m) on the Kapiti plains to approximately 4,200 feet (1,280 m) to a line Nairobi station-Thika, a slope nearly identical with that of the sub-volcanic floor.

The lava, which was laid down on an eroded surface covered in places by Tertiary conglomerates and grits (Fairburn, 1963 p 24), formed part of the first Miocene flood eruptions. Derived from the area to the south, it flowed in a northerly direction from vents either situated on the flanks of the Rift Valley or, what is more probable, from the site of the former central volcano, Olorgasailie (Baker, 1958). The lava lapped the west flank of the Mua hills and Kanzalu range which formed an eastern barrier to the flow and thence flowed in a north-westerly direction where it was joined by the flows of similar lava, of similar age, derived from the north and which gave rise to the Yatta Plateau Phonolite. The Kapiti lava flooded the Athi River area, thinning westwards against the higher ground nearly as far west as Lion Drift in the National Park. Evidence for this is suggested by the presence of Kapiti Phonolite in boreholes within the Nairobi metropolitan area but absent from those in and around the National Park. The concealed ridge of Precambrian rocks beneath Wattle Blossom Farm probably formed a local barrier preventing the spread of lava in this part of the area. Gevaerts (1964, p 9) reports several flows separated by sedimentary strata and borehole evidence in the Athi River township area indicates the presence of clays and sediments intercalated between lava flows.

The Kapiti Phonolite is exposed in the south-eastern corner of the area near Athi River township. Outcrops are not extensive and are confined mainly to the valley of the Athi river from a point approximately two miles west of the National Park boundary downstream to the eastern border of the area. More extensive outcrops occur farther south in the valley of the Stony Athi River which forms the north-western border of the Kapiti plains. The upper cindery surface of the phonolite is exposed in pits about 40 feet (12 m) above river level on the north bank of the Athi River, 1.5 miles (2.4 km) north-east of Athi River station.

Elsewhere the upper surface, when exposed, suggests that the phonolite was slightly vesicular to glassy and resembled a *pahoehoe*-type lava. Other outcrops to the south include occurrences in tributary valleys of the Kitengele river in proximity to the eastern margin of the Mbagathi Phonolitic Trachyte.

The rock is distinctive in hand specimens. Large white crystals of feldspar and waxy-looking nephelines are set in a fine-grained dark green to black or dark bluish-grey groundmass. Gregory (1921, p 193) considered the presence of phenocrysts of these two minerals to be diagnostic, enabling Kapiti Phonolite to be distinguished from other Kenya lavas. Some exposures reveal the vesicular nature of parts of the phonolite and small patches of calcite and zeolite-filled amygdales are common, the principal zeolite being natrolite. Elongated phenocrysts of feldspar range up to three inches (76 mm) in length and, like the vesicles, frequently display a preferred orientation.

In thin sections of the phonolite, phenocrysts of anorthoclase and nepheline are set in an interstitial groundmass in which laths of feldspar divide the field into triangular and polygonal areas occupied by aegirine, cossyrite, kataphorite, nepheline, plates of feldspar and colourless analcime. The feldspar phenocrysts show characteristic parting and uneven extinction; they are marginally corroded and contain peripheral bands of dark inclusions, possibly iron ore. The kataphorite is strongly pleochroic with a maximum extinction, $Z \wedge c$, of 34°. It shows a tendency to be zoned, and has a green amphibole overgrowth. The mineral is associated with green aegirine and deep red-brown cossyrite. A rare amphibole showing pale blue to grey pleochroism is identified as arfvedsonite. The thin laths of anorthoclase exhibit Carlsbad twinning. Nepheline in the groundmass occurs as small euhedra,

ranging in size up to 0.4 mm, often enclosed by the analcime. Serpentinised pseudomorphs and patches of chloritic material are probably secondary after olivine. Opaque iron ore and prismatic apatite are also present. Fine-grained to glassy selvedges contain ellipsoidal amygdales and are traversed by perlitic fissures.

Similar descriptions of the Kapiti Phonolite from various localities have been given by different authors and the rock in the present area is identical to those specimens described by Prior (1903, p 241), Campbell Smith (1950, p 10) and Baker (1954, pp 13-14). The same phonolite, collected by Bowen and also by Oakley (Campbell Smith, 1950 p 4), occurs approximately 18 miles (29 km) south-east and 15 miles (24 km) south-west of Athi River township respectively. Analyses of these rocks are given in Table 12. *

Table 5 Chemical analyses of alkali-feldspars from the Kapiti Phonolite and similar rocks

	1	2	3	4
SiO_2	65.61	62.79	64.33	64.80
Al_2O_3	20.48	22.12	20.94	21.14
Fe_2O_3	}0.20	0.36	0.20	0.68
FeO		0.41	0.58	-
MgO	0.00	-	-	0.10
CaO	7.03	3.76	2.01	1.18
Na_2O	6.26	7.35	7.22	6.94
K_2O	0.32	2.98	4.71	5.26
H_2O+	0.03	0.19	0.27	
H_2O-	0.00	0.07	0.10	}0.20
Totals	99.93	100.03	100.36	100.0

1. Alkali-feldspar phenocryst (anorthoclase). From Kapiti Phonolite, Stony Athi River. (Häkli, 1960 p 101).
2. Loose crystals of anorthoclase ('potash-oligoclase'). Crater of Mount Erebus, Antarctica. (Mountain, 1925 p 331).
3. Anorthoclase. Crater slopes, Mount Kenya. (Mountain, 1925 p 331).
4. Anorthoclase phenocrysts. From kenyte, Mount Kenya. (Spencer, 1937 p 453).

Häkli (1960), investigating the feldspars in specimens from the Stony Athi River, has shown that the phenocrysts are pure alkali-feldspar. 2V angles indicate a member of the triclinic anorthoclase-sanidine-cryptoperthite series, structurally intermediate between the anorthoclase-sanidine and low albite-orthoclase series. The feldspar is not unmixed. The groundmass feldspars are unmixed and have the composition Or_{82} (Häkli, 1960 p 106) which is a measure of the degree of their zeolitization, the sodium feldspar content now being represented by analcite.

* A partial analysis of Kapiti Phonolite from Athi River Station gave SiO_2 54.00% (Sikes, 1939 p 16) (Author).

Table 6 Chemical analyses of some nephelines from East Africa

	1	2	3	4	5	6	7
SiO_2	46.41	44.47	41.16	44.26	41.30	40.20	42.12
Al_2O_3	31.07	32.10	33.54	32.25	33.07	32.51	32.96
Fe_2O_3	0.78	0.94	0.80	0.97	1.77	1.25	0.65
FeO	-	0.18	-	0.29	0.28	0.57	0.52
MgO	0.11	0.03	0.23	0.01	0.30	0.10	0.08
CaO	0.87	0.47	2.64	0.32	0.51	1.44	0.91
Na_2O	15.67	15.54	12.80	15.96	12.25	10.86	14.21
K_2O	3.81	5.23	6.54	5.06	9.36	12.22	7.83
H_2O+	0.97	1.11	2.74	0.64	0.87	0.00	0.47
H_2O-	0.17	0.04	-	0.00	0.10	0.00	0.02
TiO_2	0.00	0.04	-	0.05	0.13	0.05	0.07
P_2O_5	-	-	0.33	-	-	-	-
MnO	-	0.01	-	0.01	0.01	-	0.01
CO_2	-	0.00	-	0.00	0.00	-	0.00
Totals	99.86	100.16	100.78	99.82	99.95	99.77	99.85

1. Nepheline. From phonolite, Nairobi. (Bowen and Ellestad, 1936 p 363).
2. Nepheline. Ol Esakut, Kenya. (Smith and Sahama, 1954 p 444).
3. Nepheline. From ijolite, Usaki, Kenya. (Pulfrey, 1949 p 449).
4. Nepheline. Lumbwa, Kenya. (Smith and Sahama, 1954 p 444).
5. Nepheline. Nyamununka crater, Uganda. (Smith and Sahama, 1954 p 444).
6. Nepheline. From potash-ankaratrite, Nyiragongo, Congo. (Smith and Sahama, 1952 p 460).
7. Nepheline. Near Mount Goma, Congo. (Smith and Sahama, 1954 p 444).

The composition of the alkali-feldspar phenocrysts from the Kapiti Phonolite is quoted in Table 5 and is compared with other anorthoclase crystals from Mount Kenya and Antarctica. Although the Mount Kenya and Antarctica specimens show a steady increase in CaO with increase in the Na_2O/K_2O ratio, the Kapiti Phonolite anorthoclase exhibits a marked rise in the ratio of alkalis with increase in lime. An analysis of the nepheline from Kapiti-type phonolite 53 miles (85 km) north of Nairobi on the Nairobi-Nyeri road is given in Table 6 together with other nephelines from East African rocks.

2 Simbara Series

In the Nyeri area, Shackleton (1945, pp 2 and 6) recognised an early (Simbara) series of basaltic lavas and agglomerates which he correlated with those volcanic rocks in the Nairobi area older than the Kerichwa Valley Tuffs. Representatives of the same series are thought to occur in the Nairobi area.

Small outcrops of basalt occur in the Wabura river near Gatundu in the north-east corner and are thought to be equivalent to the Simbara basalts mapped by Thompson (1964) in the Kijabe area to the north. The basalts are considered to be older than pyroclastic rocks, phonolites and non-porphyritic trachytes of the Sattima Series which in the present area can be shown to overlie the Athi Tuffs and Lake Beds though older than the Kerichwa Valley Tuffs. Although these are the only outcrops of basalt in the present area, a number of basalt flows have been penetrated at varying depths between 200 and 300 feet (61-91 m) below surface level in a borehole sunk in the Athi sediments and tuffs. It is likely that these concealed basalts are equivalent in age to the Simbara lavas and Fig 1 suggests that they were derived from the north, reaching the Gatundu, Jacaranda Coffee Research Station, Kahawa and Nairobi airport regions, as irregular flows.

Basalts cropping out between the Komo river and Ndaragu river near Thika (Fairburn, 1963 pp 22 and 24) are also thought to be equivalent in age to the rocks in the present area though the suggested correlation with the Laikipian Basalts (Fairburn, 1963 p 25) is unlikely, for Gregory gave the name Liaikipian to the series of basalts overlying the phonolites in southern Laikipia. The fact that the basalts of this area are intercalated within the Athi sediments and tuffs would thus suggest correlation with the older Simbara Series.

The basalt forming the waterfall on the Wabura river underlies the pumiceous welded varieties of the Kerichwa Valley Tuffs and probably comprises part of the eastern margin of a lava flow derived from the Aberdare range. This blue-black rock is uniform in character, amygdaloidal and very fine-grained. In thin section small, scattered microphenocrysts of augite (2V *c* 35°) are set in a matrix consisting mainly of augite, sodic labradorite (An_{50}) and granular magnetite. Matrix olivines are rare and are completely altered to greenish-yellow serpentinite similar to the material filling the amygdales, suggesting a late deuteric phase within the magma. Patches of brown glass, 0.75-1 mm in length are common and in this respect the lava is similar to Simbara-type basalts described from the Kijabe area (Thompson, 1964 p 16).

3 Athi Tuffs and Lake Beds

Shackleton (1945, table opp p 6), in a provisional correlation of Tertiary to Pleistocene rocks east of the Rift Valley, grouped all sediments lying between the Nairobi and Kapiti Phonolites east of Nairobi in his Athi Tuffs and Lake Beds. He divided them into two parts, Upper and Lower beds, separated by the Mbagathi (Phonolitic) Trachyte. Gevaerts (1946, pp 8-9) subsequently referred to the beds as the Athi Series and for convenience extended the series to include all strata including 'beds of the Kerichwa Valley Series' in areas where phonolite and trachytes are absent and recognised three sub-divisions of his 'Athi Series'. His upper division was separated from underlying basalts, recognised in borehole cores, and included in a middle group (see Simbara Series). Shackleton's correlation has been retained in this report though much of this formation in the present area comprises lacustrine sediments. At one locality in the Nairobi National Park, between Bushy Vale and Rocky Valley, a thin layer of dark grey tuff belonging to this formation separates the Nairobi Phonolite and the underlying Mbagathi Phonolitic Trachyte. Although no direct correlation can be made with Gevaert's subdivisions, it is probable that they represent part of his Upper Athi Series. From borehole and outcrop evidence, summarised in Fig 9, it is clear that lateral equivalents of the lacustrine beds are of terrestrial origin and must form, at depth, a large proportion of the volcanic pile forming the eastern shoulder of the Rift. Whether interbedded lavas occur at depth within the pyroclastics adjacent to the Rift is unknown for no borehole has penetrated the full succession west of Nairobi.

A series of tuffs and lake beds cropping out near Athi River separates the Nairobi and Kapiti Phonolites (confirmed from boreholes) and owe their origin mainly to lacustrine deposition. Interbedded with these are tuffs and pyroclastic rocks of probable sub-aerial origin. Because of confusion in correlation and mapping of tuffs, thought by the present writer to be later in age, the true extent of the Athi Tuffs and Lake Beds is not known. From studies of borehole evidence, of the present extent of known lacustrine sediments and of the eastern barrier of Precambrian rocks, it is thought that the maximum elevation of the Lake Beds was about 5,250 feet (1,600 m). Undoubtedly, while these predominantly lacustrine beds were being laid down, others to the west were deposited sub-aerially. These, however, are never exposed in the present area but underlie the thick cover of lavas forming the shoulder of the Rift.

Although the upper contact with the Nairobi Phonolite is frequently seen in the south-eastern part of the area, the lower contact between the sediments and the Kapiti Phonolite is rarely exposed. In places east of Athi River township, however, the sediments are in close proximity to the lava and the contact is seen near a dam on the Stony Athi River. Boreholes in the Athi River area indicate the order of superposition whilst in the Kitengele valley Kapiti Phonolite overlying Precambrian rocks is in turn overlain by sediments of this formation. At the western extremity of the outcrop the lower lava is absent and the beds rest directly on the Precambrian rocks or their weathered derivatives. The few marker bands that can be traced thoughout the deposits suggest that this formation dips at approximately 34 feet per mile (6.4 m/km or 0°22') in an east-south-easterly direction. Exposures are usually poor and correlation from locality to locality is hindered by lack of sufficiently distinctive or persistent marker beds. A green chert band is perhaps the most distinctive marker. It crops out in stream courses, small escarpments or quarries particularly in the Sosian valley, southeast of Beacon Ranch, Athi River, near the cement factory and again in quarries east of Athi River Prison. The disposition of the band suggests that the Athi sediments are gently synclinally flexed, the axis of the fold trending from the Sosian valley to Athi River plunging at about 0°22' in an east-south-easterly direction.

A maximum thickness of approximately 1000 feet (305 m) of sediments between the base of the Nairobi Phonolite and the top of the Kapiti Phonolite is recorded from the borehole at Nairobi Station. Elsewhere the thickness is variable and is indicated in the various sections accompanying a report by Gevaerts (1964).

Because of their soft and friable character these beds are often poorly exposed but a generalised, partial succession consists of:

	Feet	(Metres)
Yellow, welded tuff	10	(3.05)
Upper, grey, pyroclastic beds	100	(30.5)
White, fossiliferous beds with chert band	65	(19.8)
Grey, welded tuff (locally developed)	10	(3.05)
Lower, grey, pyroclastic beds with yellow tuff band	150	(45.7)

These thicknesses are only approximate as much lateral variation occurs within the sequence.

In a borehole on Beacon Ranch farm, sunk during investigations of bentonitic clays within the formation and logged by Pulfrey, the depth of the top bentonite beds was approximately 65 feet (19.81 m) below the base of the Nairobi Phonolite and the thickness of bentonite beds was found to be 18.5 feet (5.64 m). From sections examined elsewhere it appears that the bentonite clays occur within the upper grey pyroclastic beds.

A partial section exposed in the west side of the Sosian valley in the National Park revealed:

	Feet	(Metres)
Phonolite	20	(6.09)
Yellow grits and clays	40	(12.19)
White to green chert band	3	(0.91)
Pale grey to white clayey tuff	3	(0.91)
Yellow-buff clays and agglomeratic tuff	24	(7.31)
Grey, agglomeratic tuff	10	(3.05)
Pale yellow tuff with fossiliferous clayey tuff	25	(7.62)
Yellow-grey grit and agglomeratic tuff	base not exposed.	

Two boreholes, one (C783) six miles (9.6 km) north-west and the other (C420) nine miles (14.5 km) north of Athi River township, revealed the following sections:

C783 Wattle Blossom Farm, 1948:

	Feet	(Metres)
Black cotton soil	0-3	(0-0.91)
Grey, mottled, partly-weathered Nairobi Phonolite	3-33	(0.91-10.06)
Light grey/brown, partly-weathered Nairobi Phonolite	33-68	(10.06-20.73)
Light grey Nairobi Phonolite	68-181	(10.06-55.17)
Dark grey, fine, fresh Nairobi Phonolite	181-193	(55.17-58.83)
Grey, mottled-buff material at the contact between Nairobi Phonolite and clayey lake beds	193-198	(58.83-60.35)
Grey, mottled-white, clayey lake beds	198-242	(60.35-73.76)
Grey, mottled-black, heterogeneous lake beds with obsidian	242-265	(73.76-80.77)
Buff, off-white and grey, clayey lake beds	265-321	(80.77-97.84)
Darker grey, heterogeneous lake beds	321-338	(97.84-103.02)
Grey, fairly homogeneous lake beds (essentially tuffs)	338-375	(103.02-114.30)
Grey, mottled, heterogeneous lake beds	375-400	(114.30-121.92)

C420 Katani Ltd, 1946:

	Feet	(Metres)
Nairobi Phonolite	0-130	(0-39.62)
Land surface overlying lake beds	130-140	(39.62-42.67)
Greenish-yellow clay	140-180	(42.67-54.86)
White clay, slightly diatomaceous	180-187	(54.86-56.99)
Subaqueous ash	187-194	(56.99-59.13)
Sandy clay with lava fragments	194-230	(59.13-70.10)
Obsidian tuff	230-260	(70.10-79.24)
Pumice	260-267	(79.24-81.38)
Obsidian tuff	267-282	(81.38-85.95)
Fine, grey clay with obsidian	282-308	(85.95-93.88)
Grey tuff	308-352	(93.88-107.29)
Greenish clay and tuff	352-414	(107.29-126.19)

The sections, which were logged by members of the Public Works Department, indicate that Nairobi Phonolite overlies light-coloured lake beds, partly diatomaceous, which in turn are underlain by tuffs and lake beds characterised by the presence of obsidian. These two divisions can be correlated with those beds cropping out in the Athi River area separated by the green chert marker band.

The lowest beds consist essentially of fine to coarse grey tuffs, clays, some with chalcedony, some bentonitic, conglomerates and scoriaceous agglomerates which include lapilli, rounded and broken fragments of obsidian and Precambrian gneisses up to six inches (152 mm) in length. A hard, yellow tuff band, up to 20 feet (6.1 m) thick, within this lower sequence forms a good marker horizon and is well exposed in stream courses north of Athi River station. No further outcrops of this band were seen in the extreme eastern part of the National Park but the band reappears in the Mokoyeti valley and near Baboon escarpment. Some tuffs, with a distinctly greenish hue, and also thin intercalated marls, were noted half a mile (0.8 km) west of Marimbeti station. In the same locality, but near the base of the succession, a thin limestone band, represented by calcareous nodules, was mapped above the National Park track which follows the northern bank of the Athi river. During past economic investigations on the bentonitic clays of the series, a number of chemical analyses were made. Chemical analyses of typical examples from the Athi River township area are given in Table 14.

A hard, dark-coloured, welded tuff overlies these lower, grey beds on the north side of the Mbagathi valley near Ranger Post 3.* It forms a resistant but thin ledge about two miles (3.2 km) in length on the southward facing slopes of the phonolite-capped escarpment and is of local extent thinning rapidly east and west. Hand specimens of the rock display a eutaxitic texture in which dark lenses or *fiamme* are set in a fine-grained groundmass typical of *pipemo* structure. Brown areas that represent original pumice fragments are replaced by sub-radial crystal aggregates that have obliterated all original structure. Some are replaced by coarse crystals of alkali-feldspar roughly parallel to one another and at right angles to the wall of the original fragments. Occasional large, rectangular, collapsed pumice fragments are also present. All are set in a lighter area of glass in which cavities are filled by an indeterminate mineral, possibly tridymite.

The upper, grey beds occurring higher in the succession are separated from the similar, lower beds by 'white beds' comprising pale-coloured tuffs, clays, impure limestone and intercalated obsidian-bearing grits, some of the upper layers exhibiting slump structures. A white clay band near the top yielded fossils of the freshwater snail *Melanoides cf tuberculata* and the land snail, *Limicolaria cf martensiana*, also occurs at isolated localities.

Ostracods, silicified plant stems and tree trunks have all been recovered from these beds in the Athi River area (road quarry north-west of Athi River station) and in the Sosian valley where twig fragments are abundant. In borehole 2897, one mile (1.6 km) west of Wattle Blossom Farm, ostracods were recovered from sediments approximately 200 feet (61 m) below the base of the overlying Nairobi Phonolite. Calcareous nodules, limestone and an impersistent chert, mark the top of the 'white beds'. In the Sosian and Mokoyeti valleys, in the National Park, the chalcedonic chert has a resinous lustre and is white to bluish-white with manganese impurities that form dark blue to nearly black dendritic growths on fracture surfaces. It forms a discontinous layer that can be traced eastwards to where it changes to a grey-green or olive-green brittle chert. In places the chalcedony is up to two feet (0.6 m) thick between layers of pyroclastic rocks. The seams are irregular, nodular and locally pinch out. The thin impure limestone which overlies the chert in the Athi River area contains numerous gastropods.

At Beacon Ranch the white beds give place to the upper, grey beds consisting of soft, grey clays and tuffs, orange-weathering gritty tuffs and agglomeratic bands, bentonitic clays and diatomites. Green clays and cherts and a six- inch to one-foot (152-305 mm) red bed overlies the chert near the railway. The agglomerates are composed of rounded pumiceous and obsidian fragments which, in the lower part of the succession, are three to four inches (76-101 mm) long. A quarry on the farm, and outcrops immediately beneath the Nairobi Phonolite on the railway, show horizontally-bedded, grey tuffs with

* Ranger posts within the Nairobi National Park are numbered and reference should be made to the 1:50,000 topographic sheet (Author).

mud cracks, rain pitting and truncated cross-bedding all indicating shallow-water conditions with periods of desiccation.

One of the highest beds in the succession exposed in the present area is a hard, yellow, ten-foot (3 m) tuff exposed in a quarry four miles (6.4 km) north-north-east of Athi River station. It bears a strong resemblance to the lower,, yellow tuff which is exposed lower on the same escarpment but is more compact than the latter, although both have been locally used as building stones. Stratified, grey and brown tuffs in the south-eastern corner of the area, one and a half miles (2.4 km) south-east of Athi River station, probably represent the same stratigraphic horizon as this upper bed. Thin sections of specimen 51/903 from the quarry at 445435 * indicate the rock to be a glassy welded tuff consisting of small rock and collapsed pumice fragments in a glassy base. Large fragments within the rock are perlitic obsidian with phenocrysts of soda-orthoclase in a glass showing incipient crystallisation.The stratified tuffs in the south-eastern corner of the area also contain fragments of trachyte and crystals in a fine-grained matrix together with flattened pumice fragments and shards representing collapsed bubbles. The texture suggests disruption of the tuff during flow.

The Athi Tuffs and Lake Beds resulted by consolidation of fragmental, volcanic material which was deposited sub-aerially, into water at distances from the centres of eruption, or washed into a lake from areas to the west. Their wide extent throughout the Nairobi and adjacent areas indicates the former presence of an extensive lake or swampy country into which rivers drained from the shoulders of the Rift Valley and from the Mua hills and Kanzalu range. Periods of quiescence, during which there was little volcanic activity, are indicated by the chert deposits and probably some of the limestone bands. The volcanic eruptions were probably accompanied by earth tremors which may have been responsible for the contorted beds and slump structures seen at various localities. On a number of occasions the lake or swamps dried up as indicated by soils and rubble; mud cracks; rain pits; truncated cross-bedding; and the remains of land snails which could not have survived in water. Such dry periods were sufficiently prolonged to permit shrubs and small trees to flourish before the further deposition of volcanic debris and renewed flooding. Some of the fine-grained tuffs may have acquired a stratified appearance during lithification but the majority appear to be of lacustrine origin. Others are welded tuffs and originated as ash-flows. The presence of water-laid sediments showing signs of desiccation and plant remains at 5,150 feet (1,570 m) suggests that this represents the approximate maximum elevation of the lake, successive deposits being mainly derived by subaerial deposition. Lack of sediments east of the gap at 5,000 feet (1,524 m) between the Mua hills and Koma rock, 15 miles (24 km) east of the present area, would thus indicate that considerable erosion has occurred since the earlier Tertiary period with the consequent removal of sedimentary material in the Athi River region. Geological mapping of neighbouring areas has revealed the extension of the Athi Tuffs and Lake Beds into these areas. They have also been recognised in many of the boreholes in the Nairobi region where they form an important aquifer. Obsidian-bearing, welded tuffs, often forming prominent outcrops in the valleys near Ruiru, have been included within the Athi sediments and tuffs by previous workers. The present author, however, considers that these rocks comprise the lower member of the Kerichwa Valley Series and are described in a later section of the report.

Gevaerts (1964, p 9) has subdivided the beds on the appearance of basaltic lavas and their weathered derivatives in boreholes in the northern part of the area. The greater part of the outcrop of these Athi Tuffs and Lake and Lake Beds in the Nairobi area are likely to fall within his upper group and welded tuffs within the sequence probably occur at the same stratigraphic level as that in the Nairobi National Park. Although some of the pyroclastic rocks are of sub-aerial origin, many are lacustrine and can be conveniently grouped together. Certainly they are distinct from the demonstrably younger Kerichwa Valley Tuffs. The present author, while recognizing that the deposits may thicken in other localities not examined, considers that much confusion has resulted from the incorporation of young pyroclastic

* Map references taken from the 1:50.000 topographic sheets (Ed).

deposits in the Athi Series particularly in areas where the intervening Nairobi Phonolite is absent or where younger tuffs have overstepped onto the much older Athi tuffs and sediments. In many instances this has been unavoidable and the correlation of the Tertiary strata will not be accomplished until more detailed mapping has been completed and the relative ages and characteristics of the various volcanic deposits and lavas recognised.

4 Mbagathi Phonolitic Trachyte

The Mbagathi Phonolitic Trachyte crops out in the southern part of the area mainly in or near the Mbagathi river and has been encountered in boreholes in the Karen area where it underlies the Nairobi Phonolite. Sikes (1939, p 17) considered there to be two primary flows and the evidence south of the Mbagathi river does indicate the presence of at least two, and possibly three, flows with a minimum total thickness of 200 feet (61 m), though it is possible that the succession here is complicated by faulting. Over the plains the lava flows are likely to be thin near the outcrops of Precambrian rocks. However, in the Mbagathi valley, a thickness of almost 160 feet (49 m) was measured in the Mokoyeti Gorge. The thickness of Mbagathi Phonolitic Trachyte exposed in the various gorges and tributaries of the Mbagathi river also suggests that more than one flow is present. Boreholes sited near the Mbagathi entrance of the National Park pierced 275 feet (84 m) of lava, with 20 feet (6 m) of sediments intercalated near the base, indicating 255 feet (78 m) of phonolitic trachyte distributed in at least two flows. Further west a maximum thickness of 400 feet (122 m) has been recorded in boreholes at Langata. Between one and four miles (1.6-6.4 km) south of the Mbagathi river, the Mbach, Emagogo and Kapio tributary streams have cut through a low escarpment of the lava representing the eastern edge of a flow which overstepped the Mbagathi river lava flows onto the Athi sediments and tuffs in the vicinity of the Ngutoto Ombaar stream. Another contact between the lowest lavas and white, tuffaceous sediments of the Athi Series is exposed in a tributary of the Kapio streams. Despite the fact that the lavas are thinning here, the phonolitic trachyte is over 200 feet (61 m) thick. The flows are wide and probably originated in the Ngong area. Such a provenance is indicated by arcuate structures; flow directions from orientated feldspar crystals; and by the regional distribution of the unit (Fig 1). Although the base of the lava descends towards the north at approximately 13 feet per mile (2.5 m/km) the maximum slope of the base of the phonolitic trachyte is about 33 feet per mile (6.2 m/km) from west to east beneath the Nairobi metropolitan area. The most northerly known occurrence of the lava is in boreholes near Kikuyu. A northern lava stream wholly or partly filled an old (Mbagathi) valley cut into the underlying formation. It flowed eastwards, extending as far as the present Nairobi Phonolite contact in the vicinity of the Mokoyeti and adjacent valley. The trachyte also forms the plains south of the Mbagathi river, extending to the southern border of the area. Boreholes in the Langata, Karen and Nairobi Hill areas of Nairobi have penetrated the lava at depth and it appears to have thinned gradually in a northerly direction and extended as far as the Bernhard Estate and Kabete areas.

Westwards, near the Magadi road at Kandizi, the phonolitic trachyte is overlain by Ol Doinyo Narok agglomerate and Ngong basic lavas whilst eastwards the lava is seen to step successively onto lower formations eventually terminating in cliffs at Baboon escarpment in the Nairobi National Park. Contacts between the lava and the Nairobi Phonolite, Athi sediments and Precambrian rocks are exposed in turn. In shallow gorges in the middle reaches of the Mbagathi river the lava forms cliffs of blocky and laminated rock that differs from the lower, more massive phonolite.

The most striking feature of the lava is its texture of crowded feldspar laths set in a grey-brown matrix the colour of which is emphasised by rusty-brown weathering- and alteration-products. In many places the rock is vesicular and the feldspars, which are up to a centimetre in length, are frequently flow oriented. The fine-grained, holocrystalline rock contains tabular phenocrysts of anorthoclase and rare augite set in a groundmass of abundant alkali-feldspar together with aegirine, aegirine-augite,

kataphorite and minor cossyrite and nepheline. The green soda-pyroxene has a low extinction angle and occurs as tiny prisms with subhedral habit. The kataphorite, with 2V 50-60° and Z ∧ c 30°, is pleochroic but never shows the deeper red colour of the kataphorite in the phonolites of the area. Typically it is brown, greenish-brown to pinkish-brown. Arfvedsonite is rare in the matrix and occurs as small euhedra with characteristic pleochroism: smoky blue to a pale smoky pinkish-brown. In the finer-grained examples, radiating aggregates of feldspar are set in a brown, glassy groundmass and nephelines are sometimes clustered in small groups. The microphenocrysts of anorthoclase frequently show blotchy extinction and are often cracked. In some sections the anorthoclase exhibits polysynthetic twinning and is associated with yellow acmite and dendritic and spongy microphenocrysts of aegirine-augite. Specimens with phenocrysts of oligoclase have also been noted. Groundmass feldspars, which frequently impart a trachytic texture to the rock, are probably orthoclase and are twinned according to the Carlsbad law. Pilotaxitic examples were also noted. When present the isotropic base in the former type appears to be sodalite. Bowen (1937, p 15) gives an analysis of a phonolitic trachyte from the Nairobi area which was collected by Sikes, and it is probable that this sample was taken from outcrops of this particular flow. Unfortunately the exact locality is unknown. The analysis is quoted in Table 11.

Some authors (Shackleton, 1945 table opp p 6 and Gevaerts, 1964 p 9) have used the term Mbagathi Trachyte in describing this lava and though this is an acceptable petrographic term, it is felt that Sikes's original description (Sikes, 1939 p 17) should be retained. The rock, with recognisable nepheline, has mineralogical and chemical similarities to other Kenya rocks classified as phonolitic trachyte (Saggerson, unpublished).

5 Kandizi Phonolite

Phonolite outcrops occur near the Kandizi quarries on the Magadi-Nairobi road and in the valley of the Kandizi river between one and three miles (1.6-4.8 km) upstream from the stone quarries. At the former locality the phonolite crops out in the lower part of the valley of the Nol Chora and forms the low lying ground adjacent to the road. Contacts between the lava and adjacent Ngong lavas indicate that these overlie the phonolite and were extruded onto an eroded landscape of Kandizi phonolite. A similar relationship is seen in the Kandizi valley to the north where both Ngong lava and Kerichwa Valley Tuffs are the younger formations. Two miles (3.2 km) north-north-west of the Kandizi quarries, a third outcrop of phonolite forms the bed of the Mbagathi stream and is overlain by the Kerichwa Valley Tuffs which here crop out in the valley sides.

The rock is generally dark blue to black, of compact and granular appearance, though occasionally exhibits vesicular and flow structures suggesting that is has been derived from vents to the west. The presence of a vesicular portion of the rock in the succession exposed in the Kandizi valley suggests that more than one flow is present. Varieties with milky-white amygdales are common. Unlike many of the Tertiary lavas of the Nairobi area it exhibits characteristic spheroidal weathering. In thin section (51/937 from Kandizi) the lava is typically of Kenya-type (Prior, 1903) with tabular alkali-feldspars and microphenocrysts of nepheline set in a trachytic groundmass comprising laths of feldspar, nepheline idiomorphs together with kataphorite (Z ∧ c 24°), cossyrite, rare arfvedsonite, aegirine-augite and probably analcime. The dark minerals form small aggregates with sub-ophitic relationships towards the feldspar though the pyroxene has a tendency to develop small flakes round larger nephelines which are turbid but recognised by their typical cross-sections. Smaller crystals of nepheline, displaying little alteration, are abundant in the groundmass. As in many of the phonolites of the area, iron ore is rare or is enclosed as small granules within the feldspar where it is concentrated parallel to crystal faces suggesting zoning of the feldspar and early ore crystallisation. A single phenocryst of barkevikite was noted in specimen 51/979 from Ngoroi near Kandizi quarry. Although closely resembling the Nairobi Phonolite the Kandizi rock is more leucocratic, contains a greater

proportion of feldspar, and has conspicuous nepheline. Biotite, which is so characteristic of the former rock, is lacking in the Kandizi Phonolite.

Field relationships and rock characteristics indicate a time correlation with the Nairobi Phonolite. Borehole evidence however suggests it forms a distinct flow probably earlier in age than the Nairobi Phonolite though comprising one of the many flows of this group which occupy the same stratigraphic position between the younger Nairobi Trachyte and older Mbagathi Phonolitic Trachyte. Certainly borehole evidence reveals that the flows of Nairobi Phonolite occur to the north of the Kandizi outcrops and borehole 1270 in the Langata area is reported to pass through the Kandizi Phonolite into the Mbagathi Phonolitic Trachyte.

The occurrence of barkevikite indicates a relationship with the Ngong centre where this mineral is reported from many of the later, though more basic, lavas. Its form, as a lava apron round the northern and eastern margins of Ngong, and extension across the Karen area where it is eventually concealed beneath succeeding phonolite flows, also point to a derivation from the Ngong volcano.

6 Nairobi Phonolite

The Nairobi Phonolite, which consists of a number of flows, covers a large part of the Athi plains and extends from the National Park northwards to Kiambu. It overlies the Athi Series, probably with disconformity, and the contact between the two formations is exposed in the prominent scarp which forms most of the southern outcrop of the lava. Age determinations made on feldspars from the phonolite range from 5.2 to 10.2 Ma (Table 3), suggesting that there is more than one age of phonolite flow. On Beacon Ranch farm the base of the flow consists of pumiceous and dribbly lava which has flowed onto a slightly uneven surface of agglomeratic tuff. Numerous quarries and stream sections show that the phonolite consists of a number of flows, generally between 100 and 150 feet (30-46 m) thick, though borehole 2023 at Embakasi penetrated 260 feet (79 m) of phonolite and 212 feet (65 m) were measured in borehole C201 at Nairobi West aerodrome. From borehole evidence it is apparent that the lavas were derived from the Maguga area (Fig 1) though it is likely that phonolites, originating at Ngong, first flowed in a northerly direction and thence in a south-easterly direction across the Nairobi area. Certainly the flow directions recorded in the field suggest a south-easterly flowing lava stream immediately before consolidation. Maximum thicknesses can be expected in the airport area, the lava thinning both to the north-west and towards the south-east where it eventually solidified near Athi River township. Between Bushy Vale and Rocky Valley in the National Park the Nairobi Phonolite is separated from the underlying Mbagathi Phonolitic Trachyte by a few feet of dark grey tuff belonging to the Athi Tuffs and Lake Beds.

Like the Kapiti Phonolite it is black, or blue-grey to blue in hand specimen but is separated megascopically from the former phonolite-type because of its lack of large phenocrysts (*cf* Neilson in Gregory, 1921 p 391). Outcrops in the Sosian valley reveal minor differences in the Nairobi Phonolites, though the most consistent feature is the marked fissility and platy texture, developed locally at or near the surface, that can be attributed to flow phenomena. The outcrops also reveal the vesicular character of the upper portion of a number of the flows (51/873, Embakasi); however, the phonolites are seldom amygdaloidal. On weathering the lavas are often converted to pale brown and reddish ferricrete deposits (*murram)* but in many localities, particularly east of Nairobi, the lava surface has been autobrecciated and consists of rounded and angular fragments of phonolite cemented in a light brown, weathered base of the same material. Because the rock has every appearance of a breccia or pseudo-conglomerate, local engineers have referred to it as the 'boulder bed', thought by some to be a separate formation. Undoubtedly the rock resulted from the rapid cooling of an already viscous lava. It has been further altered by deep weathering. Aerial photographs of the plain at Nairobi Airport reveal sub-circular patches with crudely linear arrangements beneath the black cotton soil cover.

These patches probably represent the areas of maximum weathering at intersections of master joint-planes (*cf* Scott, 1963 pp 14-16).

The phonolites in thin section (*eg* 51/884 Ranger Post, Embakasi) consist of long tabular phenocrysts of sanidine, 2V 0°, showing reaction borders and peripheral bands of dark inclusions, in a fine-grained groundmass characterised by patches of soda-amphibole including cossyrite and kataphorite (Z ∧ c 26°) together with bright green aegirine and/or aegirine-augite. Nepheline occurs in small micro-phenocrysts or crystals in the groundmass ranging in size up to 0.2 mm and exhibiting twinning and lamellar partings. The larger crystals are frequently altered to a yellowish zeolite, sodalite, natrolite, analcime and calcite, and bordered by the green soda-pyroxene. Lath-like feldspar is scattered throughout the matrix in triangular areas often enclosing patches of altered nepheline. In one thin section (51/61) an amphibole, occurring as distinct crystals up to 0.2 mm long with distinctive pleochroism, greenish-brown to reddish-brown, 2V *c* 30° and Z ∧ c 30°, may be kataphorite. Characteristically Nairobi Phonolite contains elongated flakes of a strongly pleochroic biotite altered around the margins, and bordered by magnetite granules. Ore minerals are otherwise rare. Orange-brown flakes of mica also occur occasionally in the groundmass. Fluxional alignment of the feldspar is noted in some outcrops and thin sections of such rocks show the concentration of the dark components in prominent layers, the crystals displaying a tendency to form spherulitic or sub-radial to sheaf-like growths (51/1058, Ofafa Estate, Nairobi). Occasional vesicles are filled with zeolites which in one instance was identified as scolecite though elsewhere the material is unidentified due to its fine-grained texture. Radial and concentric arrangement of the minerals is characteristic. Although this rock has been correlated with Kenya-type phonolite (Fairburn, 1963 p 24), from the many thin sections examined, it is likely that variations occur in the same lava flow. The biotite content is significant, however, and although the rock lacks large phenocrysts of nepheline, the texture is more closely allied to Prior's Losaguta-type phonolite (Prior, 1903 p 238), an intermediate lava between his Kenya-type and Kapiti-type phonolite. Analyses of Nairobi Phonolite are given in Table 12* together with others for comparison.

7 Kiambu Trachyte

The Kiambu Trachyte is exposed in the vicinity of Kiambu township where it crops out in the valleys of the Riara and Gatharaini rivers and underlies the coffee estates of Fairview and Kiu, south-east of Kiambu. Here a tongue of the lava extends eastwards to within a mile (1.6 km) of the Kamiti road. Boreholes in the district indicate that the lava has a maximum thickness of 150 feet (46 m), is of limited lateral extent and does not extend much beyond the area of outcrop mapped. It probably represents the earliest of the trachyte flows that succeeded the outpourings of phonolitic lava of the Nairobi area and is seen to be directly overlain by the Nairobi Trachyte in valley sections where the Nairobi-Kiambu road crosses the Gatharaini river. No evidence was found to indicate more than one flow.

In hand specimen the rock is light grey with numerous megascopic phenocrysts of feldspar in a fine-grained groundmass. The lava is auto-brecciated and, at the most westerly outcrop on the Njunjo Estate, vesicular lava with green, chalcedony-filled amygdales were noted. Kataphorite, aegirine-augite and cossyrite, the principal dark constituents, are unevenly distributed through a base of oriented orthoclase crystals. In thin section the rock is thus similar to the succeeding Nairobi Trachyte, though a similarity to the later Kabete Trachyte is evident from the feldspar phenocrysts.

8 Nairobi Trachyte

The stratigraphic relationship of the Nairobi Trachytes, the underlying Kiambu Trachyte, Mbagathi Phonolitic Trachyte, Nairobi Phonolite and the overlying trachytes and tuffs is proved in borehole

* An SiO_2 analysis of Nairobi Phonolite from the Athi plains gave 56.70% (Sikes. 1939 p 17) (Author).

records and in the many outcrops in stream courses in the immediate vicinity of Nairobi. These trachytes have a wide distribution, extending from the Dagoretti-Karen area as far east as Nairobi City and northwards to Kiambu and South Githunguri. In places the rock forms conspicuous outcrops, particularly in the south where it forms a flat-topped plateau terminating in a low but prominent escarpment overlooking the Mbagathi valley and the National Park. Clearly the Mbagathi river is a lateral stream owing its later valley development to the trachyte outcrop. Boreholes in the Nairobi municipality have in places penetrated a continuous sequence of lavas, without interbedded sediment, totalling approximately 300 feet (91 m). At Ruaraka the lava is 200 feet (61 m) thick. A number of thin flows each with a distinct topographic expression are recognisable in the western part of Nairobi area and roads leading into the centre of Nairobi from the west cross the Nairobi Trachyte. Small steps in the escarpment overlooking the town represent the outcrops of individual flows. Shallow boreholes sunk at the reservoir near the main hospital penetrated more than one flow each having a vesicular upper contact and, in borehole 3001 at Mbagathi, three lava flows separated by sediments or tuffs were recognised. Within the Nairobi municipality the lava is separated from the underlying Nairobi Phonolite by a few feet of agglomeratic tuff exposed in a quarry in the South Hill estate representing the easterly outcrops of tuffs and sediments between the two lavas and proved in boreholes further west.

These trachyte lavas approximate closely to Prior's phonolitic trachyte (1903, p 241) and to Campbell Smith's kataphorite trachyte (1931, p 241) though the Nairobi Trachyte probably has greater affinities with the phonolitic rocks, though lacking nepheline, than to the younger trachytes of the Limuru area. The lava is greenish-grey, occasionally porphyritic, with tabular phenocrysts of feldspar in a predominantly fine-grained groundmass. Dark streaks, patches and bands indicate the segregation of mafic constituents whilst, in the more homogeneous rocks, a silvery lustre is typical of rocks of trachytic texture in the Nairobi area. Lamination and banding, which are prominent and characteristic, are due to flow and flattening within the lava body. Flow is often emphasised by fluxionally arranged feldspar laths and by variations in rock composition and colour, depending upon the presence of dark and light-coloured constituents that have been partly segregated during crystallisation. Of the numerous specimens examined, 51/869 from the National Park is typical and shows small tabular sanidine phenocrysts, with Carlsbad twinning and low optic axial angle, set in a fine-grained groundmass which exhibits a marked trachytic texture. In contrast the feldspar in the groundmass is orthoclase associated with soda-amphiboles and pyroxenes and rare iron ore. The soda-rich minerals have a characteristic distribution, with deep brown cossyrite and green aegerine-augite occurring as prominent moss-like aggregates of prismatic crystals. The alternating brown and green patches impart a mottled appearance to the rock in hand specimen. Kataphorite has a sub-ophitic relationship with the feldspar occurring as distinct crystals that have characteristic pleochroism suggestive of arfvedsonite. The latter mineral shows a pleochroic scheme which includes yellow, green, blue and brown and has a high extinction angle (*c* 20°) not normally shown by riebeckite. Barkevikite, showing typical amphibole cleavage and pleochroic formula X brown, Y pinkish-brown, Z yellow-green-brown, 2V 50°, and Z ∧ c 14°, occurs as small crystals approximately 0.25 mm long. They are frequently altered and bordered by iron ore. In other thin sections there is an irregular distribution of the ferromagnesian constituents.

9 Ololua Trachyte

A strongly porphyritic trachyte crops out near Ololua on the north-eastern slopes of Ol Keri, one of the foothills of the Ngong volcano. The lava has been faulted and its relationship to the neighbouring rocks is obscure due to poor exposure. Kerichwa Valley Tuffs crop out in a stream course that has cut a valley into the trachyte but it is uncertain whether the lava overlies the tuff or whether the tuff partly fills a pre-existing valley. It is likely that the trachyte is the older. This is partly substantiated by the megascopic and microscopic features of the lava that closely resembles Nairobi Trachyte. Thin

sections of the Ololua Trachyte (*eg* 51/981) show the rock to consist of porphyritic feldspar in a holocrystalline groundmass that contains a high proportion of mafic constituents. Anorthoclase occurs as large, tabular phenocrysts twinned according to the Carlsbad law. The larger crystals are irregular in outline often showing terminal corrosion and crowded with inclusions of soda-pyroxene. These may be concentrated near the margins of the feldspar as a dusty or granular zone. Within the groundmass, alkali-feldspar shows a tendency to form leucocratic patches associated with strongly pleochroic, green aegirine-augite, brown to opaque cossyrite and kataphorite. The kataphorite is highly altered to a mixture of limonite and iron ore and is subordinate to the soda-pyroxene.

10 Ol Doinyo Narok Agglomerate

Typical volcanic tuffs and breccias of sub-aerial origin and referred to as the Ol Doinyo Narok Agglomerate (Matheson, 1966 p 22) underlie the country south of Kiserian where they are exposed mainly in shallow stream sections. They thin eastwards and near the Kiserian-Magadi pipeline track, overlap onto the Mbagathi Phonolitic Trachyte. In contrast with many of the other tuffs in the area, these rocks are generally light coloured in shades of brown and contain numerous lithic clasts, including fragments of Mbagathi Phonolitic Trachyte, Nairobi-type phonolite, Ngong basic lavas, and obsidian. The formation increases in thickness southwards. It exceeds 200 feet (61 m) in the valley of the river Kiserian in the present area and at Ol Doinyo Narok, 18 miles (30 km) to the south, a thickness of at least 700 feet (213 m) has been estimated (Matheson, 1966 p 23). The deposits were undoubtedly laid down on a surface sloping gently eastwards and form the northern fringe of pyroclastic rocks that had their origin to the south of the present area. The nature of the deposit suggests that it was derived by violent explosive action rather than as a flowing sheet of welded tuff which is so characteristic of the younger Kerichwa Valley Tuffs. As the deposit is traced northwards from the southern boundary of the area, it is seen to underlie the basic lavas of Ngong and, at Ngoroi, crops out at the road bridge in the Kandizi valley where it is overlain by tannbuschite (Fig 3). On the other hand, the Kerichwa Valley Tuffs are welded varieties that were derived from the north and north-west; they contain phyric feldspar though none of the rock fragments mentioned overlies the lavas of the Kandizi valley. These relationships are also revealed in stream sections to the south-east and it must be concluded that the Ol Doinyo Narok Agglomerate is older than the Kerichwa Valley Tuffs though both formations post-date the Kandizi Phonolite (*cf* Matheson, 1966 p 22).

11 Ngong Volcanics

One of the most conspicuous topographic features of the Nairobi area is the Ngong hills, rising to 8,034 feet (2,449 m), and situated 15 miles (24 km) south-west of the city centre (Plate 1). These hills represent the denuded remnants of a former, probably much higher, volcano situated astride one of the major rift faults of the region. Formerly measuring approximately seven miles (11 km) in diameter, it has been bisected by a north-south trending fault, the downthrown portion of which is now buried beneath the later Limuru-type trachytic lavas that cover the Rift floor (Fig 9). The steep western flank of the hills, rising abruptly from the floor of the Rift, is in marked contrast with the gentle eastern slopes which steepen only towards the summits of the mountain. The eastern slopes represent the original undeformed surface now modified by erosion suggesting that the volcano was built to a considerable height before some of the lavas now exposed had been extruded.

No major volcanic vent has been traced though more detailed mapping of the stratified lavas, tuffs and agglomerates with pyroclastic ejectamenta predominating in the western face (Sikes, 1939 p 18) may reveal the necessary evidence. Although the topography of the hills indicates that the principal foci of eruption were along a north-south line (*cf* Sikes, p 18), it is problematical whether the peaks forming the skyline (Plate 1) represent actual volcanic centres or are merely the dissected remnants of a single massive volcano. A minor eruptive centre occurs at Kandizi where ultrabasic lavas have

issued from the Ngoroi vent (Fig 3). Former flows can be partly recognised particularly where they form spurs on the eastern flanks of the volcano. Many, however, are now largely concealed by a thick soil cover. On the north-western slopes individual horizons are obscured by screes and fallen boulders.

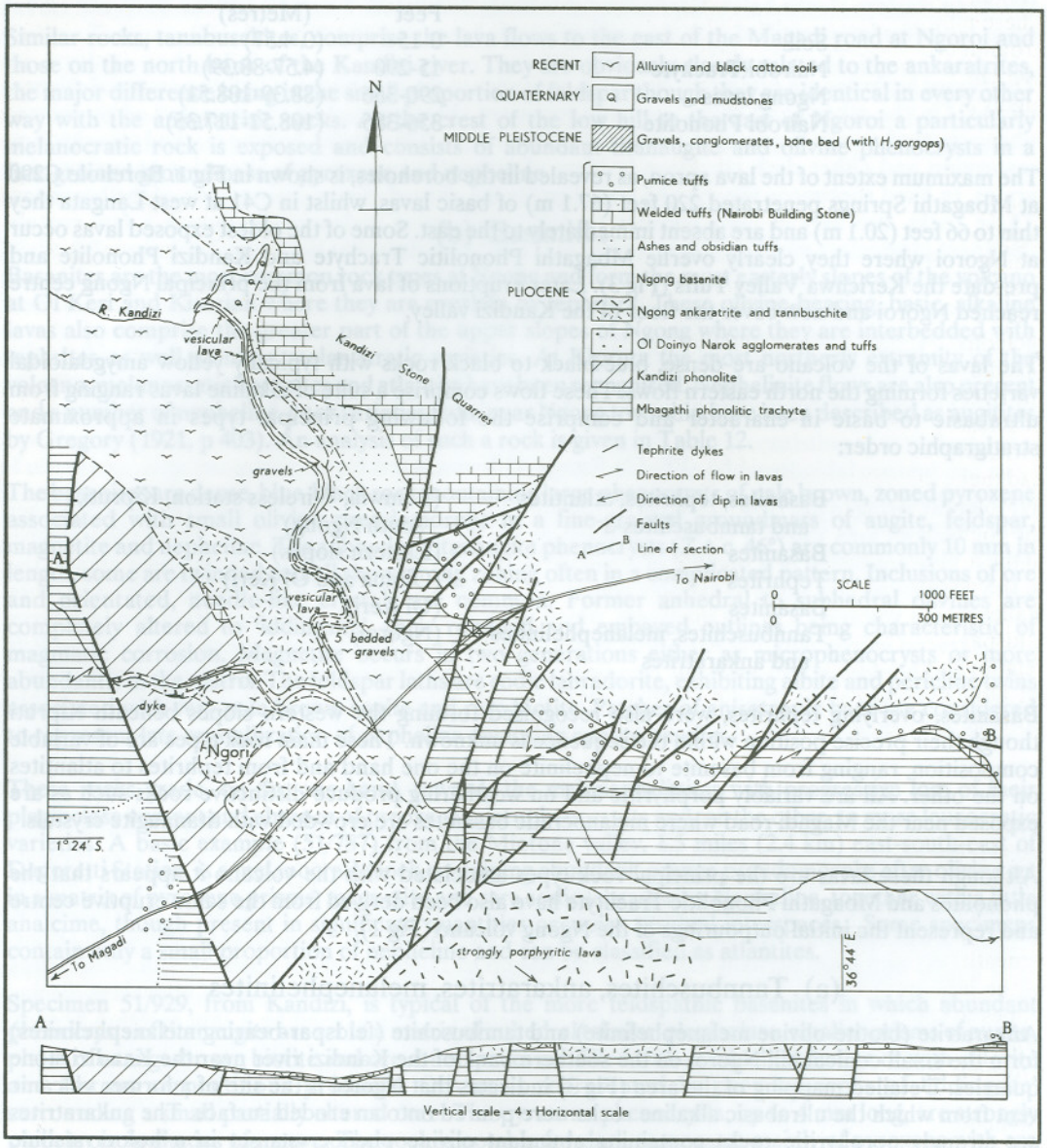


Figure 3 Geological map of the Kandizi area, Ngong

The oldest Ngong lavas are probably those penetrated in boreholes in the Karen-Langata area where they occur between Nairobi Trachyte and Kandizi Phonolite. Borehole C41 at Karen passed through the following strata:

	Feet	(Metres)
Soil	0-15	(0-4.57)
Nairobi Trachyte	15-290	(4.57-88.39)
Ngong lavas	290-356	(88.39-108.51)
Nairobi Phonolite	356-385	(108.51-117.35)

The maximum extent of the lava apron, as revealed in the boreholes, is shown in Fig 1. Borehole C290 at Mbagathi Springs penetrated 220 feet (67.1 m) of basic lavas, whilst in C41 at west Langata they thin to 66 feet (20.1 m) and are absent immediately to the east. Some of the oldest exposed lavas occur at Ngoroi where they clearly overlie Mbagathi Phonolitic Trachyte and Kandizi Phonolite and pre-date the Kerichwa Valley Tuffs (Fig 3). Later eruptions of lava from the principal Ngong centre reached Ngoroi and now cover the floor of the Kandizi valley.

The lavas of the volcano are dense, blue-black to black rocks with typically yellow amygdaloidal varieties forming the north eastern flows. These flows comprise a suite of alkaline lavas ranging from ultrabasic to basic in character and comprise the following principal types in approximate stratigraphic order:

Basanites, tephrites, atlantites and tannbuschites	(Lamwia, Wireless station, Kipruti, south Ngong)
Basanites	(Eastern slopes)
Tephrites	(Ololua and Ol Keri)
Basanites	(Ol Keri)
Tannbuschites, melanephelinites and ankaratrites	(Ngoroi)

Basanites, overlying tephrites, were also recognised forming the western slopes beneath Kipruti though their precise position within the sequence is unknown. These main rock types are of variable composition, ranging from basanite to nephelinite on the one hand and from tephrites to atlantites on the other. All are variably porphyritic and on weathering produce distinctive rocks such as are exposed near the Magadi road where melanocratic basanites are crowded with titanaugite crystals.

Although these lavas are the principal rock types associated with the volcano it appears that the phonolites and Mbagathi Phonolitic Trachtyte have also been derived from the same eruptive centre and represent the initial outpourings of the Ngong volcano (Fig 1).

(a) Tannbuschites, ankaratrites, melanephelinites

Ankaratrite (biotite-olivine melanephelinite) and tannbuschite (feldspar-bearing melanephelinites) form the small conical hill Ngoroi on the southern bank of the Kandizi river near the Kandizi stone quarries. Detailed mapping of the area (Fig 3) indicates that Ngoroi is the site of a former volcanic vent from which the ultrabasic alkaline rocks were poured onto an eroded surface. The ankaratrites are strongly porphyritic rocks containing abundant olivine phenocrysts set in a holocrystalline groundmass. The olivine ranges up to 10 mm in length and has a prominent, orange 'iddingsite' alteration rim frequently associated with iron ore granules. Orange to yellow-brown biotite occasionally forms a discontinuous outer zone round the olivine which internally shows partial alteration to chlorite and serpentine. Abundant pale brown pyroxene prisms and magnetite grains in

the groundmass occur with subhedral nepheline which exhibits a poikilitic habit towards the former minerals. Biotite, strongly pleochroic from orange to brown, is present in small but distinct flaky crystals. Zoning of the pyroxene is exhibited by the strongly pleochroic green terminations of aegirine-augite in melanephelinites (51/972).

Similar rocks, tannbuschites, comprise the lava flows to the east of the Magadi road at Ngoroi and those on the north bank of the Kandizi river. They are obviously closely related to the ankaratrites, the major difference being in the small proportion of feldspar though they are identical in every other way with the ankaratritic rocks. At the crest of the low hill to the east of Ngoroi a particularly melanocratic rock is exposed and consists of abundant titanaugite and olivine phenocrysts in a fine-grained groundmass of pyroxene and nepheline.

(b) Basanites

Basanites are the most common rock types at Ngong and form the most easterly slopes of the volcano at Ol Keri and Kiserian where they are overlain by tephrites. These olivine-bearing, basic, alkaline lavas also comprise the greater part of the upper slopes of Ngong where they are interbedded with tephrites as well as more melanocratic varieties. At Kipruti, the most northerly extremity of the volcano, melanocratic basanites and atlantite have been recognised. Nephelinite flows are also present and a number of nepheline-poor varieties from near Ngong township have been described as augitites by Gregory (1921, p 403). An analysis of such a rock is given in Table 12.

The basanites are dense, blue-black rocks containing large phenocrysts of pale brown, zoned pyroxene associated with small olivine pseudomorphs in a fine-grained groundmass of augite, feldspar, magnetite and nepheline. The subhedral titanaugite phenocrysts ($Z \wedge c$ 46°) are commonly 10 mm in length, some are twinned and all show strong zoning often in a complicated pattern. Inclusions of ore and orientated, needle-like crystals are common. Former anhedral to subhedral olivines are completely altered to 'iddingsite', their rounded and embayed outlines being characteristic of magmatic corrosion. Magnetite occurs in two generations either as microphenocrysts or more abundantly in the matrix. The feldspar laths are sodic labradorite, exhibiting albite and pericline twins associated with very pale brown augite and rare biotite. Patches of anisotropic base are considered to represent late crystallization of nepheline enclosing apatite needles.

These rocks grade, on the one hand, towards the melanephelinites with progressive loss of their plagioclase content and absence of pyroxene microphenocrysts and, on the other, to more leucocratic varieties. A basic example (51/787) from the Miotone valley, 1.5 miles (2.4 km) east-south-east of Dagoretti Station, is a melanocratic rock containing abundant, orange pseudomorphs after olivine set in a matrix of pyroxene prisms, magnetite and rare sodic labradorite. Nepheline, together with a little analcime, though present in significant quantities occupies residual interspaces. Some specimens contain only a small proportion of nepheline and can be classified as atlantites.

Specimen 51/929, from Kandizi, is typical of the more feldspathic basanites in which abundant phenocrysts of titanaugite are set in a matrix of euhedral tabular plagioclase, smaller prisms of augite, plates of orange-brown biotite and ore. Interspaces are filled with residual nepheline or with chlorite and fibrous serpentinous products. Olivine is represented by pseudomorphs of 'iddingsite' surrounding a small partially altered core. The pyroxene phenocrysts, up to 4 mm long, are strongly pleochroic in shades of mauve. The rock is notable for dark aggregates mainly of pyroxene with ore and nepheline which are pseudomorphous after original amphiboles. The various alteration products in these rocks are thought to be the result of deuteric phenomena. Barkevikite (2V 50° and $Z \wedge c$ 10°) occurs in prominent phenocrysts which usually have marked pleochroism, resorption and dark corrosion borders of magnetite.

(c) Tephrites

Tephrites are prominent along the eastern margin of Ngong, and nearly continuous exposures occur between the Veterinary Station in the north and Kiserian in the south. Similar rock types crop out on the steep western slopes below Kipruti and it is likely that detailed mapping of the flows will reveal other tephrites interstratified with the predominantly basanite succession.

The Ngong tephrites are essentially similar in character to the basanites but lack the essential mineral olivine. On the other hand these less basic rocks are characterised by the presence of prominent phenocrysts of orange-brown barkevikite (2V 50° and Z ∧ c 10°) usually showing marked pleochroism, resorption and either dark corrosion borders of magnetite or complete alteration to opaque ore grains. In hand specimens this may be mistaken for the altered olivine phenocrysts of the basanites. These rocks also vary in their feldspar content, some being melanocratic though a few contain dominant plagioclase which is characteristic of the later Ol Esayeiti Oligoclase Tephrite.

(d) Dykes

Few dykes have been reported from the area. Sikes (1939, p 18) records two vertical dykes of basanite and basanitoid respectively, exposed on the western slopes of the Ngong hills and during the present survey thin tephritic dykes were noted in the Kandizi valley associated with the Ngoroi centre.

12 Ol Esayeiti Volcanics *

Ol Esayeiti, rising to just over 7,000 feet (2,134 m) above sea-level, occupies the south-western corner of the Nairobi area where it is overshadowed by the neighbouring Ngong hills. From this eruptive centre, now consisting of a number of separate peaks that extend into the neighbouring area to the south, numerous lava flows of variable composition were extruded onto the slightly older and more basic Ngong volcanics. On the mountain, which is covered only by sparse vegetation, the lava flows can be traced individually, but eastwards they have been faulted along the eastern margin of the Rift Valley and boulder screes and soils frequently conceal the relationships between the various flows. Fortunately many of the flows are sufficiently distinctive to be recognised both in the field and in thin section and can be correlated with flows recognised by Matheson (1966).

(a) Ol Esayeiti Phonolite

Although the true relationship between this lava and the Ol Esayeiti Oligoclase Tephrite was not seen during the present survey, the outcrop pattern and the evidence from the neighbouring area suggests that the phonolite overlies the tephrite. On the eastern slopes of the escarpment at Olchoro Onyore, the phonolite (51/1063) is a blue-grey, fine-grained to slightly porphyritic rock in which waxy nepheline crystals are prominent. Thin sections show the rock to be a typical Losaguta-type phonolite (Prior, 1903 p 238) with large partially altered nephelines up to 15 mm in length together with phenocrysts of anorthoclase, titanaugite and strongly pleochroic sphene. Rare xenocrysts of oligoclase display considerable resorption, while zoning in the nephelines is emphasised by a thin reaction border. Aegirine-augite, cossyrite and kataphorite are uniformly scattered through the groundmass which consists largely of alkali-feldspar and some oligoclase. Staining of the rock reveals interstitial birefringent material thought to be nepheline, though much of the groundmass is calcitised and apparently secondary after the feldspathoid.

* The mapping of the Ol Esayeiti and the southern end of the Ngong hills was greatly facilitated by the unpublished geological map of the region by Shackleton (Author).

(b) Ol Esayeiti Tephrite

This tephrite* is of distinctive appearance in hand specimen being strongly feldsparphyric and bearing a resemblance to soda-plagioclase-bearing rocks from Ol Doinyo Sambu on the Kenya-Tanzania border (Saggerson, 1966 p 36) and the trachydolerites described by the early German explorers from nothern Tanzania (Finckh, 1903 p 501). Lehmann (1924) in his account of the Rungwe volcanics, from the northern end of Lake Nyasa, referred to tephrites as trachydolerites containing considerable nepheline and essential barkevikite. In addition the presence of the aegirine molecule in the pyroxene was considered diagnostic. Because of their intermediate character such rocks are referred to as nepheline andesites by Johanssen (1939, p 215) and the present rocks are certainly unlike the more typical labradorite-bearing tephrites of Ngong. They more closely resemble kenyte though lack the essential olivine of this basic phonolitic trachyte (*cf* Campbell Smith, 1931).

Slight differences, both in megascopic and microscopic appearance, suggest that more than one flow comprises the unit which crops out on the plateau at the southern end of the Ngong hills where it is seen to overlie typical Ngong tephrites. Excellent outcrops also occur in the Nairobi-Magadi road near its junction with the Ngong circular track. Typically, this bluish-black rock has uneven fracture and has large, tabular or lathy feldspar as the dominant phenocryst. In thin section large, strongly zoned, oligoclase phenocrysts, up to 15 mm in length, are associated with titanaugite and barkevikite, the amphibole showing prominent reaction borders rich in magnetite. The phenocrysts, which have a marked preferred orientation, are set in a fine-grained, trachytic matrix consisting of abundant laths of oligoclase, aegirine-augite, nepheline and magnetite. Much of the feldspathoidal content can only be recognised after staining. Farther east, on the track to Olchoro Onyore, the rock more closely resembles a variety described by Matheson (1966, p 24) in which phenocrysts of titanaugite with barkevikite are set in an oligoclase-rich matrix. Xenoliths of this rock are occasionally found within the feldsparphyric variety, indicating consanguinity.

(c) Ol Esayeiti Trachyte

One specimen of this rock type, collected from the northern flank of Ol Esayeiti at its contact with the overlying Limuru trachyte, is a fine-grained rock containing few phenocrysts. These consist of bright green aegirine-augite and sanidine, showing fine lamellae twinning and with margins marked by small rows of inclusions, in a hypocrystalline groundmass of alkali-feldspar and interstitial glass in which aegirine-augite, sphene and ore are evenly distributed. A little cossyrite and pale brown kataphorite are also present.

(d) Phonolites

The association of two phonolites with the Ol Esayeiti lavas at the southern end of the Ngong hills suggests their probable derivation from this volcanic centre. Exposures of the older of these flows occurs in a stream course approximately one mile (1.6 km) east of Olchoro Onyore where it is associated with the Ol Doinyo Narok Agglomerate and apparently overlain by the Ol Esayeiti Phonolite. Although no precise age relationships were established, it is likely that this lava corresponds with the phonolite described by Matheson at this stratigraphic level (1966, p 23). They a greenish-black, granular rocks of slabby appearance with a tendency to have a resinous lustre w the older Nairobi and Kandizi Phonolites.

In specimen 51/1065 small phenocrysts of anorthoclase, with fine twin structure, have peri of dark inclusions, are corroded and exhibit marked resorption. They are set in a groun nepheline is interspersed between flow-orientated, alkali-feldspar laths. Aegirine

* Problems of petrographic nomenclature have been discussed by Harkin (1960, p 31 *et seq*) preferred for rocks of this composition (Author).

and kataphorite, pleochroic from pale brown to green, occur in sub-ophitic patches or tufted aggregates interpenetrated by the feldspar. Rare, bluish riebeckite is also present.

The second of these phonolites crops out south of Olepolos on the Ngong circular track where it is considered to overlie the Ol Esayeiti Oligoclase Tephrite. This rock is characterised by phenocrysts of titanaugite in glomeroporphyritic aggregates in a matrix of abundant nepheline interstitial between the laths of feldspar. Unlike many of the other intermediate lavas of this area, aegirine-augite is the only notable ferromagnesian constituent in the matrix, the usual soda-amphibole being rare or absent. An unusual feature of the rock, however, is the presence of altered microphenocrysts of barkevikite and rare serpentinised olivine crystals.

13 Sattima Series

A number of lava flows, with intercalated tuffs, form a group of non-porphyritic to porphyritic rocks collectively named the Limuru Trachytes by Sikes (1939, pp 22-23). These lavas occupy the north-western part of the Nairobi area and are primarily distinguished by their grey colour and generally softer, fissile character from the stratigraphically lower trachytes and phonolites equivalent in age to the Simbara Series of the areas further north. They represent a later period of volcanic eruption which in other areas can be shown to post-date the first major episode of rift faulting (McCall, 1962 p 343) and can be inferred from the present area.

Emplacement of the Kerichwa Valley Tuffs marked this second phase of volcanicity, the tuffs everywhere forming the basal formation of the succession. These and similar rocks were assigned to the Laikipian Series by Gregory (1921, p 166) and to the Sattima Series in the Nyeri area by Shackleton (1945, p 2 and table opp p 6) where they form part of the extensive outcrops of the Aberdare range. Baker, in a later publication (1958, p 18), referred to the Limuru Trachytes as the Plateau Trachyte Series. Age determinations, made on Limuru Trachytes from the Ministry of Works quarry two miles (3.2 km) due west of Limuru on the Nairobi-Nakuru road, indicate an age of 2.4 Ma. Determinations made on similar trachytes from the Magadi area gave a younger age of 0.63 Ma, indicating a period over which this lava type was erupted. Because of the general similarity in characteristics of these lavas in the Nairobi area, it is considered that they represent eruptions and lava extrusions that occurred during late Pliocene to lower Pleistocene time. For convenience, the Limuru Trachytes have been included with the younger formations on the geological map as it is probable that the bulk of the lava was erupted during this period. It is of interest to note that a reversal of the earth's magnetic field is indicated by palaeomagnetic determinations made on Limuru Trachyte from the Ministry of Works quarry though younger lavas from the same series show no reversal. From observations made on rocks from other parts of the world it is known that the last magnetic reversal took place near the base of the Pleistocene. The Limuru Trachytes therefore, may represent a local base for the Pleistocene in this part of Kenya.

(a) Kerichwa Valley Tuffs

The Kerichwa Valley Tuffs are well exposed in the Kerichwa stream that flows through Nairobi (Gregory, 1921 p 164) and were designated by Shackleton (1945, table opp p 6) to include a group of trachytic tuffs and agglomerates in the Nairobi area younger than the Nairobi Trachyte. The pumice-rich formation is widespread and, from descriptions in other geological reports on central Kenya, it is probable that the rocks extend as far north as Nyeri and Nanyuki. These ash and pumice flows, termed froth flows by McCall (1964), occupy a considerable volume and appear to be the result of explosive eruption over a short interval of time. They cannot be traced to any volcanic vents however and it is probable that they are the result of rapid pressure release along fissures following Rift faulting and graben-forming collapse. The tuffs are in turn affected by the later period of grid faulting.

These tuffs overlie the Nairobi Trachyte and nearly every other older formation and their resemblance to some of the Athi Tuffs and Lake Beds and younger tuffs associated with the Limuru Trachytes has caused much confusion in the mapping of litho-stratigraphic boundaries in neighbouring areas. A number of the tuffs, inter-bedded in the lavas overlying this formation, also have a strong megascopic similarity and in deeply weathered profiles it is often extremely difficult to distinguish tuff from lava. Microscopic examination of many of the younger tuffs indicate, however, that they are not related genetically to the Kerichwa Valley Tuffs but have been derived mainly as a result of sub-aerial deposition and can be classified as air-fall tuffs.

The age of the Kerichwa Valley Tuffs is not in doubt for everywhere their stratigraphic relationship with other rock types can be mapped and proved in boreholes. Age determinations made recently on alkali-feldspars from the tuffs yield discrepancies, however (see Tables 3 and 4), and it can but be concluded that the somewhat older ages for the feldspars from the tuffs indicate their early formation prior to extrusion.

Throughout the Nairobi municipality the formation can be subdivided into three main members that are recognised by their colour, texture, jointing, degree of welding and distribution:

Upper Tuffs	Grey, mauve, green and brown, agglomeratic and partly welded tuffs with light- and dark-coloured pumiceous fragments at the base. Welded tuffs with eutaxitic texture, lenticulites.
Middle Tuffs (Vari-coloured Nairobi Stone)	Upper Welded Tuff. Thin tuffs and local conglomerates. Lower Welded Tuff
Lower Tuffs	Thin, brown, agglomeratic tuff. Grey and black ashes and tuffs with obsidian fragments, locally grading into thin, agglomeratic tuffs. Grey-green, welded tuff with flattened pumice fragments

The tuffs vary in thickness and any or all of the members may be absent thus complicating the local stratigraphy. It is for this reason and due also to patchy development that it is not practicable to show the tuffs as separate bands on the geological map but the Middle and the Upper Tuffs are shown distinct from the the Lower Tuff.

Though the megascopic characteristics of the three major units sometimes suggest a single ash flow, the presence of soil horizons, local conglomerates and fluvial deposits, attributable to periods of erosion, indicate time intervals between successive flows. Gregory (1921, p 163) in his description of the section at Ainsworth Bridge in the centre of Nairobi, referred to the smooth and planed surface of the 'freestone' (Nairobi Stone) overlain by an 'obviously' old land surface on which the succeeding tuffs had been laid unconformably.

The deposits of Kerichwa Valley Tuffs buried a pre-existing landscape, the former valleys of which are now being re-excavated to reveal Nairobi Trachyte and Nairobi Phonolite. In practically every occurrence mapped, the Lower and Middle Tuffs are confined to the former valleys, whereas the upper tuffs filled the valleys and spilled over onto the interfluves covering the larger part of the area under a blanket of pumiceous tuff that sloped eastward from the Rift margin. Examination of borehole records suggests that in parts of the area, such as at Kiambu, the bulk of the Kerichwa Valley Tuffs have been extensively stripped re-exposing the Nairobi Trachyte and, where present, the tuffs are no

more than a few feet thick. Deep dissection and formation of gorge-like valleys suggests rapid uplift and the dip of strata in the Athi Tuffs and Lake Beds indicates the magnitude of such uplift.

The Kerichwa Valley Tuffs have similarities to those deposits emplaced as hot avalanche-like masses and described from different parts of the world. They were erupted as ash-flows or froth flows (McCall, 1964) from fault fissures in the Rift zone in multiple flow units. Moderate temperatures of formation are consistent with the field and microscopic evidence though locally intense welding occurs towards the base of the various sheets, suggesting elevated temperatures within part of the main flows. The Middle (welded) Tuffs probably represent ash-flows that were emplaced at maximum temperatures and rapidly followed the deposition of the lower flows before the latter had cooled. Such rapid extravasation prevented the immediate rapid chilling of, and imparted characteristics to, the Nairobi Stone which are usually attributable to welding within a thick flow due to pressure of the superincumbent load. Lower temperatures of formation probably characterised the Upper Tuffs or pumice flows which show only partial or moderate collapse of the cognate pumice fragments. It can be concluded that all tuffs, having similarities both physical and chemical and close juxtaposition, have been derived from different phases of the same explosive period of volcanicity. Although these rocks may have originated as *nuée ardente*-type eruptions, their occurrence in steep-sided, narrow valleys suggests that they could have originated as froth-flows (*cf* McCall, 1962) or rivers of incandescent fragmental material. In no single instance were these tuffs seen to pass laterally into lava. Chips and fragments of older rocks can be found in the tuffs at different localities. The presence of crystals of kyanite and other metamorphic minerals in soils at Embakasi suggest that they were probably derived from weathering of a former extension of the tuffs in this region.

Lower Tuffs

The oldest ash-flow deposits are widely scattered throughout the southern part of the area forming the base of many good sections. They are generally found in valleys or less frequently as stratified deposits overlying the Nairobi Phonolite. Deposits of these rocks were probably much more extensive but have suffered considerable erosion due to their friability. In many re-excavated valleys these lowest deposits probably filled as much as one third of each original valley. Excellent exposures may be seen in most river courses in and around the Nairobi municipality, notably at Ainsworth Bridge, in sections first described by Maufe (1908) and Gregory (1921).

Many of the rocks are soft, porous, buff to black, ashy tuffs. Lapilli, consisting of sub-rounded fragments of black glass, pumice or small rock fragments, vary in size up to two inches (51 mm) and lie in a matrix of dark, ashy, crystallo-lithic tuff. Locally the rocks are agglomeratic. Colour variations are common particularly near the top of the succession and are partly due to weathering. Examination of excellent fresh rock faces exposed during building excavations in the Nairobi municipality during 1962 showed the formation to consist of lenticular beds of ash and tuffs, some with crude scour and fill structures, suggesting a sub-aerial or shallow lacustrine origin. Other beds appeared to have been water-laid over an uneven surface that had been subject to partial flooding. At the Auto Silo excavation, approximately 20 feet (6 m) of alternating black and yellow, stratified tuffs overlie the auto-brecciated surface of the Nairobi Phonolite. The tuffs have been weathered to varying degrees resulting in bleaching and development of clay partings parallel to the layering, cross-cutting joints and irregular fissures. Weathered exposures in the Nairobi river at Ainsworth Bridge are also bleached and are identical to outcrops in the Mbagathi Valley two miles (3.2 km) west of the Mbagathi entrance to the National Park. Here, water running over bare outcrops has gouged smooth runnels in the soft rock and has removed the dark-coloured material.

The local base of the Lower Tuff is represented by a grey-green, pumiceous welded tuff which was seen only in the valley of the Gitathura river a few tens of metres upstream from the Limuru Road

bridge at Muthaiga. The rock exhibits a eutaxitic texture containing flattened, glassy pumice fragments in a base of glassy trachyte. In thin section the tuffs consist of fine, black to brown, pumice or ash, the pumice fragments showing partial devitrification and development of radial spherulites. Fragmental crystals form up to approximately ten per cent of the tuff and consist mainly of anorthoclase. Associated with them are accidental inclusions of trachyte or sub-rounded, brown glass fragments showing perlitic cracks. Much of the base is unidentifiable due to the fine-grained character of the ash and to heavy staining.

Northwards, the character of the Lower Tuffs changes. Conglomerates, tuffs, agglomerates and prominent welded tuffs, cropping out in the area north of Kiambu-Kahawa, were previously considered to form the Upper Athi Series. However, the frequent association of these dark grey pyroclastics and ash flows with the outcrops of Nairobi Stone and pumiceous, welded tuffs of the upper member of the series, which always overlie them, suggests that they comprise part of the Lower Kerichwa Valley Tuffs. Traced from Nairobi towards the north and north-west, these beds thicken and there is an increase in the obsidian content. At Nairobi the obsidian occurs as small pellets as, for example, beneath Ainsworth Bridge, but north-west of Ruiru the obsidian forms elongated *fiamme* up to three feet (0.9 m) across and flattened parallel to the upper and lower margins of the unit. Presumably the amount of obsidian increases the closer to the source area which probably lies north of Limuru. One welded tuff approximately 15 feet (4.6 m) thick forms prominent benches in many of the valleys west of the Thika road near Ruiru. This same band is a strong waterfall maker, one of the best examples being that on the river Ruiru where it crosses the main Thika road. Southwards, this band becomes less prominent and gives way to a number of lapilli tuffs with obsidian. Even Maufe, as early as 1905, like his successors, traced the same rock northwards where it was seen to form the sill of the Chania Falls (in the area to the north of the present one) and rests upon a thick bed of agglomerate. To the north-west, wherever this flow crops out within the bed of a river, a small waterfall is formed. The underlying agglomerate is more easily eroded and prominent sections along the valley sides are often undercut giving rise to cave-like embayments. The Nairobi Stone frequently overlies this band in the west but more often agglomerates, tuffs and eutaxitic tuffs separate the two members. It is not possible to estimate a maximum thickness for this formation but sections in excess of 200 feet (61 m) are known. Greater thicknesses are likely to be present in the northern part of the area but estimation is made difficult by deep weathering and the similarity of Limuru-type tuffs, Kerichwa Valley Tuffs and certain beds in the Athi Tuffs and Lake Beds.

From evidence in various parts of the Nairobi area, particularly in the north, the Kerichwa Valley Tuffs are frequently bleached. Loss of colour and transformation of many of the constituents of the rock to clays is typical of the upper tuffs though occasionally part of the Nairobi Stone is also bleached to yellow or buff, presumably where the overlying agglomeratic tuffs are thin or absent. This bleaching is apparently not entirely connected with present-day weathering and probably represents a period of erosion and decomposition prior to the deposition of the overlying Limuru trachytes and tuffs.

Middle Tuffs

The Middle Tuffs have been variously named Nairobi Claystone, Nairobi Building Stone, Nairobi Freestone, lava, devitrified trachyte, pitchstone, axiolitic phonolite and rhyolite. Previous authors recognised its fine-grained and partially devitrified character and indistinct banding, thus assuming it to be an ancient lava flow. The rock is remarkable for its consistency over tens of square miles and its distribution, conchoidal fracture and tendency to develop columnar jointing all suggest a rock that was previously fluid. The regular jointing which has clearly developed during the period of cooling is confined to this unit (Plate 5).

The Nairobi Stone can be subdivided into an upper and a lower band, often separated by thin soft greyish tuff. Locally the base of the stone is marked by a thin conglomerate which represents the eroded surface of the Lower Tuffs on which it was laid. The stone is often absent and in some localities the upper, grey to mauve agglomeratic tuffs directly overlie the Lower Tuffs.

These rocks are dense welded tuffs of ash-flow origin with fairly uniform characteristics, the important differences being in colour and variation of texture that are sometimes emphasised by weathering. Differing degrees of welding and development of eutaxitic structures are sometimes observed though compound characteristics in the flows are lacking (*cf* Smith, 1960 p 157). Attractive hues, in shades of grey, green, blue, mauve, purple, pink, orange-brown and pale buff, in a rock of generally even grain, have rendered it most suitable for building purposes. The best stone is a dense, massive tuff typically blue-grey, the less welded varieties containing flattened cognate inclusions characteristic of *piperno* structure. Colour variations in these varieties are undoubtedly due to the distribution of iron oxide and its state of oxidation. Large pumice fragments and crystals are relatively few though phenocrysts, cognate and accidental, are more typical of pulverulent varieties. Generally, the rock though soft is coherent and the best building stone has a distinctive ring when struck with a hammer. An analysis of the rock is given in Table 11.

Neilson (in Gregory, 1921 p 390) described the rock as an axiolitic, phonolitic rhyolite in which phenocrysts of anorthoclase are set in a decomposed, cryptocrystalline groundmass showing traces of axiolitic structure along the walls of collapsed vesicles. Fragmental crystals, in numerous thin sections of the rock collected during the present survey, include orthoclase, anorthoclase, plagioclase, soda-pyroxene, soda-amphibole together with rock fragments of phonolite, trachyte and patches of brown glass showing perlitic cracks. These are set in a glassy base containing wisps and flattened shards of brown glass often showing a preferred orientation. Crinkling and turbulence of the glass fragments is common round the various inclusions. Examples of devitrification are best seen in the most densely welded varieties where crystallisation and growth of radial spherulites has occurred within collapsed and flattened vesicles. Variations in the degree of welding is apparent in many specimens with the progressive loss of pore space and the development of axiolitic structures in the most dense rocks.

Upper Tuffs

Although the Lower and Middle Tuffs are confined mainly to valleys or the low ground overlying the older lavas, the Upper Tuffs are more widespread and originally must have covered nearly the entire area, valleys and interfluves alike, in a blanket of pumiceous tuff. Stratigraphic relationships are best seen in the southern part of the area for north of Kiambu erosion has probably stripped the tuff, exposing the underlying Nairobi Trachyte beneath the eroded scarp of Limuru Trachyte. Nevertheless, members of the Kerichwa Valley Tuffs are occasionally exposed at the contact between the Limuru Trachyte and underlying lavas as seen at the marked change in slope on the Riara road 2.5 miles (4 km) west of Kiambu. Elsewhere the contact is often concealed by thick red soil.

Examples of the buried topography are shown by the outcrops of Kerichwa Valley Tuffs in the Kiara river, five miles (8 km) north of Kiambu and also in the area four miles (6.4 km) north-east of the township where the outcrops of the Nairobi Trachyte are often at a higher altitude and bordered on the east and north by the tuffs.

Bedding is absent in the tuffs and thickness is not uniform but is dependent on the degree of welding and on the relief of the underlying buried landscape. Rarely, the tuff is unconsolidated and then the rock approaches an indurated, agglomeratic or pumiceous tuff. It is unlikely that more than one ash flow unit is present over the larger part of the area though a conglomerate lens within the tuff, in the

railway cutting near the Meteorological Office on the western outskirts of Nairobi, suggests a period of erosion between two successive ash flows. Neverthess, the relatively thin deposits (a maximum thickness of about 130 feet (40 m) was observed in the Mokoyeti valley) and its overall similarity suggests that the bulk of the deposit was laid down as a single sheet. Over wide areas the tuff is soft and porous, contains pumice fragments and locally becomes welded and harder with increase in its content of glassy fragments. The rock though soft is tenacious. It does not fracture easily when hammered and consequently is used extensively as a building stone. Variation in the degree of welding is apparent in many specimens with the progressive loss of pore space due to collapse of vesicles.

Jointing, which is very irregular, consists mainly of sub-vertical or curvilinear fractures that cause the rock to break into irregularly shaped blocks. These joints permit the downward percolation of groundwater and different blocks, often in juxtaposition, may be variably wet and dry. Road sections exposed during the building of the highway at Ainsworth Bridge revealed these apparent lateral differences in the tuffs, the porosity of which is probably a function of welding and compaction.

The colour of the deposits ranges through white, buff, brown, red, maroon, blue-grey and grey. Some of the brown material is due to oxidation whereby former iron-bearing rock and mineral fragments have been partly or wholly replaced by brown iron oxide. Maroon colouration suggests that the fine matrix of the tuffs has been subjected to hydrothermal alteration. Perhaps the most spectacular are maroon rocks containing bright green pumice fragments. A downward change in colour is apparent nearly everywhere and though some effects may partly be due to weathering, the changes in texture that accompany colour differences can only be ascribed to vertical differences in the character of the original ash flow.

The various differences in this partially welded tuff probably represent zones of differential welding as described by Smith (1960, p 154) after a study of American examples. Gradations range from partially welded material, in which pumice fragments have not collapsed, to rocks with virtually no pores. Usually, the dense, collapsed zones occur near the base of the sheets possibly due, in part, to the superincumbent load. Smith (1960) does indicate , that the thickness of the welded portion is in a general way an index of the emplacement temperature of the ash flow; thus the lack of thick beds of tuff in the Nairobi area suggests that temperature, rather than load, is the controlling factor in the welding of these tuffs. Although the Upper Tuffs differ in thickness at different localities, colour variations are not always present in all parts of the area. The degree of lateral variation is unknown but vertical sections show that the colour-zone boundaries are gradational. Typical examples in the Upper Tuffs are:

Mokoyeti valley	Ft	(m)	R.Ormanyi	Nairobi Dam	Ft	(m)
Grey and green tuff	70	(21)	Mauve tuff	Orange-brown tuff	5	(1.5)
White tuff	33	(10)	Orange tuff	Grey tuff	5	(1.5)
Grey tuff	20	(6)	Grey tuff	Orange-brown tuff	5	(1.5)
Conglomerate	2	(0.6)	Buff tuff	Grey tuff with obsidian fragments	25	(7.6)
				Brown tuff with obsidian fragments	5	(1.5)

Marked changes in the texture of the tuffs occur between the base and the top. Usually the base is compact, brown and contains lapilli and pumice fragments that are partially or completely collapsed and flattened, imparting a marked eutaxitic texture. In some specimens the fragments become darker, cindery or have a tendency to be vitreous. At the Nairobi dam the local base of the member consists of vitreous pumice fragments that are totally collapsed, and compaction foliation is evident. The vitreous obsidian-like fragments are set in an ash base having a dark grey to green, vitreous lustre

representing a thoroughly welded tuff with typical *pipemo* structure. The upper zone, on the other hand, consists of light grey or maroon rocks with dark, ellipsoidal pumice fragments that have devitrified without collapse.

A complete absence of sorting in the tuffs, together with welded, eutaxitic and lenticulitic textures, devitrification, and axiolitic structures, point to their derivation from ash flows. Rocks of this kind, with a preponderance of pumice fragments which characterise the Upper Tuffs, are best referred to as pumice tuffs (Ross and Smith, 1961 p 33). In thin sections of tuffs from the upper part of the sequence, the pumice fragments exhibit no flattening and are set in a glassy or clastic base containing abundant dust. Glass shards of variable size are frequent and usually show lack of distinctive distribution. Partial devitrification is represented by white margins to the shards which are often unresolvable under the microscope. The pumice fragments are ellipsoidal and composed of isotropic, brown or black glass. Such unwelded specimens are in marked contrast to the more welded varieties in which phenocrysts and rock fragments occur in a fine-grained, glassy base of compressed shards and fine dust. The shards are frequently moulded against the phenocrysts, thus imparting a pseudo-flow structure to the rock. Glassy pumice fragments are elongated, devitrified and show marked axiolitic structure. Feldspar phenocrysts have been disrupted along cleavage traces and are occasionally embayed along their margins (*eg* 51/1015 from Dagoretti). Specimen 51/876 from Katani Estate was originally a glassy tuff but is now wholly devitrified, consisting predominantly of sanidine needles. This tendency to devitrification is accompanied by pale coloration of the rock. Those rocks generally poor in phenocrysts consist largely of glass shards, partly or totally welded, in which alignment is due to compaction, resulting in accommodation between shards. In highly welded specimens a marked alignment of shards indicates extreme compaction and thorough welding. Evidence of plasticity during this process is shown by the moulding of glassy material round the phenocrysts. Cognate inclusions mainly include pumice fragments, consisting of glassy material crowded with pore spaces or, more rarely, bubbles showing spherulitic texture. Where compaction has occurred these fragments are flattened, occurring as elongated masses that are sometimes devitrified and are typical of the tuffs in the area north-west of Ruiru. Accidential crystalline material is common and includes fragments of early lavas such as trachyte but, more frequently, particles of both alkali and plagioclase feldspar, soda-pyroxene, soda-amphibole and ore.

The amount of gas emitted from these flows was probably very limited for these Upper Tuffs contain few or no crystalline encrustations precipitated from vapour. Lack of flattening of the pumice fragments on a large scale indicates that the flows were viscous though of sufficiently high temperature to permit flow and partial welding.

(b) Kabete Trachyte

The Kabete Trachyte is a grey-green, porphyritic rock of granular appearance, weathering to a soft grey colour and having a similar appearance to the grey Nairobi Stone. Typically, it crops out in the Kabete area where it overlies both the Kerichwa Valley Tuffs and the Nairobi Trachyte and is, in turn, overlain by the Karura and Limuru Trachytes. The best exposures were noted in the Bugichi, Gatara and Gitathuru rivers. In the Muguga-Kabete area the trachyte is seen overlying the Kerichwa Valley Tuffs in the river Thigirie, one mile (1.6 km) north-east of Wangige, and is, in turn, overlain by the Karura Trachyte. Its most northerly extension was mapped in the Tusoga stream, a tributary of the Ruiruaka, and it seems that the trachyte was a relatively narrow lava flow erupted from the Muguga-Limuru area and flowed as far east as longitude 36°45' at its maximum extent. Nowhere does it form the prominent features exhibited by other lavas and it must be concluded that the lava is comparatively thin in relation to others of the Nairobi region. Boreholes in the Kabete area penetrated about 100 feet (30 m) of the lava.

Gregory (1921, p 162) reports the presence of two varieties of phonolite in the vicinity of Fort Smith (Kabete) which he considered to be of the Kenya and Kapiti type.* The similarity of some of the lavas of the Kabete area to phonolitic rocks probably accounts for his description and it is here suggested that he probably examined exposures of Nairobi and Kabete Trachyte during his journey towards the Rift shoulder.

In thin section (51/1013 River Gatara, Kabete) the Kabete Trachyte is similar to the Nairobi and Kiambu Trachytes. It is porphyritic, with phenocrysts of tabular sanidine, and abundant feldspar laths, green aegirine, nearly opaque or dark brown cossyrite and kataphorite, evenly distributed throughout the trachytic matrix. The cossyrite shows marked pleochroism in browns and pinkish-red while the kataphorite, which is less abundant than in the Nairobi Trachyte, is pleochroic from brownish-green to pale reddish-brown. Other sections sometimes show the mafic minerals distributed in a groundmass of tabular feldspar. Prior (1903, p 241) compared this rock type with the acmite-trachyte of the Azores classifying it as a phonolitic trachyte. Campbell Smith (1931, p 224), on the other hand, grouped it under his kataphorite trachytes.

(c) Ruiru Dam Trachyte

In the vicinity of Ruiru Dam a trachyte, indistinguishable from the Nairobi and Kabete Trachyte, crops out in the deep valleys east of Limuru and Uplands forest. The lava apparently overlies an irregular surface of Kerichwa Valley Tuffs and is, in turn, overlain by Limuru Trachyte, the contact between the two rock types forming an excellent aquifer from which various springs emerge on the north side of the Uplands-Ruiru road. This lava, which is probably about 200 feet (61 m) thick (though no boreholes have penetrated the flow), occurs stratigraphically higher in the succession than the Nairobi Trachyte (Fig 9) but is probably equivalent in age to the Karura Trachyte to which it bears a strong resemblance. Exposures of trachyte, in fault blocks north of Escarpment and near the northern border of the area, are probably part of the same flow.

(d) Karura Trachyte

A fine-grained, dull grey to lustrous trachyte overlies the Kabete Trachyte in two localities, north and south of Redhill road (Limuru 'D' route) in the Kiambaa location. The lava is exposed in the Turoni, the Mutundu, Thigirie and Mwetata tributaries of the Karura river whence it takes its name. Although megascopically similar to the Nairobi Trachyte, it occurs stratigraphically higher in the lava succession and may be distinguished from the Lower Trachyte by its spotted appearance when weathered. It lacks the fissility so characteristic of the Nairobi Trachyte. Near the western margin of its outcrop the Karura Trachyte has been down-thrown to the west by the southerly continuation of the Tigoni Fault.

Typically non-porphyritic in thin sections, this rock is fine-grained and has small laths of alkali-feldspar together with aegirine-augite and kataphorite. The proportion of mafic constituents is considerably less than in previous trachytes and cossyrite is usually rare or even absent. Soda-pyroxene, the dominant coloured mineral, is weakly pleochroic in shades of pale green and is associated with the kataphorite which is still an important constituent. The latter mineral is pleochroic from pinkish-brown to yellow-brown and is much decomposed. Dark, granular iron ore is a notable addition to this rock type and appears to be associated with alteration products of the dark minerals. In some sections the feldspar is distinctive, occurring in short prisms poikilitic towards the other constituents instead of in long laths, a feature noticed in the Kabete Trachyte. This habit suggests either differences in separate lava flows or, more probably, differences in texture in different parts of the flow, as noted in the phonolites of the present area.

* Evidently no samples were taken (Author).

(e) Tigoni Trachyte

This lava was called the Karura Quartz Trachyte by Gevaerts (1964, p 8) but to avoid confusion with the previous flow has been renamed the Tigoni Trachyte. It crops out mainly in the vicinity of Tigoni near Limuru where it is exposed over an area of about eight square miles (20 km^2). The principal exposures occur in the main river courses where a number of quarries are sited, the rock being most suitable as a building stone. Such quarries include those on the Mweteta river and its tributary at 705094 and 695085. Gevaerts indicates that perhaps two flows, separated by sediment and tuff, are revealed by numerous boreholes in the Tigoni area and both his sections and the field evidence suggest that between 150 to 200 feet (46-61 m) of lava are present west of the Tigoni Fault on Tigoni farm (080728). The lava terminates in a prominent topographic feature overlooking the Karura valley and the lower Mweteta valley at the boundary of the Kiambaa location south-west of Charpore road. At the dam on the Ithanji stream (749064) the upper surface of the lava, which here shows marked autobrecciation, is overlain by the Limuru Trachyte. A small outcrop of the lava is exposed in the headwaters of the Gitathuru river one mile (1.6 km) south-east of Muguga station and the trachyte is also found underlying Limuru Trachyte in the Rironi Fault scarp 3.5 miles (5.6 km) south of Limuru. Although its present elevation in the last locality is the same as that of the western margin of the main outcrop, at Tigoni it has been down-faulted into its present position. No other similar occurrences were noted in the fault region west of the main Nairobi-Nakuru road but it is possible that careful examination of the fault blocks of this region might reveal other outcrops of the Tigoni Trachyte in the various scarps. It is unlikely, however, that any will be seen west of the line of the Rironi Fault.

The Tigoni Trachyte is very fine-grained, and dull grey, with a flaggy appearance due to fine flow-structure, that is emphasised by colour banding on weathered surfaces. In thin section the rock consists of small laths of generally untwinned alkali-feldspar in which tiny moss-like aggregates are evenly distributed. Kataphorite is the predominant mafic mineral, pleochroic in shades of yellow-brown to dull, green-brown associated with faintly pleochroic, green aegirine-augite. Cossyrite, in dark brown crystals, also occurs in the dark aggregates. Late crystallisation of quartz is indicated by a common interstitial habit throughout the rock often in optical continuity over small areas. Both Prior (1903, p 242) and Miss Neilson (1921, p 396) commented on the mode of occurrence of the quartz in their phonolitic quartz trachyte, referring to the micropoikilitic patches of that mineral which form an interstitial paste.

(f) Limuru Trachyte

The Limuru Trachyte and associated pyroclastic rocks cover an area of approximately 300 square miles (777 km^2) and represent some of the final out-pourings of lava and volcanic ejectamenta from this part of the Rift zone. Compared with the older alkaline lavas, they form the thickest individual lava type in the Nairobi area and, with the intercalated trachytic and agglomerate tuffs, more than 500 feet (152 m) are estimated to be present in some boreholes (Gevaerts, 1964 p 7). They certainly represent a very large volume of lava for they are also extensively developed in the neighbouring Kajiado area (Matheson, 1966) and in the Magadi area where they extend across the Tanzania border (Baker, 1958 and 1963). The trachytes were derived by eruptions along fault zones connected with rift faulting rather than from central volcanoes, the evidence available suggesting their derivation from the Kedong escarpment northwards to the Aberdare range. Many of the flows spilled over the margin of the Rift, flooding the eastern slopes of the Kikuyu highlands as far east as Nairobi. Others are confined to the Rift zone and have flowed in a southerly direction consequent upon the slope of the Rift floor (Plate 6).

In the Limuru and Uplands districts they build successive flows that have a gentle easterly dip, consequent upon the slope of the ground over which they flowed. Two main tongues of lava extend in an easterly direction forming prominent ridges, one to the north of Kiambu, the second in the

Nairobi municipality where the lava underlies the old Sclater's road as far as Westlands, a westerly suburb of the city. Within the faulted section of the Rift zone, the lavas crop out in numerous, prominent scarps and ridges, a consequence of the predominantly north-south faulting so characteristic of the grid structure of this zone. Throughout the region, the lava retains a similarity over wide areas and comparisons made with the same lava-type in neighbouring areas indicate that individual lava flows were very extensive with little variation in rock type. In the main, the trachytes are usually the only rocks that crop out at the surface except for minor tuff intercalations. Though no vents were discovered, tuffs and agglomeratic tuffs are conspicuous in the faulted region from Uplands southwards to the Mrithu Fault, suggesting that the lavas represent former eruptions in which periods of quiet evisceration of lava were temporarily broken by more violent and explosive activity. Such evidence points to the principal centre of extrusion being in the Uplands-Limuru area from whence the lavas poured eastwards down the flank of the Rift zone or into the Rift where they inundated and covered the earlier lavas, particularly those from the Ngong volcano.

The many scarps near Limuru provide excellent exposures and quarry sites from which the rock is extracted for building purposes. Some of the flows are vesicular and centres of lava extrusion may be represented by dome-like outcrops exhibiting fan-shaped contraction joints (*cf* Sikes, 1926, Plate facing p 388). Elsewhere the lava shows prominent vertical jointing and well-developed horizontal jointing in cliff faces. Within the mist belt over the Uplands region adjacent to the Rift where the rainfall is high, the trachytes weather to a reddish-brown colour, eventually providing a thick soil cover rendering mapping difficult.

Gregory (1921, pp 161-163) described a traverse in southern Kikuyu and subsequently classified the rocks as part of his Upper Laikipian Series (pp 204-205) which were thought to be younger than the Kamasian Series of the Rift zone to the north and the more basic lavas of the present and surrounding areas. Baker (1958, p 18) suggested the term Plateau Trachyte Series to include these rocks and rightly correlated them with the Limuru Trachyte. Other accounts (Shackleton, 1945 and Thompson, 1964) have included the Limuru Trachyte as part of the Sattima Series and equated them to the Laikipian lavas of the areas to the north of the present one; this has been retained in the present report.

The Limuru Trachyte is soft, but rarely fissile, and highly porphyritic with stumpy feldspars in a pale grey groundmass. Typically, the rock contains large anorthoclase phenocrysts in a matrix of untwinned orthoclase, kataphorite, aegirine-augite and rare cossyrite. The phenocrysts of anorthoclase are frequently cracked and range in size up to a centimetre, occurring as separate crystals or as small glomeroporphyritic aggregates. Inclusions within the feldspars are common; some may be concentrated round the margins of the phenocrysts, and were identified as soda-pyroxene. Kataphorite is the dominant mafic constituent and is pleochroic from pale smoky-brown to yellow-green to purplish-brown. Rare examples of zoning in the soda-amphibole with overgrowths in blue, surmounted by yellow-green zones, suggest late but distinct changes in composition during crystallisation to an amphibole of arfvedsonitic or riebeckitic composition. Such examples may indicate changes in the upper lavas to rocks of more rhyolitic composition and are typified by a specimen from the lava flow from the Ondiri Fault Scarp north of Sigona Golf Club. In this rock, quartz occurs in the base as an interstitial mineral, occasionally in patches with a sub-poikilitic relationship towards the other minerals, particularly feldspar. This flow probably represents one of the latest in the volcanic history of the area and is equivalent to the soda-rhyolite extrusions on the Rift floor.

Some specimens of Limuru Trachyte contain occasional phenocrysts of pale apple-green aegirine-augite as well as patches of iron ore (limonite) and 'iddingsite', presumably pseudomorphic after olivine. Similar specimens have been described by Campbell Smith (1931, pp 220-222) and closely resemble Washington's Gibelé-type soda-trachyte from Pantelleria. One of these was described by



PLATE 1 The Ngong hills looking west. This former volcano is composed of alkaline lavas, mainly basanites and tephrites



PLATE 2 Fault scarp in Limuru Trachyte at Kiboko near Limuru. The depression on the down-throw side of the fault is now occupied by a clay filled swamp



PLATE 3 The Gicheru diatomite deposit. The deposit is flanked by alkaline, rhyolitic lavas while the scarp in the distance is composed of alkaline trachytes



PLATE 4 The main diatomite bed at Gicheru



PLATE 5 The Nairobi building stone at Ruarake quarry showing the typically massive nature of this welded unit of the Middle Kerichwa Valley Tuffs



PLATE 6 View from Lusigetti looking south towards the Ngong hills. Grid faulting has resulted in small, *en échelon* steps in the Limuru Trachytes

Lacroix (1923, p 255) an analysis of which is given in Table 11. In his description of these soda-trachytes Campbell Smith refers to specimen GN 459 from near the foot of the upper scarp where the former Sclater's road descended to the Kedong. He considered the rock to represent a hyaline facies, classifying it as a pantelleritic trachyte. The rock is porphyritic, vesicular, with an aphanitic, dark greyish-olive groundmass with phenocrysts of soda-orthoclase. Small pale green pyroxenes, olivines and magnetite are present and the groundmass consists of tawny-olive glass crowded with minute feldspar laths and needless of soda-pyroxene (Campbell Smith, 1931 p 222). Other rocks, with similar characteristics, crop out in the scarp three miles (4.8 km) south of the Gicheru Diatomite quarry and are clearly related to, or form part of, the same flow from which GN 459 was collected. Lacroix (1923, p 255) also collected similar specimens from the same area, describing them as *trachyte phonolitique* (Table 11) to which a variety of rock names has been applied.

The Limuru Trachyte thus exhibits much variation in texture and mineralogical content and all variations, from specimens without quartz to those containing abundant micrographic intergrowths, are present.

(g) Orthophyre Trachyte

Baker (1958, p 21) first recognised a distinctive trachyte that rests conformably on the Limuru Trachytes. Although similar mineralogically to the latter rock, the Orthophyre Trachyte contains no quartz and in the field weathers to large, rounded boulders that make it easily distinguished in the field and on aerial photographs. Outcrops of this rock type occur in the south-western corner of the area, the lava having been recognised and described by Matheson (1966, p 28) from the adjacent Kijabe area.

(h) Trachyrhyolites, rhyolites and obsidians

Many of the trachyrhyolites bear a strong resemblance to the Limuru Trachytes to which they are indeed related, clearly representing a more acid phase. The trachytes grade into the rhyolites by addition of quartz which occurs interstitially within the groundmass or as patchy poikilitic intergrowths with alkali-feldspar. Rarely does quartz occur as phenocrysts though these have been noted from rocks cropping out near the main road south-west of Escarpment Station. Megascopically there is little difference between the various rock types though the more acid varieties tend to be massive, weathering to boulders, and are dark grey though still characterised by porphyritic sanidine.

Shand described rocks from the Kedong Scarp (1937, pp 262-271) after his visit to Kenya in 1936 and, at Escarpment, recognised an upper trachyte division of 350 feet (107 m), plus an unknown thickness above Escarpment station, separated by 60 feet (18 m) of tuff from a lower, second trachyte division, 50 feet (15 m) thick. These trachytes have essentially the same characteristics as the Limuru Trachytes and differ chiefly in their crystallinity. Another specimen, collected by Shand from the south end of the Kijabe Embayment where the old Sclater's road makes its last descent to the floor of the valley, was described by him as a trachyrhyolite (p 265). It is comparable with a specimen described by Lacroix (1923, p 258) which was included by Campbell Smith in his Gibelé-type soda-trachyte (1931, pp 220-222). A number of Gregory's specimens and those described by Neilson (1921, p 396) are also included in this group. Analyses of some of these rocks are given in Table 11. A trachytic rock, collected during the present survey from the Ondiri Fault scarp near Sigona Golf Club, is probably transitional to Prior's soda-rhyolite (1903, p 242) in which feldspar phenocrysts are set in a pseudo-spherulitic matrix consisting of abundant micropoikilitic quartz-feldspar intergrowths in leucocratic patches associated with soda-pyroxene and soda-amphibole. An amphibole, showing pleochroism from citron-yellow to deep blue, is probably riebeckite and the presence of this mineral suggests an affinity with the comendites of the Naivasha area. This rock forms part of a flow, or flows, lying conformably upon the Limuru Trachyte which have subsequently been down-faulted to the west.

The downthrown rocks are probably represented by the trachyrhyolites cropping out on the lower Kedong platform and sampled by Lacroix and Shand.

The rhyolites and associated lavas occur as extrusive sheets, forming the lower part of the Rift escarpment bordering the Kedong valley, and extend from the northern border of the area, a distance of nearly 18 miles (29 km), to south of Gicheru. They have been affected by the grid faults and form a series of low hills and dipping sheets more than four miles (6.4 km) wide. It is probable that the lavas form the southerly extent of the Pleistocene acid alkaline lavas that were extruded from volcanic centres at Naivasha (Thompson and Dodson, 1963), rather than flows derived from Suswa as has been suggested. Wherever they originated, the larger proportion of the lavas is confined to the lower part of the Kedong escarpment and it seems likely that they lapped against a pre-existing, easterly confining escarpment. They represent the final phase of volcanicity in the Nairobi area (other than those younger lavas derived from Longonot) that took place during Pleistocene times, pre-dating the diatomite deposits of the Rift Valley. It is the acid nature of these rocks that provided the environment for the growth and continued existence of diatoms in isolated and ponded lakes within fault troughs, one important deposit being represented by the Gicheru occurrence.

Like the trachytes, these rocks in thin section show sanidine phenocrysts and glomeroporphyritic aggregates set in a finer-grained matrix of alkali-feldspar laths, quartz and variable amounts of aegirine-augite, cossyrite and kataphorite, often in micro-ophitic patches in which the feldspars are scattered. Iron ore is rare. Some specimens are notable for the high content of kataphorite to the total exclusion of cossyrite and a marked reduction in the proportion of soda-pyroxene. The kataphorite usually exhibits pleochroism from yellow to brownish-green to deep purplish-brown, though in specimens from west of the base of Githinguchi hill, kataphorite with reddish pleochroism is clearly the α variety (Prior 1903, p 236). A bluish-green amphibole, of arfvedsonite-riebeckite composition, was recognised in lavas west of the Nairobi-Nakuru road and north-west of Githunguchi hill. Riebeckite trachyte described by Kunzli (1901, p 142) from the western edge of the Kikuyu plateau is almost certainly a comendite (Campbell Smith, 1931, p 216) and is similar to specimens containing riebeckite examined during the present survey. A specimen (G211), described by Gregory and referred to as a pantelleritic soda-rhyolite, also appears to have been collected from the same area (his Lake Suess).

Vitreous lavas and obsidians are interbedded with the trachyrhyolites one particularly striking exposure occurring on the motorable track which descends the escarpment to the Gicheru diatomite diggings. Here, near Wanyaga, interbedded glassy rocks, exhibiting flow phenomena and fluted surface features related to shearing in congealing, viscous lava, are perhaps the most striking examples. Obsidians, containing rare phenocrysts set in a glassy base free of microlites, are rare but also are found interbanded in the trachyrhyolites. These glasses are nearly colourless, show banding and contain orientated fluid inclusions. Elsewhere the glasses are partly crystalline; fibrous, spherulitic aggregates with well-defined extinction crosses having developed in brown glass.

(i) Sediments and Tuffs

Although no other bedded deposits comparable to the Athi Tuffs and Lake Beds crop out in the Nairobi area, a number of boreholes have pierced tuffaceous sediments that are interbedded in the lava sequence. Many must represent the lateral equivalent of the more easterly, waterlain Athi Tuffs and Lake Beds, having been deposited sub-aerially upon the eastern slopes of the Rift margin. The total extent of these rocks is unknown and certainly, towards the Rift, it is likely that they are interstratified at depth with lava. Between Langata, in the western environs of Nairobi and the Nairobi National Park, boreholes (3161, 3159, 3001, 635, 613, 1401) reveal tuffs and clays interbedded between Mbagathi Phonolitic Trachyte and younger, overlying Nairobi Trachyte. A maximum of 140 feet (43 m) of tuffs (sediments) occurs in boreholes located near the main gate of the Park (1401) and they

thin progressively southwards where boreholes near the Mbagathi gate (3001) indicate a thickness of only 80 feet (24 m). No outcrops of these sediments were noted in the Mbagathi valley west of the National Park. The contact between the Nairobi Trachyte and older Mbagathi Phonolitic Trachyte, as seen near the Escarpment track south of Langata, is masked by scree though it is likely that the Nairobi Trachyte has here overstepped onto the older lava. Gevaerts (1964), in his hydrogeological report, shows these sediments in his Figure 2 and has equated them with the upper part of his Athi Series, presumably on similarity of composition and locality to the later rocks. The writer, however, considers that these rocks occupy a different stratigraphic position being separated by a number of unconformities from the older rocks: they also occupy a position within the Middle Trachytic Group of lavas rather than the Lower Phonolitic Group and for these reasons are considered a distinct formation. Other bands of similar composition have been penetrated in other boreholes, *eg* 3159 and 3001, and clearly represented periods of erosion when volcanic material, including tuffs, ashes and lava fragments, was being washed into its present position or sub-aerially distributed during volcanic activity. Elsewhere charred plant remains have been recovered from these interstratified deposits in boreholes. Whether such beds are totally lacustrine in origin is not known though locally they probably were laid down in small pools. Thus, it is likely that each lava type within the Nairobi succession is separated from succeeding flows by such deposits, representing periods when local erosion was most active. Coarse, unstratified tuffs, characterised by their bright yellow colour, are exposed in the north-western part of the area where good sections are revealed in railway cuttings near Uplands railway station.

These tuffs, which appear to overlie the Limuru Trachyte, have been traced northwards where they have been referred to as the Kinari Tuff (Gevaerts, 1964 p 7). Similar coarse tuffs exposed at various altitudes are interbedded within the Limuru Trachytes. Because of deep weathering on the Kikuyu escarpment, these softer rocks are poorly exposed but outcrops along the Kiboko Fault scarp north of Limuru, in the quarry south of the Uplands-Ruiru road at the Forest Guard Post, and in fault scarps west of the main road between Limuru and Kikuyu, are typical. The presence of these interstratified tuffs indicates that outpourings of Limuru Trachyte were accompanied by deposition of sub-aerial tuffs, probably as a result of volcanic activity within the Rift Valley, from centres such as Suswa and Longonot. Weathered tuff and ash beds have been recognised in the soil profiles of the Nairobi area, indicating the continuation of volcanic activity into Recent times.

14 Longonot Trachyte

The youngest lava in the area crops out in the extreme north-western corner of the area where it forms the southern extremity of a flow derived from the volcano Longonot, six miles (9.6 km) to the north. This porphyritic lava, whilst similar in mineralogical composition to the earlier trachytes, contains a certain proportion of glass and in this respect is transitional to the pantelleritic trachytes of the Rift region, though it lacks the characteristic occurrence of quartz in micropoikilitic patches. The specimen collected from the scoriaceous toe of the flow on the north side of the Narok road is highly vesicular, extremely fine grained and heavily iron-stained. Compared with the bare surfaces of Recent lavas, the sparse cover of vegetation over this blocky lava suggests a late Pleistocene age, in common with other lavas from Longonot.

15 Pleistocene Deposits

Although no fossils were found in sediments exposed in the Kedong river, from evidence in the areas further north the larger part of the floor of the Rift in the Kedong valley is underlain by sediments of lacustrine and fluviatile origin deposited mainly during Pleistocene time. Much of the floor is covered by loose soil and superficial deposits but in some of the deep gullies bedded deposits are exposed. The Kedong river partly occupies an open plain and partly is in short canyons, which display excellent

sections of bedded gravels, conglomerates, clays and tuffs. No evidence was found to support previous suggestions that the Kedong was the site of a former lake, though it is not unlikely that small lakes of local extent were present during pluvial periods. Faulting on the Mount Margaret Estate has exposed light-coloured lacustrine sediments and associated pyroclastics and, because of their resemblance to Kamasian rocks further north in the Rift Valley, Thompson (1964) assigned a Kamasian age to them whilst other rocks were thought to be Gamblian in age. Immediately west of Mount Margaret faulting has displaced tuffs, including welded varieties, which have been intruded by sill-like bodies of pumiceous lavas.

Perhaps the most interesting lacustrine deposits are those occurring on the eastern flanks of the Rift at Gicheru (Plates 3 and 4). Diatomite, chalk-like in appearance and of light weight, occurs in dry, compact, though porous, beds extending over a distance of 4000 feet (1,219 m) and in places more than 140 feet (43 m) thick. No other similar deposits were located during the survey but is is of interest that they are similar to other occurrences in the Rift Valley, *viz* Kariandusi and Olorgesailie. Analyses of the Gicheru Diatomite are given in Tables 7 and 13 where they are compared with other local and foreign deposits. There is no good evidence to date the diatomaceous beds with certainty but from stratigraphical relationships it is probable that they are Middle Pleistocene. The diatomite was probably laid down in a shallow fresh water lake impounded between fault blocks. The lake was subsequently drained by streams flowing westward from the Kikuyu escarpment into the Kedong valley, having breached the lava and pyroclastic barrier forming the western margin of the deposit. Like other large occurrences throughout the world, this deposit is associated with volcanic formations from which a ready supply of soluble silica was available over an extended period of time. It is of interest that, at Gicheru, the diatomite is associated with the most siliceous rocks: rhyolites, trachyrhyolites and obsidian-bearing strata. In this respect they are similar to the other occurrences in the Rift Valley.

Within the faulted area west of the Nairobi-Nakuru road, numerous bedded sedimentary deposits, consisting of ashes, tuffaceous gravels, conglomerates and partly consolidated pyroclastics, were noted. They have accumulated in scattered, small hollows and gullies and, in some instances, post-date the trachyrhyolites which have been found as included boulders within them. Although some are local products of erosion following grid faulting, others are sub-aerial deposits resulting from distant explosive volcanic activity. Where stream courses have deeply eroded the lower parts of the scarp above Gicheru, gullies expose conglomerates, pebble beds, red beds and gravels that represent former hill wash and scree accumulations. Many of the low-lying areas, shown on the map as covered by alluvium, are likely to be underlain by deposits of this kind.

Few other Pleistocene deposits occur in the area. L S B Leakey (personal communication) reports that a number of hand axes, similar to those from Kariandusi, have been found in the area where the diatomite beds occur at Munyu wa Kecheru (Gicheru) but none was found *in situ*. East of the main exposures, a rich Gamblian site was discovered though the details remain unpublished. Cultural remains belonging to the very late Pleistocene have been found in caves and rock shelters and these include:

a) Below the Veterinary Research Laboratory, Kabete, under a waterfall on the Bogaji stream
b) On St. Austin's Mission Land, near St. Mary's school
c) On the Ithanji stream, near Chief Koinge's home, Kiambu District

A prehistoric site occurs in the Nairobi National Park in the north Mokoyeti valley where it crosses the Embakasi track, the deposits consisting mainly of indurated gravels, clays and sands in which a number of 'levels' have been recognised. Chert flakes and tools occurring in the upper ferruginised

gravels are typical Levallois flakes and blades of the Late Stillbay Culture. Towards the base of the deposit are large hand axes of Acheulean type and a small badly preserved bone was recovered here some years ago. A bolas stone from the surface of the site probably originated from this lower level. Elsewhere, Levallois-type flakes and blades can be obtained at the soil surface and are found scattered throughout the area, mainly on the plains.

Table 7 Chemical analyses of some Gicheru, other Kenyan and foreign diatomites.

	1	2	3	4	5	6	7	8	9
SiO_2	83.65	83.14	87.56	79.60	86.00	86.00	79.72	79.92	87.30
AL_2O_3	3.11	2.73	3.88	7.90	5.27	5.80	4.52	6.58	3.50
Fe_2O_3	4.10	1.61	1.56	5.80	2.12	1.60	4.33	3.56	0.70
MgO	0.35	0.28	0.26	1.50	0.39	0.29	0.98	0.98	}0.40
CaO	0.26	0.38	0.46	2.10	0.34	0.70	4.17	1.43	
Na_2O	}2.17	-	0.46	1.70	0.24	0.48	0.38	0.65	}0.20
K_2O		-	0.70	1.20	0.29	0.53	1.16	0.72	
H_2O+	-	}8.08	-	-	-	-	-	-	}6.90
H_2O-	-		-	-	-	-	-	-	
TiO_2	0.25	0.16	0.19	-	0.21	0.22	0.34	0.48	-
P_2O_5	-	-	-	-	0.06	0.03	0.63	-	-
MnO	-	-	0.01	-	-	-	-	-	-
SO_3	-	-	-	-	-	-	1.60	-	-
loss on ig	6.88	3.84	4.90	-	4.90	4.40	0.79	4.91	-
	100.77	100.22	99.97	99.80	99.94	100.00	100.21	99.23	99.00

1. Diatomite. Gicheru, Kikuyu.
2. Diatomite. Gicheru, Kikuyu.
3. F grade Diatomite. Kariandusi. (By kind permission of the East African Diatomite Syndicate Ltd, Kenya).
4. Diatomite. Mile 61, Magadi Railway. (Imperial Institute, 1928).
5. Nevada USA.
6. Japan, Nilgata earth.
7. Germany, Green Label (calcined).
8. Russia, Kamyshlov, Urals.
9. Mozambique, Nacala. (De Kun, 1965).

(Analyses 5, 6, 7 and 8 from *Industrial Minerals and Rocks*, American Institute of Mining. Metallurgical and Petroleum Engineering, 1960)

Deposits of Pleistocene age are reported from the south-east corner of the area and from farms north of the river Athi. Fossils and hand axes have been recovered from them but their ages are unknown. Gravels, sandy clays and a conglomerate band comprise a ten-foot (3 m) thick section overlying Ngong-type lava in the valley of the Kandizi river (Fig 3). Bones and plant remains were recovered by the author from the finer-grained material, the tusks and teeth of *Hippopotamus gorgops* indicating the Pleistocene age of this former stream deposit. Axes, flakes and other Stone-Age tools are widely distributed throughout the area and are particularly abundant in the Rift Valley which, to judge from detailed descriptions of the many important prehistoric sites to north and south of the present area, was occupied by Palaeolithic man.

Calcrete (*kunkar*) and sheet limestones are developed as nodular deposits or as travertine sheets within black cotton soils located in poorly drained *vleie* *that overlie lavas or overlying Quaternary deposits as exposed in the Kedong. Many are minor occurrences but others, such as those near Kiambu, are large and have assumed economic importance as a source of lime. Similar *kunkar* limestones are developed in the dark soils overlying the Athi Tuffs and Lake Beds and owe their origin, in part, to the leaching of calcareous material from these sediments. Although many of the *kunkar* limestones are of Recent age, exposures in stream courses near Athi River, where conglomerates and soils are found overlying the *kunkar* layers, suggest that their time range can probably be extended to the Pleistocene if not the upper part of the Pliocene. Analyses of some of these limestones are quoted in Table 15 and 16.

16 Recent Deposits

(a) Superficial Deposits

Superficial deposits of Recent age include alluvia and conglomerates exposed in the principal river courses and in particular the Athi river and its tributaries near the south-eastern corner of the area. A typical pebble bed, approximately two feet (0.6 m) thick, was formerly exposed in the cliff side forming the north bank of the Mbagathi river at Baboon Escarpment within the National Park. This conglomerate band was composed of boulders and pebbles of local lava and was partly indurated, differentiating it from more modern uncemented gravels exposed along the course of the Mbagathi. Other indurated pebble sheets were also noted in the upper reaches of the same river and resemble Pleistocene deposits above the quarry workings in the Kandizi river. Elsewhere, most of the streams draining the high ground east of the Rift have deposits of shallow stony soils associated with rock outcrops along their courses. Where drainage has been impeded, swamps have developed resulting in accumulations of poorly-drained soils of high humus content.

Black swamp soils and clays are developed at the foot of the fault scarp near Limuru where drainage is locally impeded. Many of the depressions are near-permanent swamps and include the Nyakumu Swamp, where black clays fill the fault depressions. Brown to black soils and clays are developed in the fault troughs of the Rift Valley where the floors of the numerous graben are covered in sheets of superficial gravel and soils derived from volcanic ash. Some soils in the Kedong area undoubtedly owe their origin to the weathering of relatively soft Pleistocene deposits. This part of the area receives a low annual rainfall and the clays and soils quickly dry and form grey to buff loess-like dust that frequently conceals the underlying superficial deposits.

On weathering, much of the lava and tuff alters to a pale brown or reddish ferruginous soil and ferricrete (*murram*). The material is frequently hard and of sufficient thickness to permit quarrying for road metal. Perhaps the most notable of these deposits occurs on the Langata road immediately west of the Nairobi dam where the Nairobi Trachyte escarpment is sufficiently weathered to provide

* Broad, grass-covered, swampy valley (Ed).

deposits of ferricrete. Both the National Park authorities and contractors in Nairobi win the material from near the base of the scarp and utilise it for surfacing earth roads and tracks. Elsewhere local authorities and farmers use the material derived from the weathering of tuffs to surface dirt roads.

(b) Gypsiferous Beds

Poor exposures of Recent gypsiferous clays associated with or overlain by black cotton soil occur in pits to the south-east of the Stony Athi river. The gypsum occurs as crystal aggregates at varying depths and does not appear to form distinct layers. A deposit of this kind was discovered, below black cotton soil, by P H Cull near Konza railway station 13 miles (21 km) to the south-east (Baker, 1954 p 30) and others have come to light in the same area in the last few years. The relationship between the deposits and other formations is obscure but it seems that they have accumulated in hollows on the Kapiti Phonolite and probably formed from sulphated surfaces water in poorly drained soils. Approximately three miles (4.8 km) south-east of the south-east corner of this area, a borehole (C31) penetrated 100 feet (30 m) of clay before reaching Kapiti Phonolite, suggesting that they might represent derived products from the weathering of the upper deposits of the Athi Tuffs and Lake Beds. Similar deposits have been located near Konza and the gypsum is sufficiently concentrated to be mined in a small way. An analysis by the EAIRO of gypsum nodules from this deposit gave:

	%
SiO_2	5.43
R_2O_3	1.07
MgO	0.31
CaO	29.54
Moisture (at 45°C)	0.13
Combined H_2O(at 220°C)	19.35
SO_3 4	2.01
CO_2	not det.
Total	97.84

Calculating the sulphates to gypsum, $CaSO_4$ $2H_20$, the sample contains 90.3% (being 0.1% CaO in excess of the theoretical requirement).

Patchy deposits of gypsum crystals, too small to be of economic value, occur along the western margin of the Ngong hills.

(c) Soils

The soils of the Nairobi area are products of weathering of mainly volcanic rocks under relatively high temperature and rainfall, good drainage prevailing in the Kikuyu highlands in the west and poorer drainage conditions typifying the Athi plains in the east. Weathering in the former case has produced red soils that reach more than 50 feet (15 m) in thickness.

Soils of the Nairobi area have been examined in detail by Scott, former soil surveyor of the East African Agriculture and Forestry Research Organisation (Scott, 1963). Classification is based on that of the soil map in the Atlas of Kenya where the soils are mainly separated into major world groups, modified by Scott to facilitate a survey carried out as an exercise in the interpretation of aerial photos (Scott, 1963, p 3). A number of subdivisions are recognised according to drainage, climatic regions and slope, and other categories have been introduced for lithosols and regosols. Fig 4 is a simplified version of Scott's map.

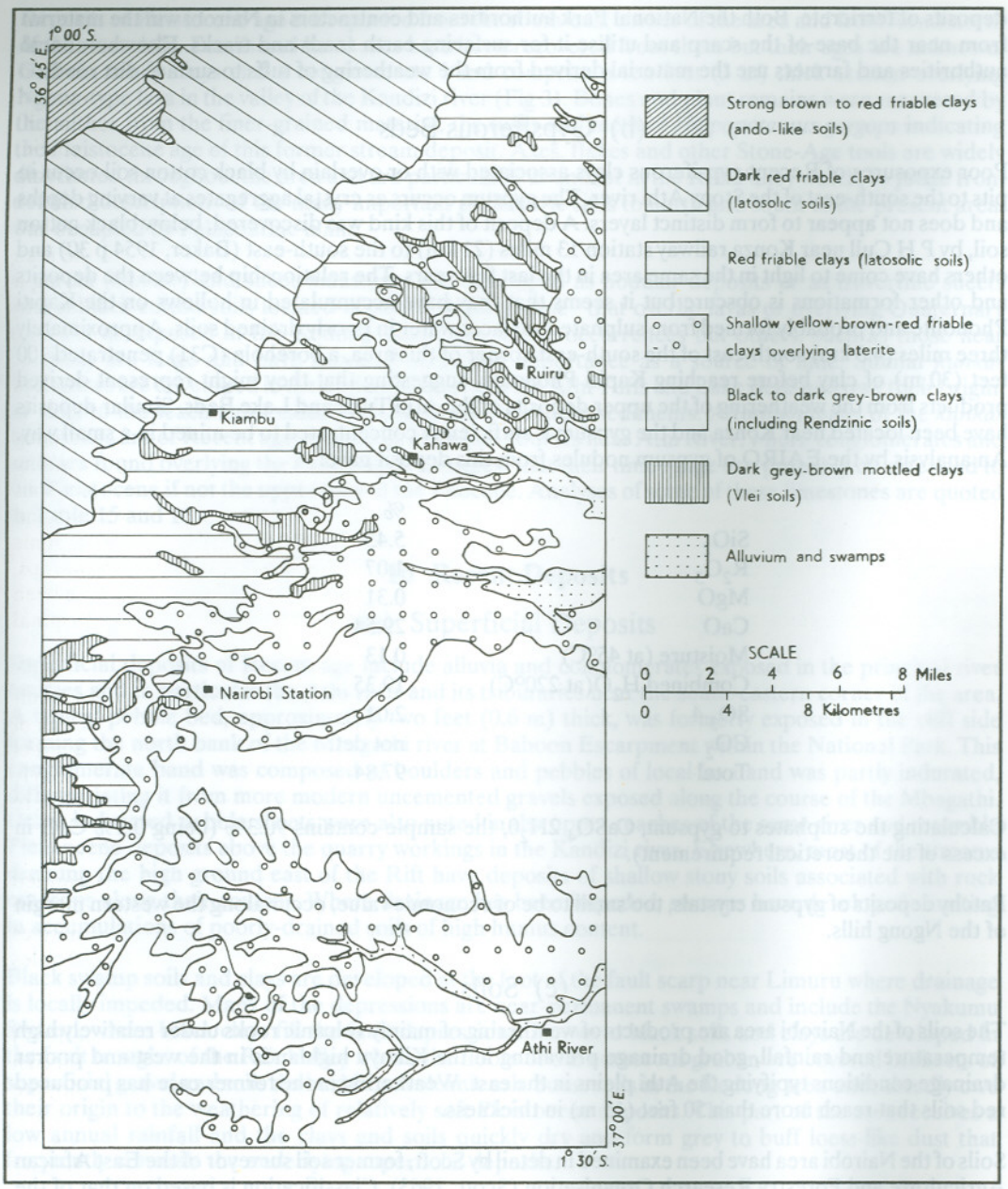


Figure 4 Soil map of part of the Nairobi area

The principal soils overlying the trachytic rocks of the north-west part of the area include strong brown to yellow-red friable clays (Ando-like soils) and dark red friable clays (latosolic soils) with a high humus layer overlying clay. These are developed from lava, volcanic tuff and ash in a humid region with a rainfall of more than 40 inches (1,000 mm) per annum and give place south-eastwards to red friable clays (latosolic soils) developed over similar rock types in areas where the annual rainfall is 30 to 40 inches (762-1,000 mm). These soils of the high ground flanking the Rift Valley are polygenetic, being derived by weathering of volcanic ash that fell over well-developed red soils of the underlying land surface. Between each ash shower, sufficient time must have elapsed to develop a new soil for buried humic horizons are a feature of the profiles. The soils and ash are developed on summits and hill slopes, indicating the irregular character of the land surface over which the ash fell. In the area Ruiru-Kahawa-Nairobi the soils are shallow, yellow-brown to yellow-red, friable clays overlying a laterite horizon. They usually show a low humus layer overlying friable clay passing downwards into massive laterite (ferricrete) and represent soils with slight seasonal impeded drainage.

Where drainage is impeded over the Athi plains east of Nairobi, the soils are black to dark grey clays (grumosolic) comprising black cotton soils with calcareous and non-calcareous variants. It is significant that these soils mainly overlie the Nairobi and Kapiti Phonolites, both lavas forming impermeable strata over which ill-drained soils can be expected to develop. Similar soils in the Ngong area would also form under similar conditions due to poor drainage. Locally, swamp and *vlei* soils and alluvium are recognised and patches of dark soils, overlying parts of the Nairobi municipality and Kikuyu highlands, are classified as dark greyish-brown, mottled clays (gley soils, *vlei* soils), some overlying the generally flat surface of the Nairobi Trachyte. Shallow stony soils with rock outcrops, which characterise the ESE trending valleys, have been derived from various soil types that have been subjected to accelerated erosion, principally on steep slopes, and have lost their original characteristics.

Reddish-brown, sandy clay loams occur in pockets and bands in the Athi River area overlying a tuff bed and their distribution has been attributed to erosion of a former land surface or the presence of an old lake (Scott, 1963, p 19). A more tenable explanation seems that the soils, which bear a direct relationship to the tuff bed, as suggested by Scott, are products of erosion of nearly horizontally-bedded members of the Athi Series that outcrop in the area and would be formed where the appropriate tuff bed crops out on hillside, summit or valley bottom.

Many of the red soils in the coffee farming areas are deficient in magnesia which is artificially added in the form of magnesite. A glance at the chemical analyses of the rocks from which these soils are derived indicates their very low magnesia content compared with the basic lavas of the area. Analyses of a number of clays and soil are given in Table 8 together with a clay from the Sasumua area, 20 miles (32 km) to the north of Ruiru Dam.

Recent studies made on the red clay soils of the Nairobi area (Dumbleton, 1967 and Sherwood, 1967) have revealed that leaching of the red soils removes the soluble bases and silica leaving the soil rich in iron oxide, haematite and goethite and also aluminium in the form of clay minerals, metahalloysite and hydrated halloysite. In these soils, the clay particles are cemented together by free iron oxide. The more easily leached components persist or accumulate on lower ground where the black soils, containing montmorillonite, are formed. In such soils calcium is present in the form of carbonate nodules. Sherwood (1967, p 47) has shown that the red clay gives anomolous results when subjected to British Standards soil classification tests because of the cementation of the particles by free iron oxide. Results of tests made on Kenya red clay soils are given in Table 9.

Table 8 Chemical analyses of clays and soil.

	1	2	3	4
SiO_2	40.65	34.16	38.69	35.60
Al_2O_3	20.98	25.55	32.74	30.75
Fe_2O_3	11.48	14.15	13.56	15.55
FeO	-	0.90	-	-
MgO	1.50	0.37	0.26	-
CaO	2.00	1.09	tr	-
Na_2O	-	0.09	nd	-
K_2O	-	0.34	nd	-
H_2O+	9.62	9.24	-	-
H_2O-	12.51	11.10	-	-
TiO_2	-	3.12	1.07	1.40
MnO	-	0.38	0.19	-
Loss on ig	-	-	13.14	15.03
Total	98.74	100.49	99.65	98.33

1. Clay. Fairview Estate, Kiambu.
2. Red clay. Escarpment. Kiambu. (Maufe, 1908 p 51)
3. Red soil. Kiambu. (EAIRB, 1953. Technical Pamphlet 61)
4. Clay. Sasamua. (Terzaghi, 1958 p 389)

Table 9 Soil classification tests on red clays from the Nairobi area. (Sherwood, 1967 p 48).

Location	Soil No.	Clay content (BS 1377) %	Liquid limit %	Plastic limit %	Plasticity index %
Kabete	816	82	76	39	37
Limuru	830	83	87	44	43
Nairobi-Limuru road	639	88	87	48	39

Similar tests, laboratory studies, and also investigations of the suitability of soils from Sasumua and Kabete for stabilization with Portland Cement and hydrated lime, were conducted by Nevill (1961). Investigation into the nature of the black cotton soils overlying Nairobi Phonolite forming the Athi plains have also been investigated by Stephen *et al* (1956) in connection with uneven growth of crops.

7 PETROGENESIS OF THE CAINOZOIC VOLCANIC ROCKS

The respective lava types of the Nairobi area, basic on the one hand and trachyte-phonolite-trachyrhyolite on the other, were erupted from different volcanic environments. Similar rock types are recognised as far north as Nanyuki implying the presence of large masses of magma which were available from time to time, the more acid varieties being erupted from fissures and the more basic and strongly alkaline rocks from localised centres.

At some stage, after the extrusion of the lower, basic lava group a period of quiescence ensued, permitting the build-up of renewed pressure and heat and the concentration of hyperfusibles in the roof of a comparatively shallow magma chamber. Later faulting, probably in part due to critical conditions of temperature and tension, resulted in a release of pressure and renewed, more acidic volcanism. The proportion of tuff to lava increases in the later lava sequences indicating a more explosive volcanicity producing ignimbrites that avalanched down pre-existing valleys producing extensive 'flood-tuffs' (van Bemmelen, 1961). This initial outburst of highly gas-charged tuff would lower the pressure and Healy (1964, p 15) has shown that such action can cause vesiculation of the magma which might explain the highly pumiceous character of the Kerichwa Valley Tuffs.

The rocks are alkaline in character, dominantly sodic, and comprise a wide range of rock types from melanephelinite to trachyrhyolite. Intermediate rocks are comparatively rare. In general the bulk of these rocks was erupted in order of increasing acidity from fissures situated along the eastern shoulders of the Rift zone in the neighbourhood of Limuru and Kikuyu and it is noticeable that, with few exceptions, distance from the Rift margin decreases with crystal fractionation. The extreme distances covered by the ash flows and welded tuffs is undoubtedly a measure of their former hyperfusible content. The majority, if not all, of the lavas are of late Cainozoic age and many of the later, more silicic, are of Middle Pleistocene age. Out-pourings of lava evidently extended over a period of approximately 12 Ma. Basic lavas were erupted from Ngong and Ol Esayeiti volcanoes during the later part of the episode. A few miles to the north of the present area early, basaltic eruptions are recorded. These outpourings of basic material were obviously associated with eruption of the central type and clearly such material was available from time to time during the formation of the Rift.

The principal sequence of volcanic rocks may be divided into three major divisions (Table 4). The earlier, Lower Trachyte Division, representing a period of 7 Ma, is characterised by basalts, phonolites, phonolitic trachytes and trachytes.

A later group of leucocratic alkali-trachytes, the Middle Trachyte Division, followed a hiatus and includes a number of welded tuffs and ash flows of trachytic character, produced during a short period of explosive activity, that can be traced as far north as Nanyuki. That this period of volcanic activity was from time to time explosive is evident from the widespread occurrence of interbedded tuffs within the trachytic sequence. The flows clearly derived from fissures during relatively short episodes with the formation of 'flood tuffs' and pumiceous flows. Some show only partial welding but have the typical properties of ignimbrites as described by van Bemmelen (1961, p 493). Their field characteristics do not suggest their derivation from *nuées ardentes* and they lack the features of orogenic volcanism.

The third, Upper Trachyte Division, is characterised by trachytes, basalts, rhyolites and obsidians and includes the most westerly lavas as well as the most siliceous of the lavas erupted in the Nairobi region. The later Pliocene-Pleistocene trachytic tuffs of the Ololua region near Ngong contain granitic gneiss fragments and associated with these fragmental rocks are basaltic and trachytic lavas. Before the trachyte magma was exhausted nephelinitic magma was erupted from the Ngong centre and is

Table 10 Mineral compositions of trachytes and phonolites from the Kikuyu escarpment.

		PHENOCRYSTS								MATRIX									
	Rock Type	Sanidine	Anorthoclase	Nepheline	Aegirine Aegirine-augite	Titanaugite	Olivine	Biotite	Barkevikite	Alkali feldspar	Nepheline	Quartz	Aegirine Aegirine-augite	Cossyrite	Kataphorite α	Kataphorite β	Riebeckite Arfvedsonite	Biotite	Barkevikite
UPPER DIVISION	Rhyolites including pantellerites and commendites	x	x						r	x		x	x				x		
	Trachyrhyolites	x			r		r (a)			x		x		x		x	x		
	Orthophyre trachyte		x		x					x			x	x					
	Limuru Trachyte (mainly in the west)	x			x		r (a)			x			x	r		x	r		
	Limuru Trachyte (inc Gibelé type)	x					r (a)			x		x	x	r		x	r		
MIDDLE DIVISION	Tigoni Trachyte									x		x	x	ac		x			
	Karura Trachyte									x			x		x				
	Ruiri Dam Trachyte	x								x			x	x	x		x		
	Kabete Trachyte	x								x			x	x	x		x		
	Ololua Trachyte		x							x			x	x	ac		s		s
LOWER DIVISION	Nairobi Trachyte	x								x			ok	x	x				
	Kiambu Trachyte		r							x			x	x	x				
	Nairobi Phonolite	x						x		x	x		x	x	l			x	
	Kandizi Phonolite	r								x	x		on	x	x				r
	Mbagathi Phonolitic Trachyte	ac	x			r				x	x		x	x		x	x		
	Kapiti Phonolite		x	x		x	r			x	x		x		x				

Properties of kataphorite:

α Colourless to pale brownish-yellow
Smoky-brown to rose-red
Reddish yellow

Cleavage 124°
Z∧c 40°

β Pale smoky-brown to geenish yellow
Deep purplish brown to opaque

Z∧c 23°

x present
r rare
(a) altered
s some flows
ac accessory
ok overgrowths on kataphorite
on overgrowths on nepheline
l including large crystals

found interbedded in the normal lava sequence of that part of the area. Final phases of eruption and fractionation are represented by soda-rhyolites, that are restricted to the Kedong valley or occur as thin flows capping the Limuru Trachyte succession. Intrusive masses are absent and no interstratified lavas of other types were noted in the Ngong trachyte group. The early group characterised by phonolite were extremely fluid, inundating wide areas underlain by eroded Precambrian crystalline rocks. The later flows became successively less fluid except for the Limuru Trachyte which covers a much wider area than perhaps any other rock type in this part of the Rift region.

A summary of the mineral compositions of the trachytes and phonolites given in Table 10 shows that there is a tendency for the later lavas to contain a greater proportion of kataphorite and riebeckite and/or arfvedsonite, with respect to the soda-pyroxenes. Aegirine or aegirine-augite is rarely lacking and occurs as rare microphenocrysts in some of the youngest flows. At the same time there is a general change in the composition of the kataphorite from α to β variety (pleochroism in this mineral is somewhat diverse, however, in the different rock types). Presumably the change in magmatic composition is reflected, first in the increase in amphibole over pyroxene, and secondly by the composition of the soda-amphibole. Nepheline is found only in the early lavas, whilst the appearance of quartz, most frequently in micropoikilitic intergrowths with feldspar in the lavas of the Upper Trachyte Division, is also accompanied in some rocks by highly altered olivines.

Bowen, in his classic account of Petrogeny's Residua System (1937), has shown that the crystal-liquid equilibrium has been the dominant control in the production of rocks rich in alkali-alumina silicates and that such rocks, for the most part, are residual liquids of crystallising magmas. Many of the analyses used in his discussion were of Gregory Rift Valley rocks and included a number of lavas from the present area. He showed that these rocks fall within the low temperature field of the experimentally investigated system, $NaAlSiO_4$ - $KAlSiO_4$ - SiO_2 and can therefore be considered as a residual product of crystallisation differentiation. A number of variation diagrams support the hypothesis and suggest that the local parent magma was an alkali-olivine basalt represented by lavas extruded in the vicinity of Ngong.

Some significance must be placed on the generally early appearance of basic lavas though basic magma was erupted from certain centres, such as Ngong, from time to time during the extrusion of the later and more acid lava types. As in other volcanic regions , the absence of intermediate types of lava might suggest that the basic lavas, originating at depth in a region of subsidence, would provide the heat necessary for the melting of sialic material thus giving rise to acid magma and the subsequent differentiation of the phonolite-trachyte-soda-rhyolite rocks, as noted in the present area. The variation diagrams do suggest, however, a single, local, parental magma for both the basic and the acid series . The origin of the two types must therefore be explained from the evidence of other criteria such as tectonic setting and not in terms of crystallisation differentiation alone. Significantly the more strongly alkaline rocks are usually associated with eruption from central volcanoes such as Ngong, whereas the mildly alkaline and more siliceous rocks are products of fissure eruption.

Chemical analyses of a number of the volcanic rocks in the Nairobi area are presented in Tables 11 and 12, together with analyses of rocks from adjacent areas which clearly are products of the same volcanic episode.

Table 11 Chemical analyses of mildly alkaline lavas

	170	167	165	160	156	152	151	148	203	95
SiO_2	43.50	43.90	44.25	45.40	45.98	46.58	46.74	48.19	57.42	59.38
Al_2O_3	18.65	11.79	17.05	17.74	15.34	13.67	18.88	18.32	17.92	10.84
Fe_2O_3	1.70	2.97	3.15	3.10	6.11	6.15	3.11	8.01	}7.50	3.92
FeO	10.48	9.22	9.98	8.15	8.39	6.37	7.15	3.88		4.28
MgO	7.42	11.46	5.28	6.27	3.98	7.66	3.16	2.40	1.17	0.89
CaO	10.26	11.52	11.04	12.12	7.74	11.20	9.30	7.82	tr	3.31
Na_2O	2.63	1.96	3.05	2.29	3.35	2.55	4.17	4.25	-	5.60
K_2O	0.94	0.81	1.16	0.68	1.75	1.30	1.67	1.50	-	5.01
H_2O+	0.54	1.00	0.26	0.32	1.47	1.70	0.63	0.80	-	
H_2O-	0.80	1.45	0.75	0.66	0.52	0.46	1.07	1.08	-	}3.14
TiO_2	2.40	3.13	3.30	2.84	3.80	2.66	2.44	2.98	0.60	0.81
P_2O_5	0.62	0.27	0.50	0.28	1.46	0.25	1.29	0.65	n.d.	1.00
MnO	0.12	0.27	0.11	0.10	0.24	tr	0.18	0.19	-	0.35
CO_2	-	tr	-	-	-	-	0.16	-	3.42	1.30
SO_3	-	-	-	-	-	-	-	-	0.15	0.04
CL	-	-	-	-	-	-	-	-	-	0.01
F	-	-	-	-	-	-	0.11	-	-	-
S	-	-	-	-	-	-	-	-	-	-
- O eqv	-	-	-	-	-	-	0.05	-	-	-
Totals	100.06	99.75	99.88	99.95	100.13	100.55	100.01	100.07	-	99.88

170. Alkali basalt (NG.426), Rogati river, Kikuyu (W Campbell Smith,1931, p 252).

167. Picritic basalt (GN.385), 9480 feet on Sattima scarp, Naivasha-Nyeri road (W Campbell Smith 1931, p 252).

165. Alkali basalt (GN.640), Upper Nguruma Escapment, Magadi (W Campbell Smith 1931, p 252).

160. Alkali basalt (GN.219), Nyuki Scarp. Magadi (W Campbell Smith, 1931, p 252).

156. Laikipia basalt, Oloronyi . Anal. D O G S.

152. Simbara olivine basalt (43/586A), W slope of Niandarawa. Anal. J Furst.

151. Olivine basalt, Kijabe Hill (Shand, 1937, p 266).

148. Simbara basalt (Kijabe type) (43/1325), Melawa Ndogo gorge. Anal. D O G S.

203.Tuff (661), junction Ngong-Dagoretti roads . Nairobi (Imp. Inst. 1927 p 377).

95. Alkali trachyte (Plateau Trachyte Series), Magadi Hospital (Baker, 1958, p 20).

Table 11 (continued) Chemical analyses of mildly alkaline lavas

	94	202	93	92 +	91	90	87	201	W15 *	85
SiO_2	59.41	59.70	60.25	60.74	61.20	61.24	62.54	62.55	62.56	63.81
Al_2O_3	12.03	19.20	10.87	15.58	14.36	13.53	15.85	14.50	14.96	12.76
Fe_2O_3	4.53	}8.00	5.08	3.66	4.31	4.52	3.66	}7.65	3.25	4.74
FeO	3.93		3.50	3.55	4.09	3.36	2.62		3.36	1.65
MgO	0.63	0.30	0.83	0.38	0.77	1.06	0.36	1.13	0.36	0.57
CaO	1.39	2.40	2.73	0.97	2.54	1.98	1.46	nil	1.21	0.40
Na_2O	6.37	6.40	6.29	6.59	5.46	4.95	6.12	6.02	6.42	5.67
K_2O	4.36	2.80	4.77	4.68	4.72	3.86	5.07	4.04	5.64	5.12
H_2O+	}4.05	-	}1.25	1.20	1.18	2.50	0.59	-	0.54	2.67
H_2O-		-		1.21	0.60	-	0.45	-	0.73	-
TiO_2	0.81	1.2	0.88	1.05	0.35	0.99	1.07	1.47	0.66	0.69
P_2O_5	1.06	-	1.62	0.07	0.09	0.99	0.13	-	0.10	1.58
MnO	0.65	-	0.83	0.26	0.17	0.34	-	-	0.19	0.31
CO_2	tr	-	1.06	tr	-	0.35	-	-	nil	0.18
SO_3	0.27	-	0.08	nil	-	0.09	0.08	-	0.00	0.24
CL	0.05	-	0.06	0.01	-	0.02	0.04	-	0.04	tr
F	-	-	-	-	-	-	-	-	-	-
S	-	-	-	-	-	-	-	-	-	-
- O eqv	0.01	-	0.02	0.02	-	0.01	0.01	1.41	0.02	-
Totals	99.53	100.00	100.08	100.18	99.84	99.77	100.03	98.77	100.00	100.39

+ includes ZrO_2 0.19, FeS_2 0.08, $(Ce,Y)_2O_3$ 0.05 * V_2O_3, Cr_2O_3, BaO, SrO nil

94. Alkali trachyte (Plateau Trachyte Series) 1 ml. NNE of Needle Rock, Magadi (Baker, 1958, p 20).
202. Welded tuff (Nairobi building stone) Anal. E A I R B.
93. Alkali trachyte (Plateau Trachyte Series) Lake Magadi (Baker. 1958, p 20).
92. Kataphorite trachyte, (BM.1930,155,11). E of lake Naivasha (W Campbell Smith. 1931, p 227).
91. Kataphorite trachyte, (GN 630) W Shore of Lake Magadi (W Campbell Smith. 1931, p 227).
90. Alkali trachyte (Plateau Trachyte Series) 2 ml. S of Magadi golf course (Baker.1958, p 20).
87. *Trachyte phonolitique* (soda- trachyte Gibele-type). Kikuyu escarpment (Lacroix. 1923, p 258).
201. Welded tuff (Nairobi building stone) Anal. E A I R B.
W15. Nairobi trachyte, Kenyatta Avenue, Nairobi. E A I R B.
85 Alkali trachyte (Plateau Trachyte Series) Little Magadi Lake (Baker. 1958, p 20).

Table 11 (continued) Chemical analyses of mildly alkaline lavas

	82	80	83	78	77	76	75	74	73
SiO_2	64.00	64.45	65.99	70.36	70.61	73.30	73.96	75.03	75.55
Al_2O_3	10.43	15.79	14.42	9.63	8.59	11.56	11.40	11.10	12.31
Fe_2O_3	6.30	3.81	2.85	1.72	2.52	1.68	1.65	1.31	0.69
FeO	3.86	2.66	2.89	5.42	5.96	2.41	1.95	1.84	1.17
MgO	0.34	tr	0.18	0.06	0.07	0.24	0.03	nil	0.04
CaO	1.45	0.77	0.49	0.30	0.61	0.78	nil	nil	0.23
Na_2O	7.59	5.16	5.57	6.73	6.77	4.84	5.41	5.09	4.55
K_2O	4.59	5.51	5.28	4.43	4.46	3.96	4.36	4.56	4.69
H_2O+	}0.17	0.68	0.59	0.10	}0.10	0.40	0.13	0.08	0.15
H_2O-		1.06	0.39	0.01		0.30	0.02	0.01	nil
TiO_2	0.78	0.71	0.72	0.33	0.15	0.33	0.17	0.19	0.13
P_2O_5	-	tr	0.10	0.03	-	0.03	tr	tr	0.01
MnO	0.37	0.20	0.23	0.25	0.34	-	0.05	0.06	0.04
CO_2	-	-	-	-	-	-	-	-	-
SO_3	-	-	-	-	-	-	-	-	-
CL	-	-	0.01	0.40	-	-	0.41	0.27	0.21
F	-	-	0.23	0.17	-	-	0.68	0.42	0.28
S	-	-	0.01	0.02	-	-	0.01	0.01	0.01
- O eqv	-	-	0.01	0.16	-	-	0.38	0.24	0.16
Totals	99.88	100.80	99.85	99.80	100.18	99.83	99.85	99.73	99.90

82. Vitreous pantellerite (phonolitic obsidian) (BM. 85753, 3), Lake Nakuru (Prior, 1903, p 245).
80. Trachyrhyolite, Kedong Scarp (Shand, 1937, p 265).
83. Quartz trachyte (NLB. 234), 2ml. W of Ngong Scarp, Kedong (Bowen, 1937. p 14).
78. Obsidian (soda rhyolite) (NLB 230) Elburru (Bowen, 1937, p 14).
77. Vitrous pantellerite (obsidian) (BM 85763, 18) Lake Naivasha (Prior,1903, p 246).
76. Comendite (GN 106), El Barta, Njorowa gorge, Naivasha (W Campbell Smith,1931, p 219).
75. Rhyolite obsidian (comendite) (NLB 249). S shore, Lake Naivasha (Bowen.1937, p 14).
74. Obsidian (comendite) (NLB 246), Njorowa gorge, Naivasha (Bowen, 1937, p 14).
73. Rhyolite obsidian (fayalite-bearing) (NLB 248), Lake Naivasha (Bowen, 1937, p 14).

Table 11 (continued) Norms of mildly alkaline lavas

	167	160	152	151	148	95	94	93	90
Q					0.90	6.78	7.74	11.40	15.29
or	5.00	3.90	7.78	10.01	8.89	29.50	26.05	28.35	22.80
ab	12.60	18.30	21.48	28.82	36.16	28.85	37.73	29.32	40.08
an	20.80	36.10	21.96	27.52	26.41				1.66
ne	2.00	0.60		3.69					
hl						0.20	0.12	0.24	0.06
th						0.07	0.42	0.14	0.14
ac						11.05	12.47	12.46	
di	27.6	17.90	24.94	7.58	6.05	2.06	0.69		
hy			2.76		3.20	7.99	2.98	7.94	4.28
ol	17.90	12.60	6.13	8.08					
mt	4.40	4.40	8.82	4.41	4.41		0.23	1.16	6.50
hm					4.96				
il	5.90	5.40	5.02	4.56	5.62	1.52	1.52	1.67	1.82
ap	0.70	0.70	0.67	3.25	1.68	2.34	2.35	3.70	2.35
cc				0.30		2.90		1.60	0.80
ns						1.00			
nc						0.76			
C						0.81			

	87	85	80	83	78	76	75	74	73
Q	5.26	15.53	11.34	12.50	26.60	27.23	33.10	32.50	32.70
or	30.02	30.01	32.80	31.10	26.10	23.35	26.10	27.20	27.80
ab	51.87	37.20	43.49	44.50	24.60	37.20	33.50	31.40	35.10
an	0.83		3.61						
hl					0.60		0.70	0.50	0.40
th		0.42							
ac		6.00		2.30	5.10	3.23		3.70	
di	1.94				0.20	3.20			
wo	1.32					2.33			
hy		0.20		3.20	9.70		2.10	2.90	1.40
ol			0.92						
mt	5.34	3.94	5.57	3.00		0.80	2.30		0.90
hm			1.37						
il	2.05	1.22		1.40	0.60	0.61	0.30	0.50	0.30
ap	0.34	2.35		0.30		0.09			
cc		0.40							
CaF_2				0.50	0.40				0.30
NaF							1.40	0.80	0.30
ns					5.60				
C									0.40

Table 12 Chemical analyses of strongly alkaline lavas

	186	196/198	174 *	157	135	144	147	132	123
SiO_2	38.80	39.97	40.70	45.65	49.62	50.24	50.27	51.59	54.58
Al_2O_3	14.22	10.00	3.90	16.12	21.23	17.93	16.27	14.48	19.42
Fe_2O_3	7.28	9.03	4.97	3.07	3.77	2.82	3.28	7.77	1.87
FeO	6.34	4.98	14.63	9.08	2.02	5.43	7.84	-	3.17
MgO	5.65	9.06	30.78	7.38	0.65	2.58	4.89	2.90	1.42
CaO	12.35	14.57	3.14	9.70	3.40	6.58	8.66	4.53	1.53
Na_2O	5.00	3.00	0.36	2.74	9.00	5.33	3.85	-	7.77
K_2O	2.19	1.24	0.51	1.42	5.45	3.49	1.75	-	5.00
H_2O+	1.80	3.28	0.10	0.33	1.81	}2.79	0.53	}3.75	2.95
H_2O-	1.40	0.97	0.10	0.68	1.75		0.48		0.64
TiO_2	4.30	3.11	1.14	3.30	0.83	2.63	1.90	0.72	0.80
P_2O_5	0.72	0.55	tr	0.43	0.11	-	0.42	-	0.33
MnO	0.14	0.21	0.17	0.13	0.18	-	0.24	-	0.23
CO_2	-	0.16	-	-	-	-	-	-	-
SO_3	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	0.21	-	-	-	0.01
F	-	-	-	-	-	-	-	-	0.10
S	-	-	-	-	nil	-	-	-	0.04
Lss on ig	-	-	-	-	-	-	-	1.23	-
- O eqv	-	-	-	-	0.05	-	-	-	0.04
Total	100.10	100.28 +	100.50	100.03	99.88	99.82	100.38	88.97	99.82

* includes Cr_2O_3 0.10, NiO 0.10. + includes BaO 0.15

86. Nephelinite (augitite) (GN 502), W of Ngong Bazaar (W Campbell Smith, 1931, p 254).

196/198. Average of two ankaratrites (51/731 and 51/727E), Nguruma escarpment, W of Magadi (Saggerson and Williams, 1964, p 67).

174. Olivine basalt (oceanite), Lake Naivasha (Arambourg,1935, p. 41).

157. Alkali basalt (basanite) (GN 392), Nyeri road, Aberdare range (W Campbell Smith, 1931, p 252).

135. Phonolite, Ol Esakut (Tilley, 1956).

144. Lava near Ngong (precise locality not recorded). Anal. A F R Hitchens.

147. Basalt (43/1267) Elmentaita, Anal. D O G S.

132. Nairobi phonolite, Nairobi, Anal. E A I R B.

123. Phonolite (Kapiti-type) (NLB 255), Kapiti plains near Kima (Bowen, 1937, p 14).

Table 12 (continued) Chemical analyses of strongly alkaline lavas

	118	115	W43 +	W64	112	102	99	109	108
SiO_2	54.81	55.48	55.99	56.56	57.05	57.12	57.94	58.75	59.14
Al_2O_3	19.10	18.70	18.96	16.77	19.73	17.41	17.00	19.50	15.75
Fe_2O_3	1.57	3.53	2.72	3.17	1.85	4.82	4.03	1.42	6.65
FeO	3.52	2.08	2.28	2.74	4.31	2.72	1.94	3.04	1.35
MgO	0.96	1.75	1.08	1.36	0.34	0.97	1.22	0.89	0.56
CaO	1.81	2.17	3.55	1.18	1.56	3.05	0.99	1.74	1.42
Na_2O	6.88	7.04	6.40	7.53	7.54	6.68	7.63	6.97	7.23
K_2O	5.41	4.85	4.67	5.69	4.85	3.98	5.13	5.00	4.66
H_2O+	3.63	3.31	1.85	1.70	0.54	1.27	1.15	1.10	1.78
H_2O-	0.57	0.19	0.42	1.55	0.68	0.20	0.94	1.04	0.25
TiO_2	0.82	0.70	0.99	1.07	0.82	1.18	1.08	0.60	0.50
P_2O_5	0.22	0.24	0.14	0.13	0.23	0.32	0.18	0.05	0.09
MnO	0.27	0.12	0.15	0.33	0.35	0.30	0.30	0.08	0.35
CO_2	0.14	nil	0.23	0.05	-	nil	0.09	-	0.11
SO_3	-	-	nil	-	tr	-	-	-	-
Cl	0.01	tr	0.02	-	-	0.05	0.13	-	0.02
F	0.09	-	-	-	-	-	0.11	-	-
S	0.02	-	-	-	-	-	0.02	-	-
- O eqv	0.04	-	-	-	-	0.01	0.08	-	0.00
Total	99.79	100.16	0.01	99.83	99.85	100.06	99.80	100.18	99.86

+ includes BaO 0.16, SrO 0.14, V_2O_3,Cr_2O_3 nil

118. Phonolite (Kapiti-type) (NLB 243), old Nairobi-Nyeri road, (Bowen, 1937, p 14).

115. Phonolite (Kapiti type) (BM 1947, 200(1)), 12 ml. NE of Kajiado Station, (W Campbell Smith, 1950, p 5).

W43. Trachybasalt (tephrite?), Shanamu hill.

W64. Nairobi Phonolite , Quarry, Nairobi, Anal. H Lloyd.

112. Phonolite (Fayalite-bearing) (GN. 404), Nyeri hill (W Campbell Smith,1931, p 249).

102. Kenyte (phonolite) (45778), inner caldera, Suswa, (McCall and Bristow, 1965, p 29).

99. Phonolitic trachyte (NLB 303), Athi plains (Bowen,1937. p 14).

109. Phonolite (trachytoid) (GN 223), NW Spur, Olorgasailie (W Campbell Smith, 1931. p. 249).

108. Phonolite (Kenya-type) (45767), North slope, Suswa (McCall and Bristow, 1965, p 26).

Table 12 (continued) Norms of strongly alkaline lavas

	186	174	157	147	132	123	118	115	102	99	109	108
or	2.78	2.78	8.34	10.34	27.80	29.50	31.7	28.64	23.75	30.00	29.47	27.56
ab		3.14	18.86	32.58	25.68	36.10	36.1	39.82	46.99	46.40	45.69	51.92
an	9.73	751	27.52	21.95	8.34	3.30	5.30	5.00	5.73		7.03	
lc	7.85											
ne	23.00		2.27		25.56	15.90	11.90	10.65	5.17	6.90	7.15	1.70
ac										3.70		5.36
di	30.24	17.00	16.40	14.97		1.80	0.90	3.24	7.82	2.20	1.19	3.01
wo	3.25											0.80
hy				0.31								
ol		60.38	14.00	9.89	6.31	4.30	4.70	1.99	2.77	1.40	3.85	
mt	8.35	7.19	4.40	4.76	2.55	2.80	2.30	5.05	3.96	3.90	2.09	2.88
hm	1.60			3.61				0.05				2.80
il	8.21	2.13	6.20		0.61	1.50	1.50	1.32	2.23	2.10	1.14	0.95
ap	1.68		1.00	0.99	1.34	0.70	0.30	0.57	0.74	0.30	8.27	0.0
cc										0.20		0.25
CaF_2						0.10	0.10			0.10		
hl										0.20		

Although highly acid rocks from neighbouring areas are well represented, none have been analysed from the Nairobi area. To partially fill this data gap, refractive indices of glassy components of acid rock types occurring within the area have been used to estimate silica contents. The details are as follows:

Obsidian (Nairobi-Nakuru road at the escarpment)	1.508 ± .002
Rhyolite (glassy) south of Gicheru	1.522 ± .003
Glassy groundmass in trachyte, Kikuyu escarpment (from Campbell Smith, 1931 p 222)	1.54

These values correspond to hyaline material having an approximate silica content of 69.50, 66.25 and 62 per cent respectively (Kittleman, 1963 p 1408) and compare favourably with the silica content of similar analysed specimens quoted in Table 11. The refractive index of the glass in a pantelleritic obsidian, containing SiO_2 64 per cent (Prior, 1903 p 245) as determined by Campbell Smith (1931, p 218), is between 1.530 and 1.533 and fits curves given by Kittleman.

The differentiation trends of the lavas are shown in Harker variation diagrams and an FMA triangular plot (Figs 5, 6 and 7). These, together with other diagrams, suggest consanguinity and indicate a process of continuous differentiation along two trends also noted for a wider range of rocks in the northern Tanganyika Alkaline District (Saggerson and Williams, 1964, p 75).* The generally smooth curves of variation shown in the various diagrams are considered to represent the liquid line of descent of the parental magma. A separation of nepheline-bearing and nepheline-free rocks is noted in all curves. A mafic index $100(FeO + Fe_2O_3)/(FeO + Fe_2O_3 + MgO)$ plotted against a felsic index $100(Na_2O + K_2O)/(Na_2O + K_2O + CaO)$ (Simpson, 1954, pp 238-244), not illustrated, indicates a similar marked separation. The alkali-lime index for the two rock series is 49.5 and 52 respectively, the more strongly alkaline rocks being characterised by the presence of felspathoids and, as is to be expected, the mildly alkaline variety, with a higher index, falls in Peacock's alkali-calcic field (1931, p 57). The total alkalis vary antipathetically to lime as silica increases (Fig 6), the presence of quartz

* Chayes (1964, p 235) considers that the Harker diagram is of little use as evidence for fractional crystallisation (Author).

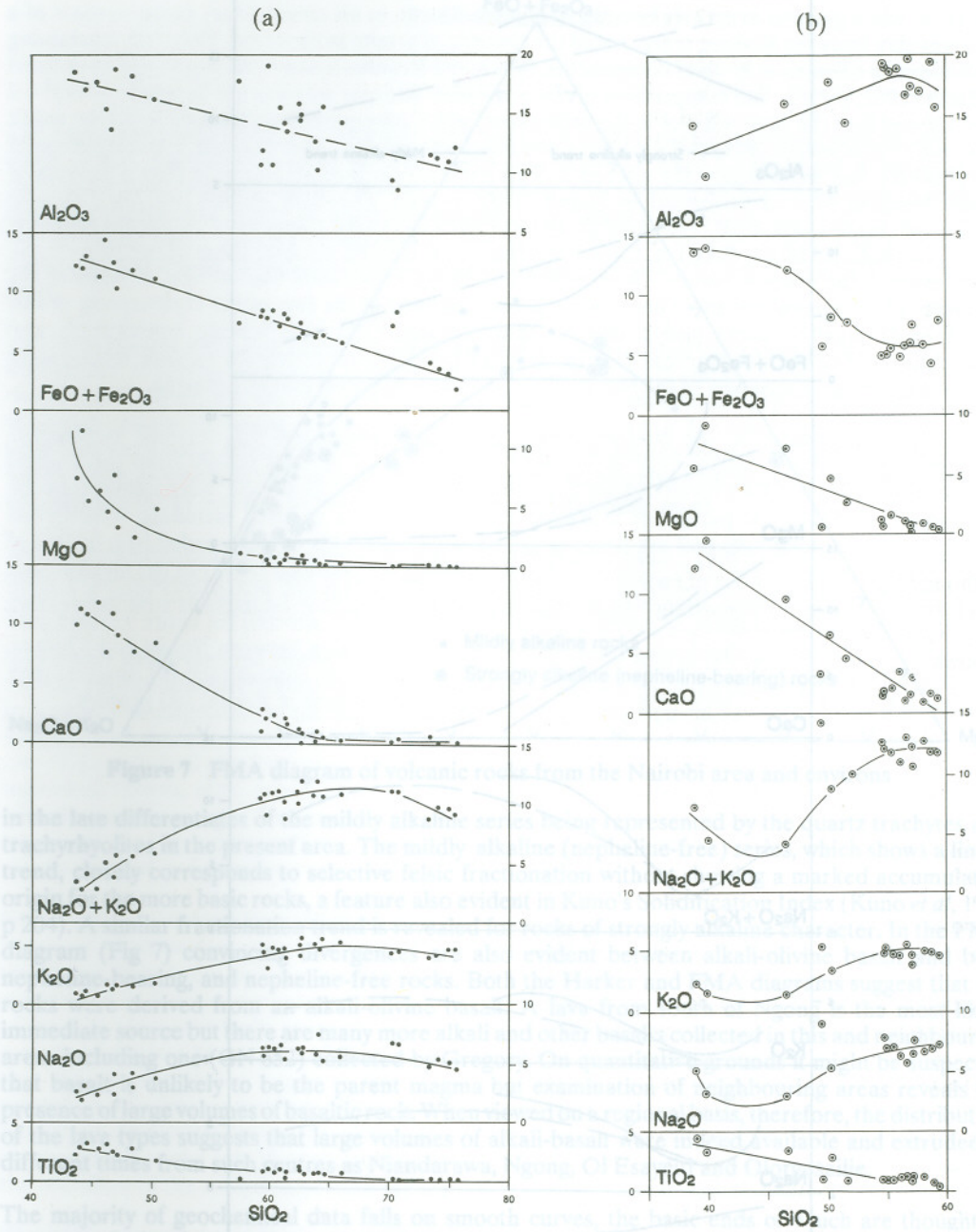


Figure 5 Harker variation diagrams of mildly (a), and strongly (b), alkaline rocks from the Nairobi area and environs.

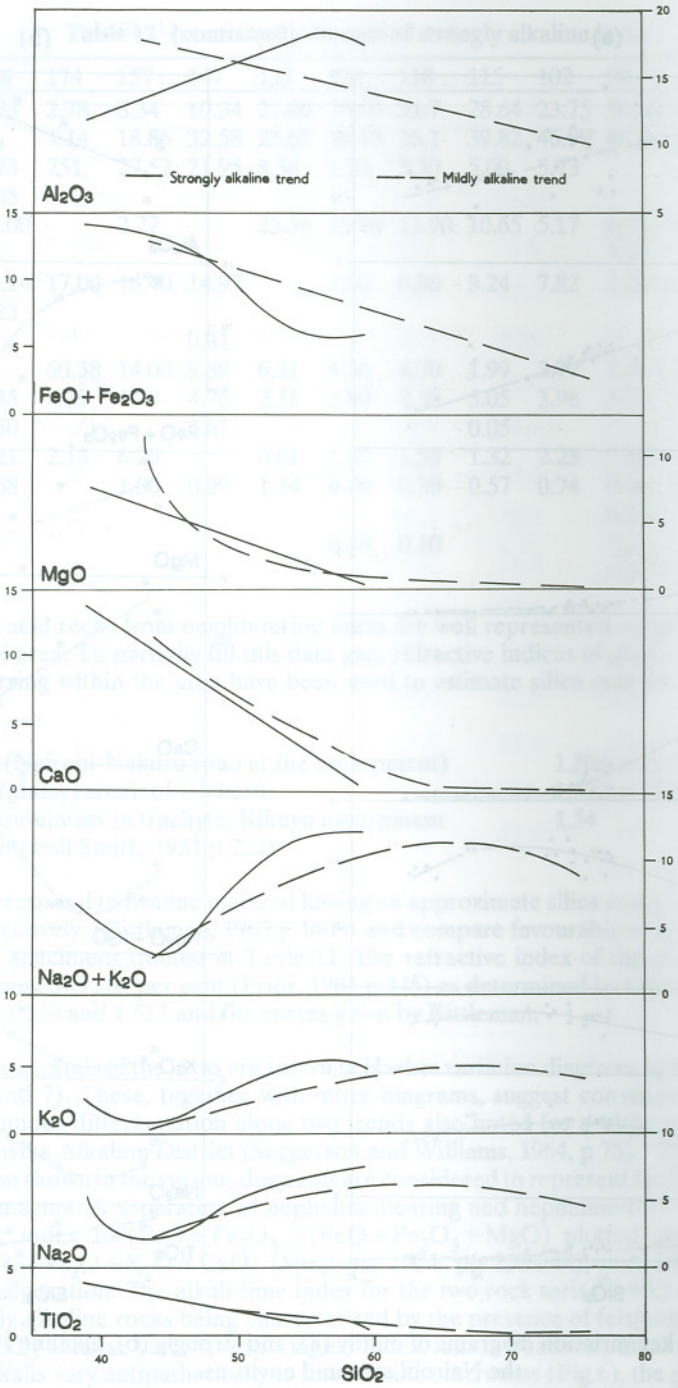


Figure 6 Harker variation diagram of volcanic rocks from the Nairobi area and environs, summarising the differentiation trends indicated in Fig 5

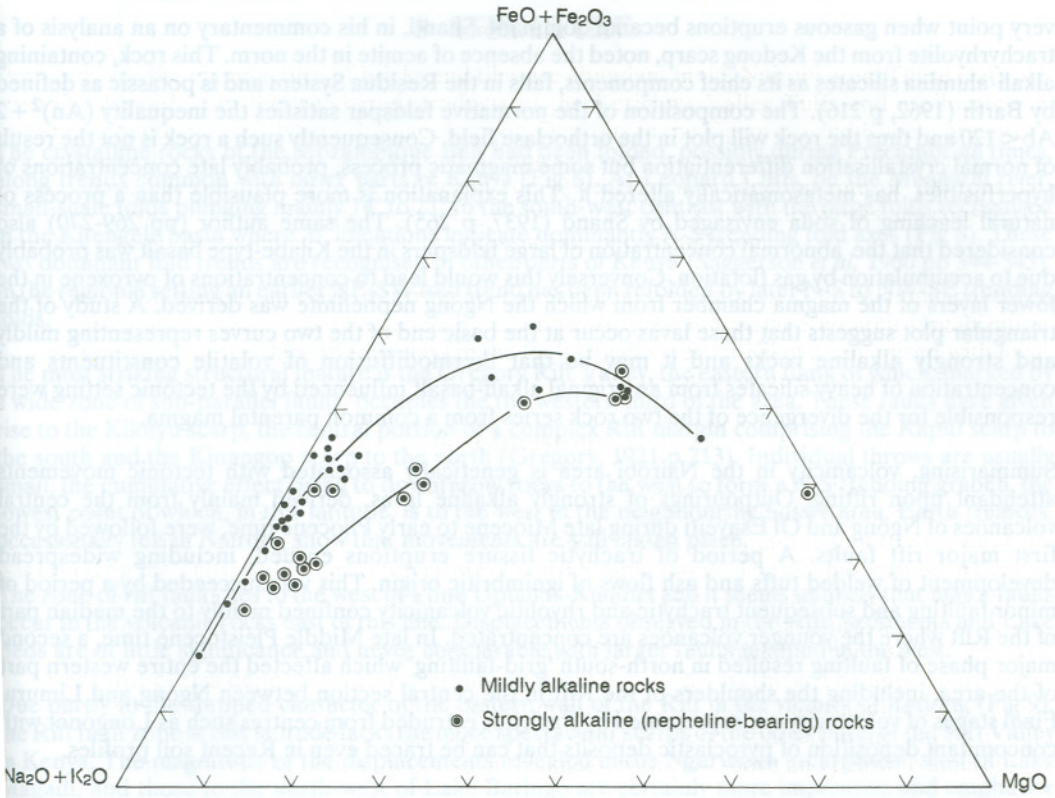


Figure 7 FMA diagram of volcanic rocks from the Nairobi area and environs

n the late differentiates of the mildly alkaline series being represented by the quartz trachytes and achyrhyolites in the present area. The mildly alkaline (nepheline-free) series, which shows a linear end, closely corresponds to selective felsic fractionation without showing a marked accumulative rigin for the more basic rocks, a feature also evident in Kuno's Solidification Index (Kuno *et al*, 1957 204). A similar fractionation trend is revealed for rocks of strongly alkaline character. In the FMA iagram (Fig 7) convincing divergences are also evident between alkali-olivine basalt and both epheline-bearing, and nepheline-free rocks. Both the Harker and FMA diagrams suggest that the ocks were derived from an alkali-olivine basalt. A lava from south of Ngong is the most likely mediate source but there are many more alkali and other basalts collected in this and neighbouring eas including one (GN 652) collected by Gregory. On quantitative grounds it might be suspected at basalt is unlikely to be the parent magma but examination of neighbouring areas reveals the esence of large volumes of basaltic rock. When viewed on a regional basis, therefore, the distribution the lava types suggests that large volumes of alkali-basalt were indeed available and extruded at fferent times from such centres as Niandarawa, Ngong, Ol Esayeiti and Olorgesailie.

ne majority of geochemical data falls on smooth curves, the basic ends of which are thought to present the local parental magma (*cf* Nockolds and Allen, 1953 p 106). Towards the alkali end there a more pronounced scattering of points which is interpreted as due to concentration of hyperfusible nstituents by gas-streaming whereby the last liquid fraction is physically separated. Intermediate cks between olivine basalt (151) and trachyte (90, 202) are not represented in the mildly alkaline ies. Possibly a process of volatile transfer has something to do with the sharp chemical break at the

very point when gaseous eruptions became dominant. Shand, in his commentary on an analysis of a trachyrhyolite from the Kedong scarp, noted the absence of acmite in the norm. This rock, containing alkali-alumina silicates as its chief components, falls in the Residua System and is potassic as defined by Barth (1962, p 216). The composition of the normative feldspar satisfies the inequality $(An)^2 + 2$ Ab < 120 and thus the rock will plot in the orthoclase field. Consequently such a rock is not the result of normal crystallisation differentiation but some magmatic process, probably late concentrations of hyperfusibles, has metasomatically altered it. This explanation is more plausible than a process of natural leaching of soda envisaged by Shand (1937, p 265). The same author (pp 269-270) also considered that the abnormal concentration of large feldspars in the Kijabe-type basalt was probably due to accumulation by gas flotation. Conversely this would lead to concentrations of pyroxene in the lower layers of the magma chamber from which the Ngong nephelinite was derived. A study of the triangular plot suggests that these lavas occur at the basic end of the two curves representing mildly and strongly alkaline rocks and it may be that thermodiffusion of volatile constituents and concentration of heavy silicates from an original alkali-basalt influenced by the tectonic setting were responsible for the divergence of the two rock series from a common parental magma.

Summarising, volcanicity in the Nairobi area is genetically associated with tectonic movements attendant upon rifting. Outpourings of strongly alkaline lavas, derived mainly from the central volcanoes of Ngong and Ol Esayeiti during late Miocene to early Pliocene time, were followed by the first major rift faults. A period of trachytic fissure eruptions ensued, including widespread development of welded tuffs and ash flows of ignimbritic origin. This was succeeded by a period of minor faulting and subsequent trachytic and rhyolitic volcanicity confined mainly to the median part of the Rift where the younger volcanoes are concentrated. In late Middle Pleistocene time, a second major phase of faulting resulted in north-south 'grid-faulting' which affected the entire western part of the area, including the shoulders of the Rift in the central section between Ngong and Limuru. Final stages of volcanicity are represented by trachytes extruded from centres such as Longonot with concomitant deposition of pyroclastic deposits that can be traced even in Recent soil profiles.

8 STRUCTURE

The crystalline rocks of the Mozambique Belt had been folded, possibly during Precambrian times, along trends common with other parts of Kenya (Fig 8). At Leopard Cliffs, on the Mbagathi river, small-scale folds plunging mainly 14° to 21° to the south-west contrast with the large folds recognised in the Kitengele basin where 'b' lineations indicate dominantly N-S trending fold axes (Fig 8). These two dominant fold trends are recognised in other parts of Kenya (Saggerson *et al,* 1960 pp 344-345). In the regional setting an earlier NE-SW fold trend has been refolded by later N-S to NW-SE trending folds.

The most striking structural feature is the Gregory Rift Valley, the eastern flank of which, marked by a wide zone of sub-parallel faults, occupies the the western third of the area. These faults have given rise to the Kikuyu scarp, the central portion of a complex Rift margin comprising the Kapiti scarp to the south and the Kinangop scarp to the north (Gregory, 1921 p 213). Individual throws are usually small, the cumulative effect being to downthrow rocks to the west to form a N-S trending graben, the lowest point of which, in this latitude, is to the west in the neighbouring Suswa area. Earth tremors, occasionally felt in Nairobi, show that movements are still taking place.

The zone of rift faults lies to the west of a line Uplands-Kandizi and it seems unlikely that major faults occur in the volcanic rocks east of this line. Displacements observed in the Athi Sediments and Lake Beds are of little significance and never comparable with larger faults mapped in the west.

Due partly to the stepped character of the eastern wall of the Rift in the vicinity of Kedong (Fig 9), the Rift fault zone at this latitude lacks the more spectacular scarps of the other parts of the Rift Valley in Kenya. The magnitude of the displacements revealed in the Nguruman escarpment, west of Lake Magadi, and those to the north-west of Lake Baringo are certainly more impressive and emphasise one of the principal physiographic features of the Rift. The western scarp frequently displays greater individual throws, often enhanced by the generally higher altitude of the Rift shoulders, compared with the eastern margin. This asymmetry led Shand (1936, p 307) to criticise the 'rather extravagant language' used by other authors, including Gregory (1896, p 220), in describing the Rift and the mechanisms of its formation.

Some authors contend that the fundamental condition for the genesis of the Rift Valley was the presence of an ancient system of fissures or pre-existing fabric parallel to the main Mozambiquian trend and though this may be true for certain sections of the Rift direct evidence is lacking in this central sector. Repeated movements along older fault lines are probably significant in the later history of the Rift, the newer faults generally following the N-S alignment of this part of the Rift Zone. From a study of the late Mesozoic and Tertiary erosion surfaces (Saggerson and Baker, 1965), it is likely that the present graben began to form after the creation of the early Tertiary or sub-Miocene peneplain. The first outpourings of lava took place during mid-Miocene times onto an already eroded landscape developed during the cutting of the end-Tertiary erosion surface. Doming, followed by downwarping of the sub-Miocene surface into the present Rift region, is thought to have preceded the initiation of the complicated fault system which in turn was followed by tectonic collapse.

The Rift region shows evidence of repeated downward movements but positive upward movement of the Rift shoulders after Miocene time has been minimal. Nevertheless, upwarping persisted intermittently in late Cainozoic time.

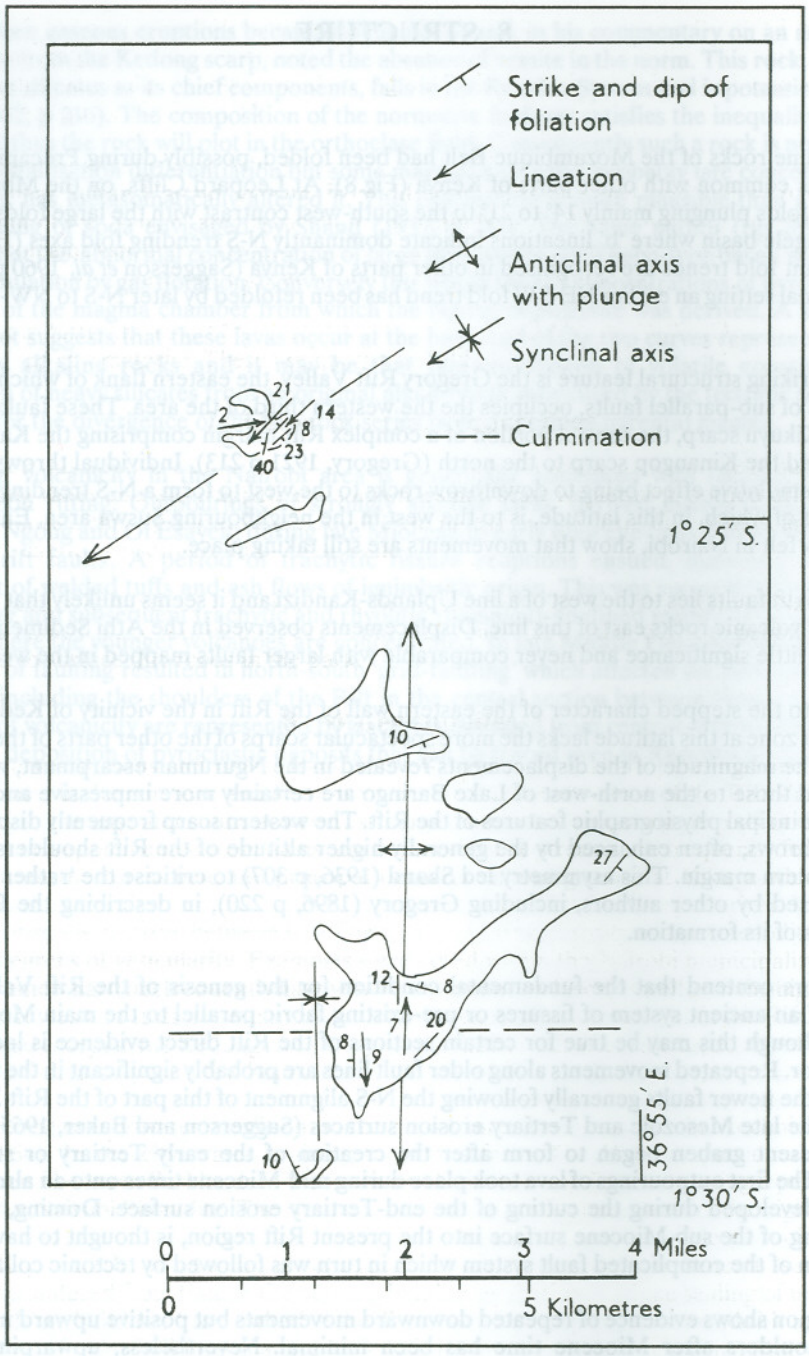


Figure 8 Structures in Precambrian rocks

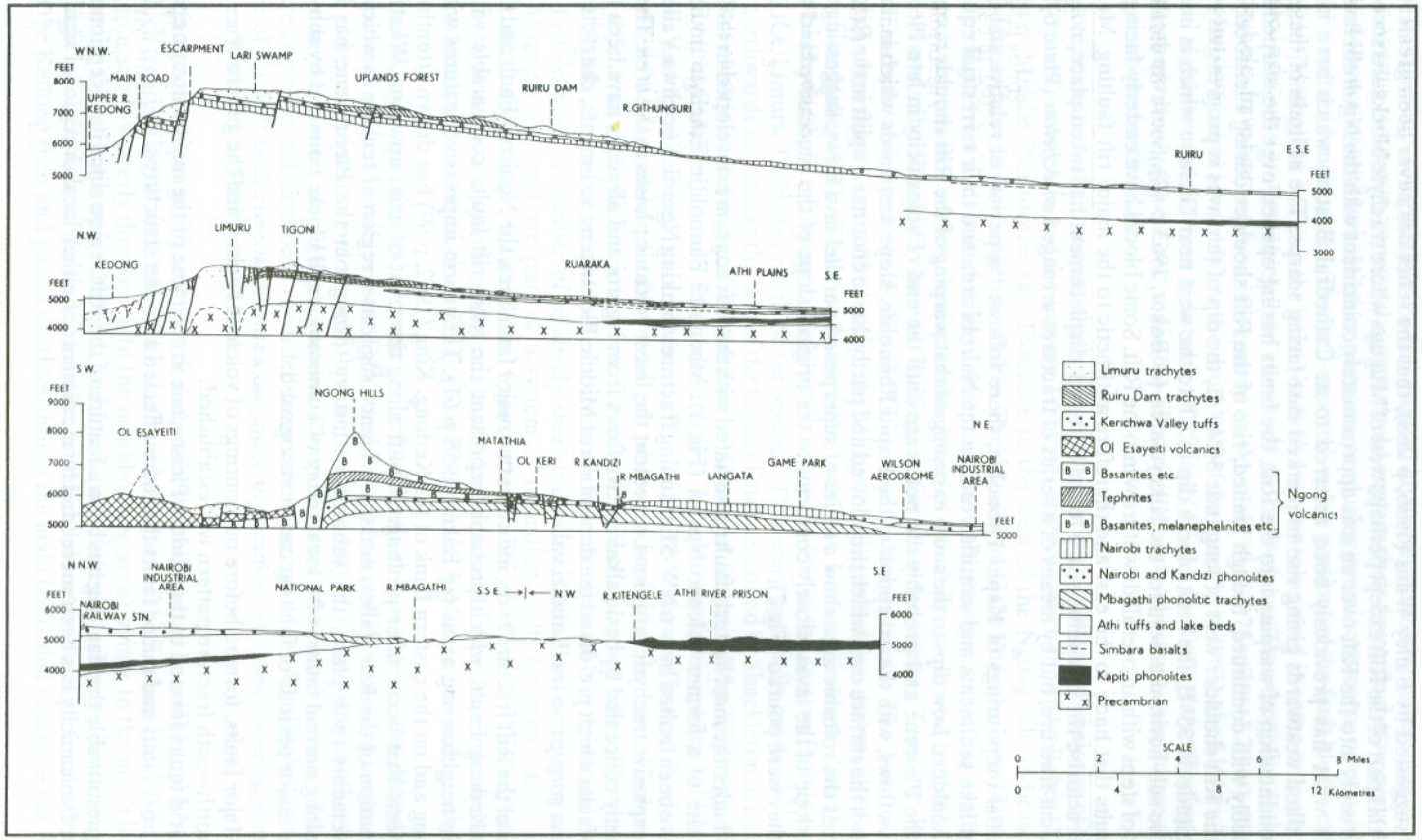


Figure 9 Cross-sections of the Nairobi area

It seems, as suggested by Bailey Willis (1936, p 268), that the relief has never been greater than at present over this part of the Rift except perhaps west of Muguga where trachyte blocks are successively tilted more steeply into the Rift over an axis approximately coincident with the Ngoirobi fault. They form part of what has previously been referred to as Cathedral Bastion which here has been successively tilted westwards giving rise to marked east-facing scarps. The attitude of these blocks suggests a continuation of warping into the Rift, the faults having opened over the warped flank of the Rift possibly with continued, though limited, rise of the Rift shoulder during Pleistocene times. Thus, from the Rift shoulder west of longitude 36°40' E, the dip of the lavas is progressively steeper until, at longitude 36°35' E, the fault blocks dip at 30° to the west near Gicheru which is in marked contrast to the sub-horizontal lavas of the Kikuyu area (*cf* Baker, 1963 p 62). Southwards, the faults form a series of steps with an overall downthrow into the Rift. Some blocks have easterly-facing scarps, indicating faults that hade to the east and therefore antithetic to the major rift-faulting. Many fault splinters characterise the bounding scarp to the Rift and displacement has taken place, not along a single, clean-cut fracture, but by means of a series of fractures arranged *en échelon* (Plate 6).

After the initial outpourings of Kapiti Phonolite, there followed a period of relative stability and deposition of lake sediments and stratified tuffs in the Nairobi area and their terrestrial equivalents on the Rift shoulders. Low dips to the south east suggest that warping of the Rift shoulders continued throughout the Pliocene and probably did not cease until the end of volcanicity in late Pleistocene times. All lava flows, with the exception of the Kapiti Phonolite, slope eastwards which is, in part, a consequence of the surface over which they flowed and partly due to continued uplift in the Rift region. Sections across the volcanic area show a series of superposed parallel lava flows, suggesting that the present-day slope of the lavas closely conforms to the original slope of the successive land surfaces onto which they were poured (Fig 2).

Minor cross-faults, the most easterly faults associated with the Rift zone, are developed in the Kandizi area at the site of a former volcano Ngoroi (Fig 3). Mbagathi Phonolitic Trachyte and Kandizi Phonolite have been faulted by two NW-SE trending fractures flanking Ngoroi. Kerichwa Valley Tuffs, products of explosive trachytic eruptions, represent the latest volcanic phases in the area. The earlier faults are partly concealed by basic alkaline lava flows from Ngoroi and all rocks have been affected by the cross-faults which pre-dated the deposition of Middle Pleistocene sediments, characterised by *Hippopotamus gorgops*, in the Kandizi valley.

Examination of the Rift fracture zone, indicates two major fault lines, the Ngoirobi Fault and the main north-south Kedong Fault, which probably represent the main rift faults comparable with those recognised in neighbouring areas (*eg* Baker, 1958 p 61). They form impressive features with steep walls at Ngong and on the eastern flank of the Kedong. King (1962, p 69) has drawn attention to the tensional effects that occur after prolonged uplift along the crest of axial upwarps. Whatever the original formation of the Rift Valley, and the evidence suggests a region of tension in which largely vertical movements took place, the subsequent history throughout the Pleistocene has been of subsidence along normal faults, with local tilting of numerous small blocks bounded by sub-parallel faults. Three major periods of faulting can be recognised:

1. Major faults, formed before outpourings of volcanic rocks when the generally north-south fracture pattern was established.
2. Grid faults formed in the Middle Pleistocene at the close of the main volcanic episode.
3. Cross faults and minor faults that have affected all other structures.

It seems unquestionable that faulting has been a feature of the Rift region since its inception and that each period of volcanicity has been succeeded by movements of either local or regional significance.

Much of the faulting is responsible for sub-parallel horsts separated by valleys that represent small graben occurring 'where no erosional agents could explain their formation' (Gregory, 1921, p 211). Other faults have tilted the lava sheets or plateaux, producing prominent scarps on one side and gently sloping lava surfaces on the other. The well-exposed, upper portions of the fault blocks exhibit vertical or columnar jointing but towards the base, the fault scarps are covered in scree or are obliterated by sediment infilling the graben which have cemented the fault planes. One exception is the brecciated zone of the Rironi Fault, exposed in a quarry on the main road 0.75 miles (1.2 km) due west of the level crossing at Limuru township. At the south end of the quarry (in 1963), the Limuru Trachyte was seen to be highly brecciated over a distance of 15 feet (4.6 m), the fault plane dipping at 20° to the west. Elsewhere swamps, *vleie* and sediment-filled depressions adjacent to scarps are characteristic features associated with faults.

Although rejuvenation of movement along older faults has been proven, the majority of the faults are relatively young, having affected the Limuru Trachytes and have been shown by Baker (1958, p 63) to be of lower Middle Pleistocene age. Evidence to the west of the Ngong hills indicates that these extrusions have obliterated younger structures. The disposition of the Pliocene lavas leaves little doubt as to their origin from the faulted Kikuyu scarp zone and the younger structures are thus probably more recent expressions of pre-existing faults, some of which lie concealed beneath the cover of younger lava. At the Mbagathi Springs, faulting, earlier than the Limuru Trachyte, but later than Nairobi Trachyte and Kerichwa Valley Tuffs, is clearly demonstrable. The base of the Limuru Trachyte can be mapped across the head of the Mbagathi valley which is a downfaulted strip in which the Kerichwa Valley Tuffs occur, while on either side, the Limuru Trachyte directly overlies the Nairobi Trachyte. Slight resurgence of movement along the line of the eastern fault is suggested by a scarp in the Limuru Trachytes north of the springs. This scarp gradually gradually becomes more distinct northwards and marks the line of the Ondiri Fault described by Shackleton in an unpublished report. The result is a horst and graben structure or 'Sikes grid' (Sikes, 1926 p 389) in which the country is broken into parallel ridges and flat-floored valleys. In some instances ephemeral lakes formed in the valleys and local sediments accumulated. The faults are never continuous. Some are relatively short and can be measured in a few hundreds of feet, others, like the main Kikuyu Fault, show considerable vertical displacements over a distance of more than twenty miles (32 km). Most of the faults are slightly sinuous or arcuate but rarely diverge from the general N-S trend and are frequently arranged *en échelon*. A number of relatively short transverse-faults, however, were mapped in the Kikuyu-Muguga area and are part of a system of bounding faults between which a number of sediment-filled depressions, have resulted from tectonic collapse (Plate 2). The largest of them, the Nyakuma depression, is approximately a mile (1.6 km) square. It is perhaps noteworthy that these small transforms are a continuation of major structures in the Kedong a few miles to the west.

Normal faults, with near-vertical movements, are evidently responsible for the ribbed topography. Those upstanding tilted blocks present E-W as well as the normal N-S trending longitudinal scarps. The lava plateaus frequently end abruptly but the structure may be taken up by another faulted block either on the same strike or slightly displaced. Ramp structures, between the ends of the *en échelon* faults, are common and have been recorded from other sections of the Rift (Baker, 1958 p 63). The structure of the Rift fault zone in this area has much in common with neighbouring areas described by such early writers as Parkinson (1914).

The Rift fault zone slopes gently southwards and, in the western part, is cut off abruptly by the Kedong Fault which trends NE-SW and defines the southern boundary of the Kedong basin. The fault (which extends in a south-westerly direction into the neighbouring area) swings to the north in the present area, near the Gicheru diatomite deposits, and forms part of the eastern scarp bordering the Kedong valley. Eight miles (13 km) to the north, a similar and parallel transverse fault transects all grid faults south of the Kedong river and passes northwards into the main faults that comprise the Kikuyu scarp

west of Escarpment station. The south-westerly continuation of this fault is buried beneath the younger sediments of the Kedong valley. These faults are probably among the youngest in the district and it is along them that final collapse into the Kedong valley was affected. The evidence seems to point to this period of faulting as post-dating the rhyolites and trachytes of the north-west corner of the area.

Some of the volcanic centres of the eastern Rift Valley seem to have been located on the eastern rim of the fault zone. One of these, the now highly eroded Ngong volcano, rises to over 8000 feet (2,438m) in the Ngong hills, the most elevated part of the area being associated with the maximum single displacement. Bailey Willis (1936, p 266), commenting on a similar feature associated with the Aberdare range, considered it to be the result of pronounced tension. The western half of the volcano has been downthrown to the west and buried beneath a cover of Limuru Trachyte which in turn has been faulted as a result of rejuvenation of movement along the former faults. The western scarp is steep and deeply dissected, a consequence of its greater age compared with the grid structure to the north.

Minor transverse-faults, the most easterly faults associated with the Rift fault zone, are developed in the Kandizi area at the site of a former volcano Ngoroi (Fig 3). Mbagathi Phonolite Trachyte and Kandizi Phonolite have been faulted by two NW-SE trending fractures flanking Ngoroi. The earliest faults are partly concealed by basaltic lava flows from Ngoroi and all rocks have been affected by the transforms which pre-dated the deposition of Middle Pleistocene sediments, containing *Hippopotamus gorgops*, in the Kandizi valley deposited after the last out-pourings of lava in this part of the area.

In brief the principal features of the Rift margin are as follows:

The chief faults defining the Rift trend N-S but are also intersected by transforms that divide the western part of the valley into basins. To the north, the Kikuyu scarp is an almost sheer cliff but as it enters the present area it mainly comprises two scarps separated by a platform extending southwards towards Cathedral Bastion. The rocks underlying the Kedong basin have been downwarped leaving an upstanding bastion bordered on the west side by the Kedong (oblique) Fault. Between this fault and a second transverse fault, the block has been tilted southwards. The volcanic centres of Ol Esayeiti, Ngong and Ngoroi may also be aligned along another concealed fracture parallel to those further north. All have been broken by a series of crowded and parallel north-south grid faults extending for 100 miles (161 km) from the Kedong to the Tanzania border.

Earth tremors are almost daily occurrences near the Rift indicating that fault movements continue. Soil subsidence is also common after heavy rains along the entire margin of the Rift. For example, close to the Research Station at Muguga, in a highly faulted section of the Rift shoulder described by Temperley (unpublished), the surface drainage pattern is abnormal. Instead of ordered tributaries there is an irregular jumble of hills, hollows and linear depressions which follow and accentuate fault traces even where these transect ridges (Fig 10). Rain water obviously finds its way underground along the fault planes and does not flow on the surface for more than short distances.

Sink holes are represented by flat-floored hollows below fault scarps or at fault-line intersections. Deposits within the hollows are a result of the direct run-off of rain water from adjacent hill slopes. In some hollows infillings of at least two ages are recognised and climatic fluctuations during Quaternary times would have led to cyclic infilling and re-opening of sinks. One such re-opening took place in 1951, 1.5 miles (2.4 km) north-west of the Research Station during exceptionally heavy rains, when a narrow sink hole, six feet deep, appeared. Disposition of drift material indicates that this basin had been filled to a depth of about 20 feet (6 m) at the centre. During a period of excessive rain the soil filling the hole subsided as material at the bottom was flushed downwards. Borehole sections are given in Fig 11.

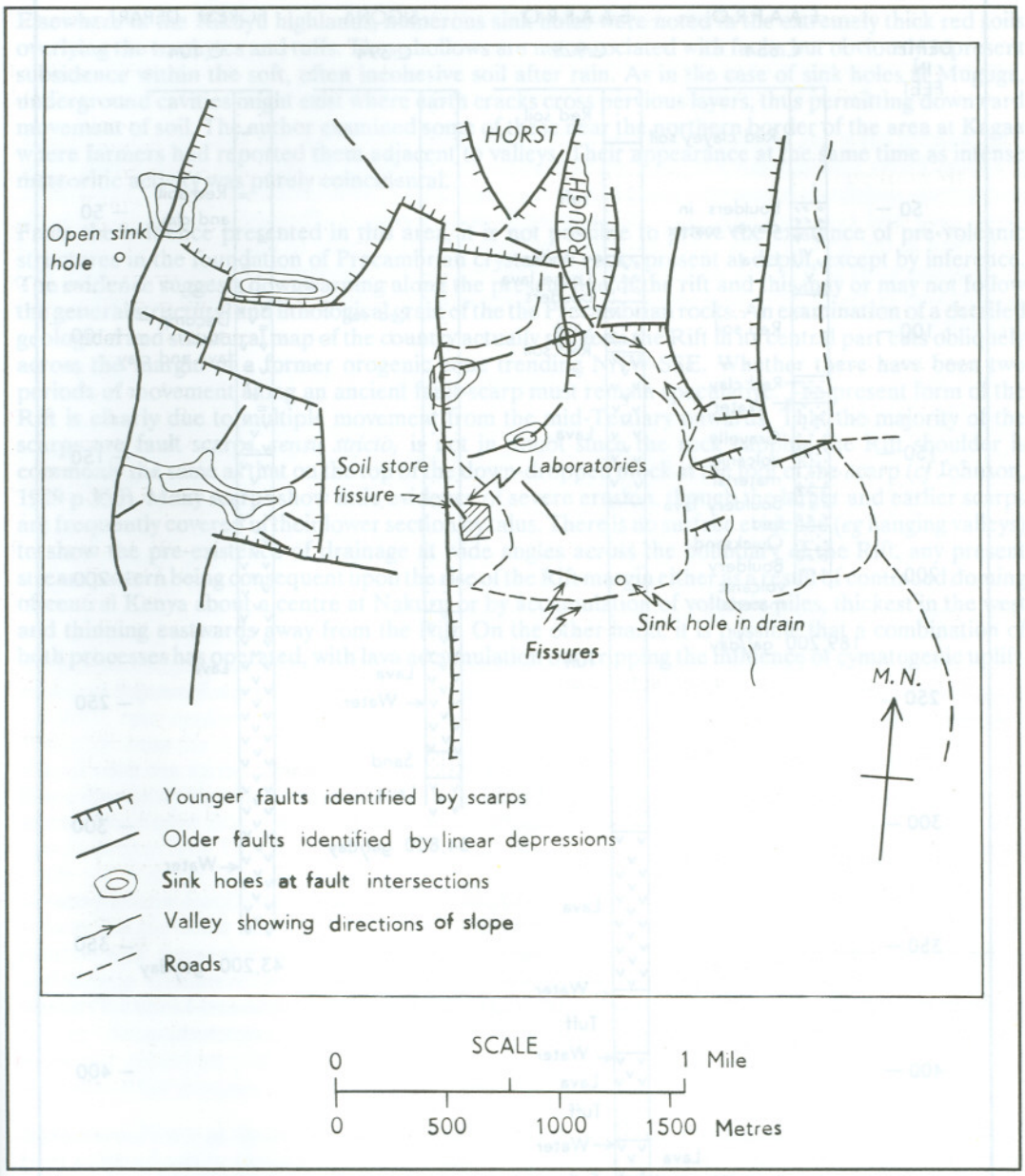


Figure 10 Faults at Muguga

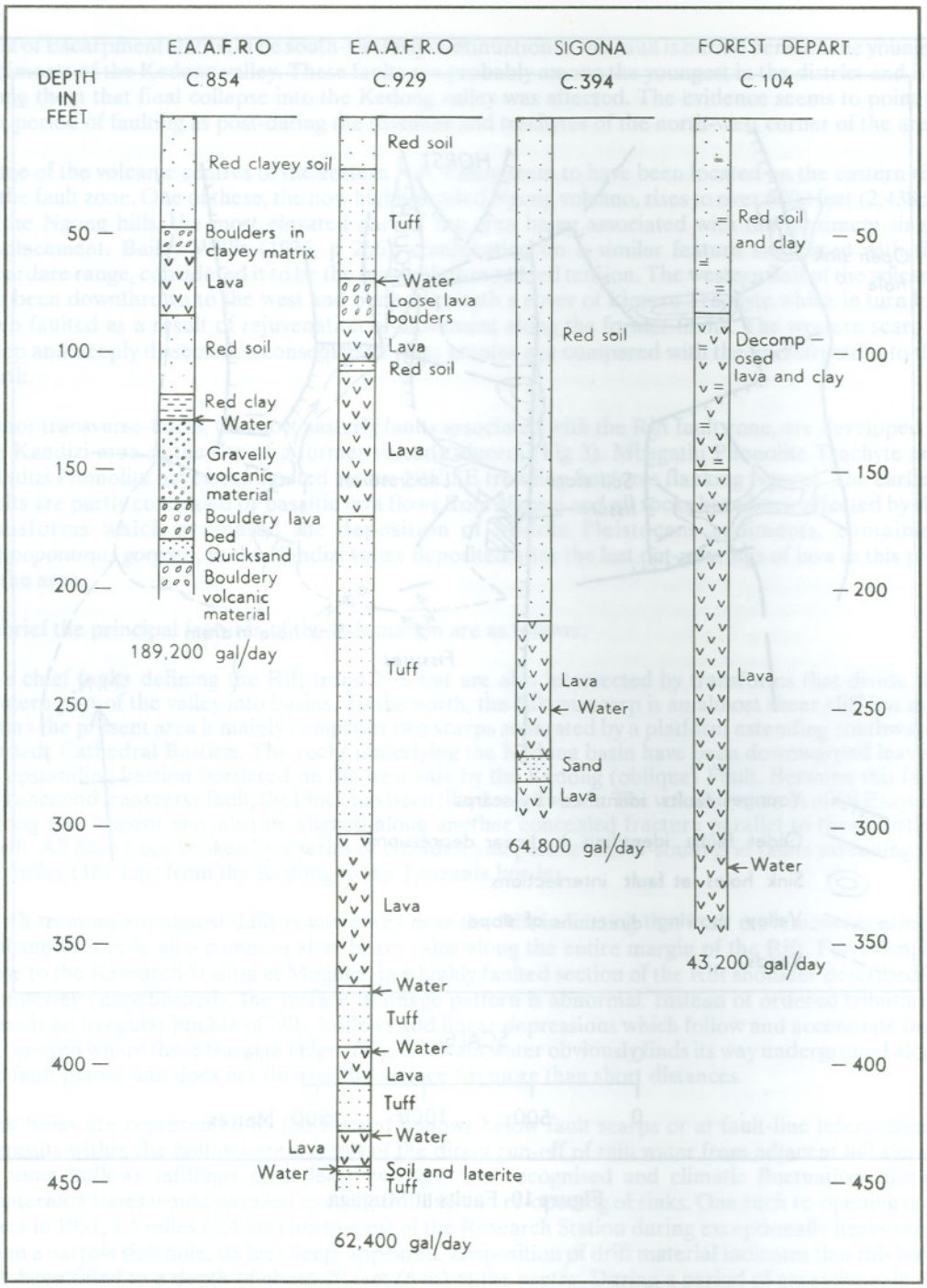


Figure 11 Borehole logs, Muguga

Elsewhere in the Kikuyu highlands, numerous sink holes were noted in the extremely thick red soils overlying the trachytes and tuffs. These hollows are not associated with faults but obviously represent subsidence within the soft, often incohesive soil after rain. As in the case of sink holes at Muguga, underground cavities might exist where earth cracks cross pervious layers, thus permitting downward movement of soil. The author examined some of these near the northern border of the area at Kagaa where farmers had reported them adjacent to valleys. Their appearance at the same time as intense meteoritic activity was purely coincidental.

From the evidence presented in this area, it is not possible to prove the existence of pre-volcanic structures in the foundation of Precambrian crystalline rocks present at depth, except by inference. The evidence suggests downwarping along the present line of the rift and this may or may not follow the general structural and lithological grain of the the Precambrian rocks. An examination of a detailed geological and structural map of the country actually suggests the Rift in its central part cuts obliquely across the margin of a former orogenic zone trending NNW-SSE. Whether there have been two periods of movement along an ancient fault-scarp must remain speculative. The present form of the Rift is clearly due to multiple movement from the mid-Tertiary onwards. That the majority of the scarps are fault scarps, *sensu stricto,* is not in doubt since the rock capping the Rift shoulder is commonly the same as that on the top of the down-dropped block at the foot of the scarp (*cf* Johnson, 1929 p 356). Many scarps show little evidence of severe erosion, though the larger and earlier scarps are frequently covered in their lower section by talus. There is no surface evidence (*eg* hanging valleys) to show the pre-existence of drainage at wide angles across the boundary of the Rift, any present stream pattern being consequent upon the rise of the Rift margin either as a result of continued doming of central Kenya about a centre at Nakuru or by accumulation of volcanic piles, thickest in the west and thinning eastwards away from the Rift. On the other hand, it is possible that a combination of both processes has operated, with lava accumulation outstripping the influence of cymatogenic uplift.

9 ECONOMIC DEPOSITS

The Nairobi area has extensive reserves of building materials. These are described in a report, prepared by the Geological Survey of Kenya (Joubert, unpublished), in which are given details of the occurrence, distribution, reserves, composition and physical properties of building stone, aggregates, clays, sand and raw materials used in the manufacture of cement. Quarrying methods presently employed in the area are also described and recommendations made to improve the extraction of these assets so that they can be utilised more effectively. Joubert's report is summarised here and accounts are given of deposits of importance including ferricrete, diatomite, bentonite, ceramic clays and limestone.

1 Building materials

Unlike many other major cities, the Nairobi municipality is fortunate in having extensive reserves of building material, most of which are derived from the volcanic rocks of the region. Volcanic tuffs of pleasing appearance are used as dimension stone which, unlike brick, permits rapid building and provides an attractive and durable exterior. The Nairobi Stone, from the middle sections of the Kerichwa Valley Tuffs, is perhaps the best known rock being fine grained, nicely coloured and easily worked. The rock crops out in most of the river valleys that cross the municipality and the largest quarries are those at Kibera, west of Nairobi Dam, and the Mathari quarries south of the Thika Road. Other small quarries provide for the needs of individual owners.

The physical properties of the stone are fairly constant, the colour being a pleasing mauvish-grey. Bleached varieties were recovered from shallow boreholes drilled by the author in Jeevanjee Gardens near the University.

Other welded and eutaxitic tuffs from the Athi Series and Plateau Trachyte Series are used locally for farm and other buildings both in the Kikuyu highlands and on the more extensive tea, coffee and sisal estates. Nearer the Rift Valley, the grey Limuru Trachyte is sufficiently soft to be used for the same purpose.

Crushed stone for concrete aggregate, roadstone and railway ballast has a more local market because of high transportation costs. In the Nairobi-Kiambu area, however, abundant materials are readily available and suppliers quarry the Nairobi Phonolite despite certain disadvantages. The Nairobi Trachyte has been quarried in the past but its fissility and trachytic texture militate against the production of stone comparable with more compact phonolite. Nairobi Stone and Limuru Trachyte are also used as aggregate, being admirably suited as a base course in road construction.

2 Ferricrete

Plentiful supplies of ferricrete (*murram*) are available for surfacing dirt roads in the Nairobi area. Within the Nairobi municipality, the weathering of Nairobi Trachyte adjacent to the Langata road provides large deposits of *murram* near the base of the low scarp between the main road and the Mitione river. Elsewhere, *murram* is plentiful in the flat country west of the main road between Kahawa and Ruiru, the deposits having been derived from weathering of the Kerichwa Valley Tuffs on interfluves where drainage is poor. Numerous small borrow pits near dirt roads are used by local authorities and farmers for supplying material for road surfacing. Ferricrete is also developed over the Nairobi Phonolite and is utilised locally.

3 Diatomite

The Pleistocene diatomite deposits at Gicheru have been mined from time to time and were evaluated in detail by Binge, of the Mines and Geological Department, in the period 1957-1959.

The deposit is located at 1°12' S, 36°35' W at an elevation of 5,200 feet (1,585 m). It lies at the base of a 1,400 feet (427 m) fault escarpment flanking the east side of the Rift Valley and can be reached from Nairobi *via* Ngong, a distance of 20 miles (32 km), by a dry-weather dirt road. An alternative track *via* the Narok road also exists. Fig 12 gives details of the deposit.

No permanent surface water supplies exist in the area, though boreholes sunk in the Kedong valley yielded potable water. Fuel is scarce, the nearest timber supplies being some ten miles (16 km) to the east.

The deposit at Gicheru (Plates 3 and 4) appears to have been deposited in a narrow hollow, wedge-shaped in plan, formed by rift faulting over a north to south distance of at least 4,000 feet (1,219 m), and up to 2,000 feet (609 m) wide. Diatomaceous beds are thickest on the western side and thin rapidly against a shelving slope of volcanic agglomerates forming part of the Rift wall to the east. The quality of the diatomite is best in the thicker, central section of the deposit. Elsewhere, where the beds are thinner, there is contamination by clay and other impurities. Some time after consolidation, the diatomite was covered by a trachytic lava, faulted and tilted to the west. The beds now dip to the west at between 4.5° and 7°.

The deposits have been considerably eroded and, along two valleys that cut through them, perpendicular cliffs yield excellent sections. The total thickness exposed is of the order of 50 feet (15 m) and in some exposures the diatomite is clearly seen to be layered, partly due to differences in iron staining. In thin section, the material consists of abundant diatom detritus together with sponge spicules, rare opaline silica grains, feldspar and limonite fragments, volcanic glass and phytoliths. Residues from the diatomite also reveal the presence of clay and epidote.

The best quality bed has an average thickness of 25 feet (7.6 m) and an area of some 45 acres (18 ha). For the most part it lies under 100 feet (30 m) of poor-grade diatomite capped to the west by 10 to 20 feet (3-6 m) of lava. The good bed has an average powder density of 13.5 lbs per cubic foot (216 kg/m^3) while some of the central portions of the deposit average under 12 lbs per cubic foot (192 kg/m^3). Super-grade material, weighing under 10 lbs per cubic foot (160 kg/m^3), is also available.

Immediately above the high-quality bed lies a series, from 16 to 37 feet thick (4.9-11.3 m), of impure and slightly coloured diatomites averaging 25 lbs per cubic foot (400 kg/m^3). Experimental work has shown that this material can be upgraded to at least 18 lbs per cubic foot (288 kg/m^3). Above this is a heavier diatomite ranging in thickness from 40 to 80 feet (12-24 m) and having a density in excess of 40 lbs per cubic foot (640 kg/m^3). The better grades of diatomite contain about 83 per cent silica and analyses of five samples are given in Table 13.

Unless some use can be made of the overlying, impure diatomite, the main bed will, for the most part, have to be extracted by deep open-cut methods involving the stripping of more than 100 feet (30 m) of overburden which, in some places, will include lava.

Ore reserves, based on the prospecting carried out, amount to 845,000 short tons (766,600 t) of medium grade diatomite averaging 13 to 14 lbs per cubic foot (208-224 kg/m^3). The assumed bulk density of diatomite *in situ* was taken as 30 lbs per cubic foot (480 kg/m^3). In addition there are four million tons (3.6 Mt) of low grade material, with a powder density 15 to 25 cubic foot (240-400 kg/m^3)

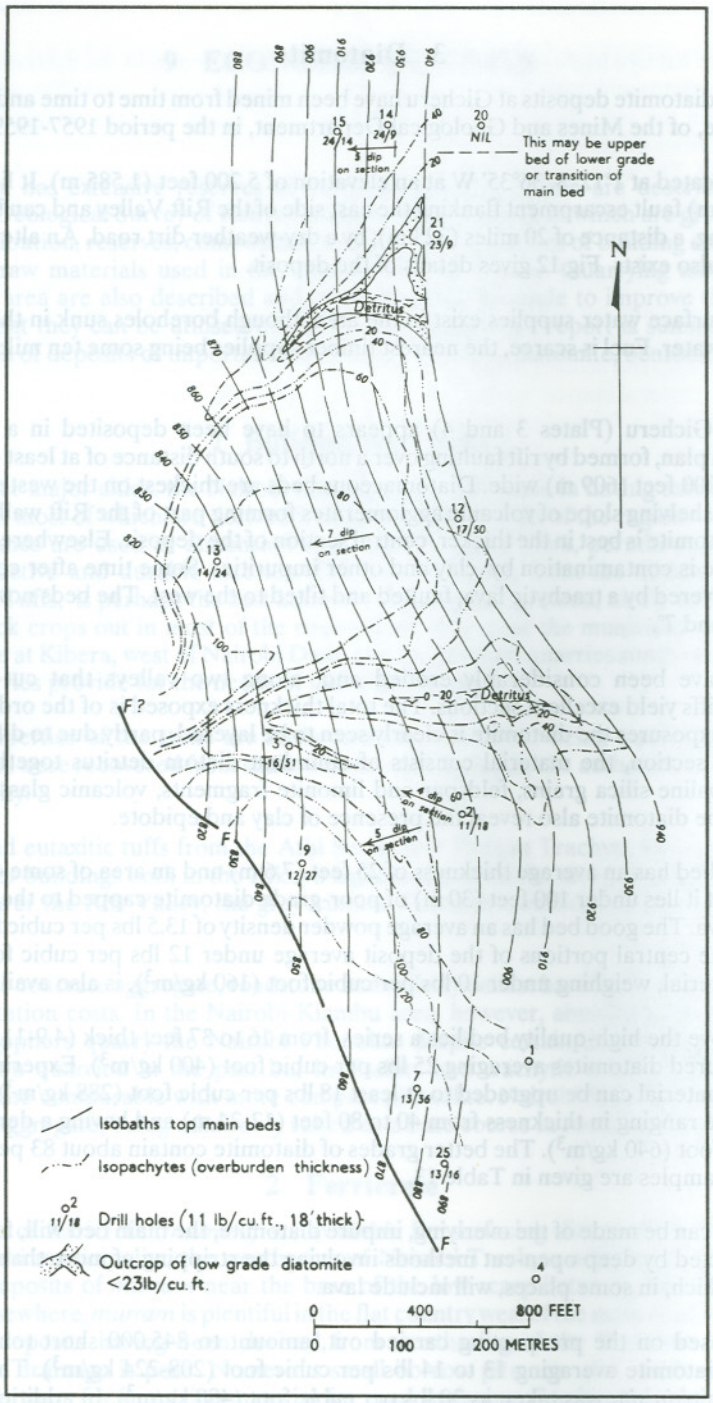


Figure 12 Isobaths and isopachytes. Gicheru diatomite deposit

Table 13 Chemical analyses of Gicheru diatomites (detailed localities unknown)

	528	529	551	556	558
SiO	83.65	83.14	85.04	80.46	78.20
Al_2O_3	3.11	2.73	-	-	-
Fe_2O_3	4.10	1.61	-	-	-
R_2O_3	-	-	6.82	9.12	11.06
MgO	0.35	0.28	-	-	-
CaO	0.26	0.38	-	-	-
Na_2O	}2.17	-	-	-	-
K_2O		-	-	-	-
H_2O+	-	}8.08	-	-	-
H_2O-	-		-	-	-
TiO_2	0.25	0.16	-	-	-
Loss on ign	6.88	3.84	-	-	-
Totals	100.77	100.22	91.86	89.58	89.26

which might justify treatment to improve the quality, and some six million tons (5.4 Mt) of poor quality diatomite.

Experiments undertaken in the Mines and Geological Department indicate that a coarse fraction in the diatomite can be air-separated, after fine crushing in cyclones, to lower the apparent powder density. Those as high as 35 lbs per cubic foot (560 kg/m^3) were also air-beneficiated to 18 lbs per cubic foot (288 kg/m^3) with a recovery of over 80 per cent. Similar powder of 25 lbs per cubic foot (400 kg/m^3) was readily improved to about 18 lbs per cubic foot (288 kg/m^3).

4 Bentonite

Clays, rich in minerals of the montmorillonite family and derived from volcanic deposits, are interbedded in the Athi Sediments and Lake Beds on Beacon Ranch farm near Athi River. Sections recorded during investigations of the deposits are given in Chapter 6. Shackleton (unpublished) found that the top bentonite layer occurs approximately 65 feet (20 m) below the base of the Nairobi Phonolite and that the vertical extent of bentonite horizons was over 18 feet (5.5 m). Unfortunately the exposed thickness of the 'best-looking' bentonite is not more than 2 feet (0.6 m). The beds are likely to extend over a large area but analyses of samples (Table 14) indicate that the material is partially silicified and therefore unsuitable for commercial use. Formerly, Atlantic Products Ltd. of Nairobi, worked clay deposits having bentonitic properties from the Athi River area but operations have now ceased.

Table 14 Chemical analyses of bentonites and clay

	307	308	316	319	324	325
SiO	62.10	61.35	53.50	52.97	50.00	49.56
Al_2O_3	14.80	15.68	16.40	14.27	9.92	8.82
Fe_2O_3	6.43	8.69	6.50	9.81	9.19	7.87
FeO	-	-	-	0.43	-	-
MgO	2.76	3.30	-	3.69	7.15	6.99
CaO	1.10	0.82	1.00	0.95	1.26	4.52
Na_2O	3.00	-	-	0.52	0.38	3.71
K_2O	-	-	-	4.28	3.08	2.29
H_2O+	-	-	}8.30	6.51	-	}13.18
H_2O-	-	-		5.50	-	
TiO_2	0.77	1.03	-	0.95	-	-
P_2O_5	-	-	-	0.03	-	-
MnO	-	-	-	0.04	-	-
CO_2	-	-	-	-	-	3.27
SO_3	-	-	-	-	0.14	-
Loss on ign	7.35	7.73	6.40	-	19.91	-
Totals	98.31	98.60	92.10	99.95	100.23	100.21

307. Bentonitic clay. Near Athi River.
308. Bentonitic clay. Eardly's Farm, Athi River.
316. Bentonite. Athi River.
319. Bentonitic clay. Eardly's Farm, Athi River
(x-ray analysis showed: illite 67%, nontronite 33%).
324. Clay. West of Athi River.
325. Green clay. Eardly's Farm, Athi River.

A large number of laboratory tests and experiments was carried out on the Athi bentonitic clays just after the war by the Imperial Institute, by the Council of Iron Foundry Associations and by the English Steel Corporation Ltd. These and other tests reveal that the material has properties no better than, and sometimes inferior to, similar clays from other parts of the world and is not a true bentonite. Although it has good binding properties, which might be of value in foundry sand preparation, and particularly good green-strength in compression, it would require preparation before use.

5 Ceramic clay

Clays used for the manufacture of bricks and tiles are abundant in the Nairobi area. These clays are generally derived from the weathered products of the Kerichwa Valley Tuffs and are located in low-lying ground and *vleie* where drainage is poor. Deposits in the Dagoretti and Kabete area were some of the first to be exploited. At Kasarani, 10 miles (16 km) from Nairobi on the Thika road, clay reserves have been estimated to be sufficient for 90 years at a production rate of 100 tons/day (Joubert). Deposits in the Karura forest, utilised by Nairobi Brick and Tile Works are considered sufficient for approximately 100 years at the present rate of consumption.

Pottery has been made from clays occurring near stream courses within the Nairobi municipality (*eg* near Kabete) and recent tests conducted by the East African Industrial Research Organization indicate that some of the dark swamp clays in the fault troughs west of Kikuyu can, mixed with local rock, produce cheap, moulded earthenware. Such clays are present in large quantities.

6 Limestone

Near Kiambu a number of limestone occurrences have in the past been worked as a source of lime, and no doubt other similar but small deposits still exist. They are found in badly drained areas, usually *vleie*, the limestone occurring as nodules (*kunkar*), broken sheets of about one foot (0.3 m) thick or, as is found on the Fairview Estate, as travertine of considerable extent. The last has formed in the soil along a narrow *vlei* and at one time was more than 3,000 feet (914 m) long and about 200 feet (61 m) wide. The Fairview deposit consists of two parts, a lower or main part consisting of a more or less continuous sheet of limestone, in most places less than 2 feet (0.6 m) thick but increasing to 7 feet (2 m). Over most of this deposit is a clay overburden about 9 feet (2.7 m) thick. The upper part of the deposit, which lies in the overburden of the lower, consists of detached *kunkar* nodules. These may be two or three inches (25-76 mm) in diameter and lie either scattered sparsely in the clay or loosely packed forming a gravel-like bed, a foot or so in thickness, with clay above and below. Numerous

Table 15 Chemical analyses of calcretes

	442	443	445	502
SiO_2 (insol. res)	2.11	4.35	4.64	(17.50)
Al_2O_3 (R_2O_3)	1.18	(2.19)	1.86	7.40
Fe_2O_3	1.01	-	1.36	1.70
MgO	0.69	0.68	0.74	1.80
CaO	51.93	51.74	49.90	37.50
H_2O^+	-	-	-	2.70
Loss on ign	41.54	42.04	-	31.50
Totals	98.46	101.00	58.50	100.10

442. Limestone. Fairview Estate. Kiambu.
443. Limestone. Fairview Estate. Kiambu.
445. Limestone. Kiambu.
502. *Kunkar* limestone (calcrete). Kedong.

variations between these two conditions occur. Analyses of this limestone from the deposit are given in Table 15. It will be noted that the travertine differs from *kunkar* limestone in containing a higher proportion of $CaCO_3$, and a lower proportion of SiO_2. The Kiambu limestone is also lower in magnesia than both *kunkar* and crystalline limestone. *Kunkar* limestone also occurs in the Kedong valley and an analysis is given in Table 15.

Other nodular limestone occurs in layers within the black cotton soil, overlying beds of the Athi Tuffs and Lake Beds near Athi River township, and is being used for cement manufacture. This material, which is clearly of Recent age, probably owes its origin in part to the calcareous nature of some of the sediments in this part of the area. On the other hand other occurrences exposed in stream courses

Table 16 Chemical analyses of *kunkar* limestones associated with Athi Tuffs and Lake Beds

	428	429	430	431	432	433	434
SiO2	5.18	12.84	13.26	19.30	21.13	21.10	36.05
Al_2O_3	0.73	0.69	2.47	2.95	3.44	4.90	8.76
Fe_2O_3	1.07	1.88	2.24	1.73	1.89	1.96	3.44
MgO	3.00	2.36	2.36	1.93	2.27	2.03	1.30
CaO	48.00	42.40	42.30	39.96	37.30	35.90	23.60
H_2O+	-	-	}3.88	-	-	-	-
H_2O-	-	-		-	-	-	-
TiO_2	tr	-	-	-	-	-	-
P_2O_5	0.05	-	-	-	-	-	-
C_2O	-	-	30.52	-	-	-	-
SO_3	0.06	-	-	-	-	-	-
Loss on ign	41.54	36.53	-	33.56	32.33	32.63	24.10
Totals	99.63	96.70	97.03	99.43	98.36	98.52	97.25

428. Limestone (hard *kunkar*). Athi Tuffs and Lake Beds. (Bull. Imp. Inst. 25, 377 (1927))
429. Limestone. Athi Tuffs and Lake Beds, Stony Athi.
430. Limestone concretions. Athi Tuffs and Lake Beds, Eardly's Farm. Athi River.
431. Limestone. Athi Tuffs and Lake Beds, Stony Athi.
432. Limestone. Athi Tuffs and Lake Beds, Stony Athi.
433. Limestone. Athi Tuffs and Lake Beds, Stony Athi.
434. Limestone. Athi Tuffs and Lake Beds, Stony Athi.

Analyses 429-434 by courtesy of East African Portland Cement Co Ltd.

Table 17 Yearly averages of analyses of *kunkar* and volcanic ash (by courtesy of the East African Portland Cement Co Ltd)

	Kunkar (Athi River)									Volcanic ash (Kabinyi hill)			
	1963	1964	1965	1966	Max MgO	Min MgO	Max CaO	Min CaO	New dep. 1966	1963	1964	1965	1966
SiO_2	19.61	19.55	25.67	27.31	22.42	19.17	17.22	33.09	23.36	36.22	37.68	37.25	37.31
Al_2O_3	3.04	2.91	4.05	4.33	3.59	2.12	2.33	4.52	3.85	17.26	16.98	17.08	16.99
Fe_2O_3	1.79	1.89	2.44	2.38	2.03	1.86	1.40	2.24	2.51	16.35	17.67	17.15	16.92
MgO	1.36	2.16	2.01	2.99	4.15	1.07	1.41	2.39	0.85	7.10	8.06	8.35	8.27
CaO	39.27	37.63	33.34	31.02	34.18	40.44	41.58	27.62	65.42	9.28	7.30	8.51	7.47
Loss on ignition	33.28	33.13	29.93	29.28	31.85	33.74	34.44	26.51	35.57	10.53	9.80	9.00	9.45
Titration total CO_3	69.42	68.00	59.86	58.45	65.13	71.50	69.55	52.44	73.80	13.83	11.85	10.99	10.02
M_S $SiO_2/(Al_2O_3 + Fe_2O_3)$	4.14	4.17	4.01	4.07	4.01	4.82	4.62	4.90	3.67	1.08	1.09	1.09	1.01
M_A Al_2O_3/Fe_2O_3	1.69	1.54	1.68	1.82	1.79	1.14	1.66	2.03	1.53	1.06	0.96	1.00	1.01
Totals	98.35	97.27	97.44	97.31	98.22	98.40	98.38	96.36	95.95	96.74	96.99	97.34	96.41

in the plains south-west of the township reveal a layer of *kunkar* directly overlying sediments with a rubbly conglomerate overlying the *kunkar* which is, in turn, overlain by black cotton soil. This profile suggests that this material probably formed during the Pleistocene but it is impossible to assign a true age. Analyses are quoted in Table 16.

In the manufacture of cement at Athi River, local materials are utilised, the limestone coming from Kabinyi Hill near Sultan Hamud, gypsum from different parts of Kenya and *kunkar* from near the eastern margin of the Nairobi area adjacent to the main Nairobi-Mombasa road. In addition, small quantities of volcanic ash, derived from a small volcanic cone at Kabinyi near Sultan Hamud, are used. Analyses of the various materials used at Athi River are given in Table 17.

In the cement industry the ratios M_S, $SiO_2/(Al_2O_3 + Fe_2O_3)$ and M_A, Al_2O_3/Fe_2O_3 are used to judge the quality of the raw material. These are quoted in Table 17.

7 Other mineral occurrences

Carbon dioxide was discovered in 1918 in fissures and holes in volcanic rocks on the Mount Margaret Estate, Kedong valley and was trapped and sold on a small scale for aerating bottled drinks. Carbon dioxide also issues from a spring at Kerita about eight miles (13 km) north of Uplands, and is present in economic quantities elsewhere in the Rift Valley.

Chalcedony occurs, in bands up to two feet (0.6 m) thick or as nodules, in the Nairobi National Park. It takes a good polish and could be used as ornamental stone. The hard nodules, of pebble and cobble size, are used to surface dirt roads in the park.

8 Water supplies

Most of the larger streams and rivers draining the Kikuyu highlands are perennial and there is no shortage of water in the northern and north-western parts of the area, east of the Rift Valley. On the lower ground to the east and south however, streams tend to dry up during periods of drought and supplies must be supplemented from dams and boreholes. The streams are frequently fed by springs that issue within the forest belt, the principal occurrences being those at Kikuyu which feed the headwaters of the Nairobi river and the Mbagathi Springs feeding the Mbagathi river. Innumerable other small springs issue from between lava flows with differing porosity and permeability as a result of differing degrees of vesicularity. Examples were noted within the Nairobi municipality where the lavas are extremely hard but frequently have vesiculated upper surfaces, as well as in the higher country where the trachytes and tuffs are relatively porous as well as permeable. Within the Rift, no flowing water was noted except in the Kedong river. Only during flash floods after storms, do any of the streams carry water and then only for a few hours.

An account of the groundwater conditions in the Nairobi area has been given in a technical report by Gevaerts (1964). In the city, water draining eastwards from 'The Hill' area accumulates on the low-lying ground between Parklands in the north and Nairobi South Estate, forming a perched water table above the Nairobi Phonolite. The Kerichwa Valley Tuffs lying to the east of the highway behave like a sponge and the contact between them and the underlying, impermeable phonolite is thus a perfect aquifer, so much so that a number of channels containing water occur beneath Nairobi. These have been encountered from time to time during building operations and the sealing of underground basements to large buildings has resulted in the diversion of water producing an additional hazard to the foundations of older buildings that are built on tuff of limited loading capacity. Many of the new buildings are built on the thick, dense phonolite which provides a stable foundation. Between the outcrop of Kerichwa Valley Tuffs of the central city area and the trachyte escarpment to the west is a deep channel in places more than 70 feet (24 m) deep and filled with black cotton soil and clay.

Much of it represents soil and debris that have accumulated at the foot of the trachyte escarpment. Kenyatta Avenue (formerly Valley Road) follows the direction of a stream course down which water flowed to debouch onto the plain below.

Access to the records of a large number of boreholes drilled in the area (more than 1,000 since 1939) has enabled a detailed appreciation to be made of the sub-surface geological conditions.* The majority of the boreholes have been drilled for irrigation. Those located in the extreme west supply water tanks for cattle herders.

Table 18 Average analyses of groundwater in parts per million (from Gevaerts, 1964)

	1	2	3	4	5	6	7	8	9	10	11
pH	6.0	6.9	7.5	8.5	8.6	8.1	6.9	6.1	8.9	8.9	5.9
Total solids dried at 180° C	112	320	260	-	520	327	523	658	1090	1720	121
Chlorides (Cl)	6	26	16	12	47	12	12	2	214	243	16
Sulphates (SO_4)	4	16	8	-	15	-	16	-	252	420	8
Total hardness ($CaCO_3$)	24	65	20	10	10	9	127	378	12	30	25
Excess alkalinity (Na_2CO_3)	15	91	107	155	273	184	247	174	295	566	16
Fluorides (F)	0.5	1.3	6.7	13.7	10.6	10.9	1.1	1.1	12.1	24.0	0.3
Free CO_2	-	-	-	-	-	-	-	490	-	-	-

(Numbers in brackets below are borehole numbers)

1. Limuru (1556, 2690, 3009).
2. Karen (1623).
3. West Langata (1050).
4. Nairobi (1987, 2031).
5. Nairobi Airport (six holes)
6. Ruaraka (565, 589, 1681, 1717, 1859, 2056, 2517).
7. Kahawa (2335, 2337).
8. Kamiti, main aquifer (1340, 1466, 2386, 2671).
9. Athi River Station (2192, 2474).
10. North of Athi River Station (1937).
11. Area west of Ondiri-Lari Fault (540, 796, 2379, 2466, 2658, 3170).

Groundwater is supplied by a number of aquifers, either in fluviatile or lacustrine deposits, intercalated in most formations or between the principal lava flows. The harder tuffs and lavas yield little or no water due to their generally impervious character. Near-surface aquifers occur in ferricrete deposits and weathered soil on former land surfaces (Gevaerts, 1964, p 13), and in addition faults,

* Borehole numbers are given in Gevaerts 1964 and borehole records, including strata, are held by the Water Development Department, Ministry of Works.

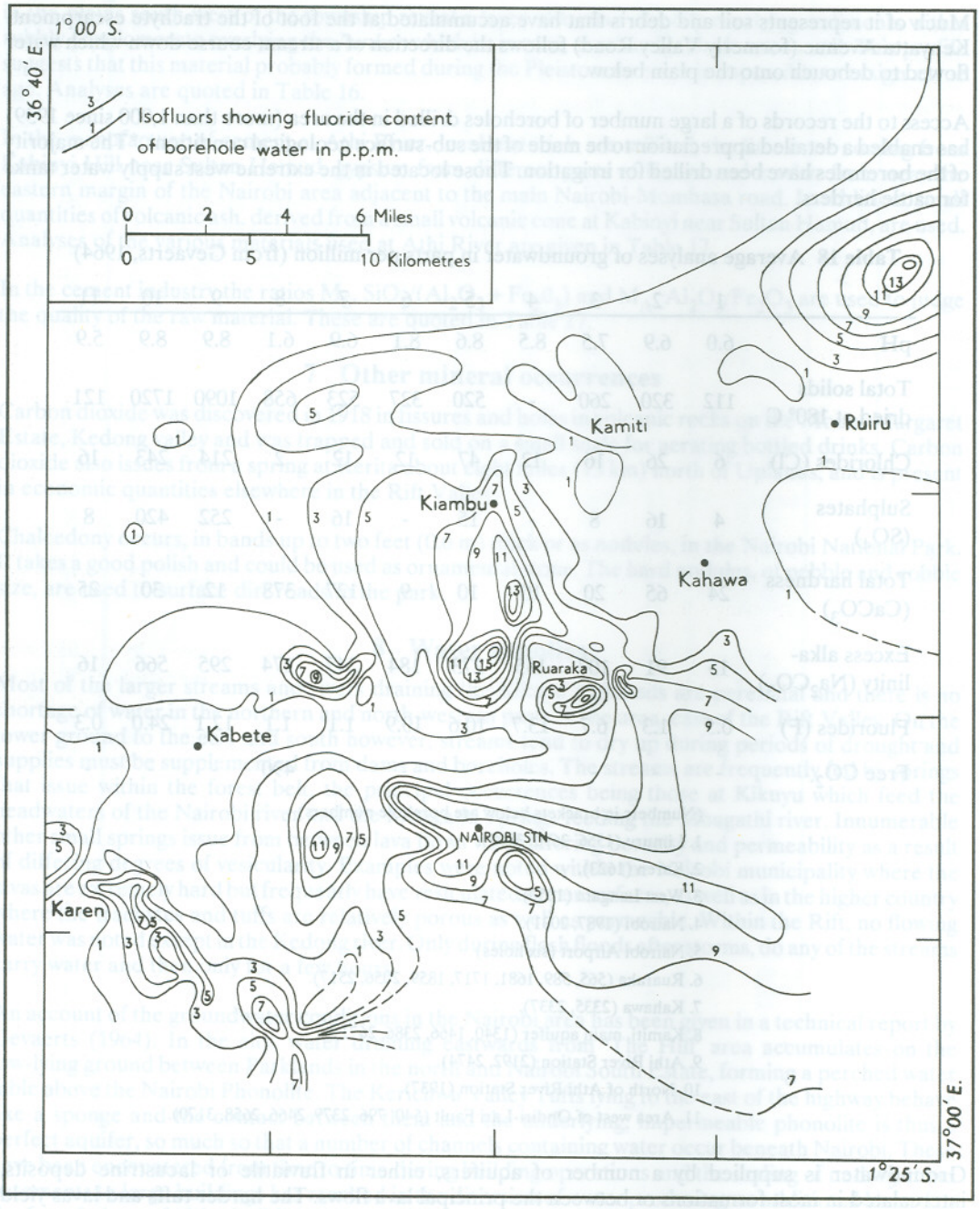


Figure 13 Isofluors (ppm) of borehole waters in the Nairobi area

fissures and joints all may carry water. Important springs feeding the main rivers often issue from the contact between the soft, weathered rocks and underlying impervious lavas. Examples of these can be found near Uplands where waters feeding the Ruiru river issue from the base of the highly weathered Limuru Trachyte at its contact with hard Ruiru Dam Trachyte. Recharge of the free groundwater appears to be adequate but some confined aquifers have been depleted by continuous, heavy abstraction (*eg* Athi River Station, Kahawa and Ruaraka).

The quality of groundwater is good throughout the area except for the fluoride content which is in exess of the desirable limit of 1.5 ppm over a large part of the area (Fig 13). South-east of a line Thika-Kiambu-Kabete-Karen many of the boreholes draw water from the Athi Tuffs and Sediments and in consequence the fluoride content is high, as much as 17 ppm being recorded west of Ruaraka and at Athi River. The extraction of water takes place at variable depth but in general those boreholes showing low fluoride content have penetrated aquifers in younger strata intercalated within the lava formations and are therefore not likely to contain high proportions of undesirable substances. Water struck in the Tertiary formations is usually alkaline and contains sodium bicarbonate. The high chloride and sulphate contents in water from sediments intercalated in the Kapiti Phonolites suggest that these salts have been derived from lacustrine deposits rather than from the phonolite. The average analyses of groundwater from boreholes in a number of areas, characterised by a similarity in the occurrence of their main water supply, are given in Table 18.

Many of the rivers draining the higher ground near Limuru are fed by local groundwater resulting from high annual rainfall. To supplement groundwater supplies farmers are increasingly constructing earth dams, though a number of larger projects have necessitated the building of concrete structures, the Ruiru Dam, supplying some of Nairobi's needs, being the largest.

A water pipe-line has been constructed by the Magadi Soda Company from the Ngong hills, a distance of more than 80 miles (129 km). The pipe-line, which passes south-eastwards from Kiserian, supplies fresh water for the needs of the company employees at Magadi where only unpotable alkaline waters are available.

10 REFERENCES

Anon, 1959. *Atlas of Kenya, 1st ed.* Nairobi: Survey of Kenya.

Anon, 1960. *Industrial Minerals and Rocks, 3rd ed.* American Institute of Mining, Metallurgical and Petroleum Engineering

Baker, B H, 1954. Geology of the south Machakos area. *Rep. geol. Surv. Kenya* **27**.

-------- 1958. Geology of the Magadi area. *Rep. geol. Surv. Kenya* **42**.

-------- 1963. Geology of the Baragoi area. *Rep. geol. Surv. Kenya* **53**.

-------- 1963. Geology of the south Magadi area. *Rep. geol. Surv. Kenya* **61**.

--------, Mitchell, J G, and Williams, L A J, 1988. Sratigraphy, geochronology and volcano-tectonic evolution of the Kedong-Naivasha-Kinangop region, Gregory Rift Valley, Kenya. *Q. J. geol. Soc. London* **145**, 107-117.

Barth, T F W, 1962. *Theoretical Petrology, 2nd ed.* New York: Wiley.

Bowen, N L, 1937. Recent high-temperature research on silicates and its significance in igneous petrology. *Am. J. Sci.* **33**, 1-21.

-------- and Ellestad, 1936. Nepheline contrasts. *Am. Min.* **21**, 363.

Chayes, F, 1964. Variance - covariance relations in some published Harker diagrams of volcanic suites. *J. Petrol.* **5**, 219-237.

Collie, E L, 1912. Plateau of British East Africa. *Bull. geol. Soc. Am.* **23**, 297-316.

De Kun, N, 1965. The mineral resources of Africa.

Dumbleton, M J, 1967. Origin and mineralogy of African red clays and Keuper Marl. *Q. J. Eng. geol.* **1**, 39-45.

Evernden, J F, Savage D E, Curtis G H, and James G T, 1964. Potassium-argon dates and the Cenozoic mammalian chronology of North America. *Am. J. Sci.* **262**, 145-198.

Fairburn, W A, 1963. Geology of the north Machakos-Thika area. *Rep. geol. Surv. Kenya* **59**.

Finckh, L, 1903. Die trachydolerite des Kibo und die Kenya. *Z. dt. geol. Ges.* **55**, 14.

Gevaerts, E A L, 1964. Hydrogeology of the Nairobi area. *Tech. Rep. Water Dev. Dept.* **1**.

Gregory, J W, 1896. *The Great Rift Valley*. London: John Murray.

-------- 1921. *The rift valleys and geology of East Africa*. London: Seeley Service.

Häkli, A, 1960. On high-temperature alkali feldspars of some volcanic rock of Kenya and northern Tanganyika. *Compte Rendu Soc. geol. Finland* **32**, 99-108.

Harkin, D A, 1960. The Rungwe Volcanics at the northern end of Lake Nyasa. *Mem. geol. Surv. Tanganyika* **11**.

Johanssen, A, 1939. *Descriptive petrology of the igneous rocks, Vol. 4*. Chicago: University of Chicago Press.

Johnson, D, 1929. Geomorphologic aspects of rift valleys. *15th Session of the International Geological Congress*, Sect. 6, 354-373.

Joubert, P, *Unpublished*. Building materials of Nairobi. *Mem. geol, Surv. Kenya*.

King, L C, 1962. *Morphology of the Earth*. Edinburgh: Oliver and Boyd.

Kittleman, L R, 1963. Glass-bead silica determination for a suite of volcanic rocks from the Owyhee Plateau, Oregon. *Bull. geol. Soc. Am.* **74**, 1405-1410.

Krenkel, E, 1925. *Geologie Afrikas, Vol. 1.* Berlin: Borntaeger.

Kuno, H, Yamasaki K, Iida C and Nagashima K, 1957. Differentiation of Hawaiian magmas. *J. geol. geogr. Japan* **28**, 179-218.

Kunzli, E, 1901. Die petrographische ausbente der Schöllerschen expedition in Aequatorial-Ostafrica (Massailand). *Vjschr. naturf. Ges. Zurich* **46**, 128-172.

Lacroix, A, 1923. *Minéralogie de Madagascar 3*. Paris: Challamel.

Lehmann, E, 1924. Das vulkangebiet am nordende des Nyassa als magmatische provinz. *Z. Vulkanol.* **4**, 175.
Matheson, F J, 1966. Geology of the Kajiado area. *Rep. geol. Surv. Kenya* **70**.
McCall, G J H, 1962. Froth-flow lavas resembling ignimbrites in the East African Rift Valley. *Nature* **194**, 343-344.
--------,1964. Froth flows in Kenya. *Geol. Rundsch.* **54**, 1148-1195.
Mountain, E D, 1925. Potash oligoclase from Mt. Erebus, Antarctic and anorthoclase from Mt. Kenya, East Africa. *Min. Mag.* **20**.
Maufe, H B, 1908. Reports relating to the geology of the East Africa Protectorate. *Colon. Rep. misc. Ser.* **45**
Morgan, W T W, ed, 1967. *Nairobi: city and region*. London: Oxford University Press.
Mussett, A E, Reilly T A, and Raja P K S, 1964. Palaeomagnetism in East Africa. Report on the geology and geophysics of the East African Rift system.
--------,1965. Palaeomagnetism in East Africa. A progress report on the Tertiary volcanics. *Proc. E. Afr. Acad.* **2**, 27-35.
Neilson, A T, 1921. Igneous rocks from British East Africa. Appendix 4 to *The Rift Valleys and geology of East Africa.* by J W Gregory, 388-407.
Nevill, D, 1961. A laboratory investigation of two red clays from Kenya. *Geotechnique* **11**, 302-318.
Nockolds, S R and Allen R, 1953. The geochemistry of some igneous rock series. *Geochem. Cosmochim. Acta.* **4**, 105-152.
Parkinson, J, 1914. The East African trough in the neighbourhood of the soda lakes. *Geogrl J.* **44**, 33-49.
Prior, G T, 1903. Contributions to the petrology of British East Africa. *Min. Mag.* **13**, 228-263.
Pulfrey, W, 1949. Ijolitic rocks near Homa Bay, Western Kenya. *Q. J. geol. Soc. London.* **105**, 425-454.
Ross, C S and Smith R L, 1961. Ash-flow tuffs: their origin, geologic relations and identification. *Prof. Pap. U S G S* **366**.
Saggerson, E P, 1966. Geology of the Loita Hills area. *Rep. geol. Surv. Kenya* **71**.
-------- ,*Unpublished*. Chemical analyses of igneous, metamorphic and sedimentary rocks and natural gas from Kenya. *Bull. geol. Surv. Kenya*.
--------, and Baker B H, 1965. Post-Jurassic erosion surfaces and their relationship to Rift structure. *Quart. J. geol. Soc. London* **121**, 51-72.
--------, Joubert P, McCall G J G and Williams L A J, 1960. Cross-folding and refolding in the Basement System of Kenya Colony. *21st Session of the International Geological Congress*, Sect. **18**, 335-346.
--------,and Williams L A J, 1964. Nguramanite from southern Kenya and its bearing on the origin of rocks in the northern Tanganyika alkaline district. *J. Petrol.* **5**, 40-81.
Sahama, Th G, 1952. Leucite, potash nepheline and clinopyroxene from SW Uganda and Belgian Congo. *Am. J. Sci*. Bowen Volume.
Scott, R M, 1963. The soils of the Nairobi-Thika-Yatta-Machakos area. *Rep. Dept. Agriculture, Kenya.*
Shackleton, R M, 1945. Geology of the Nyeri area. *Rep. geol. Surv. Kenya* **12**.
Shand, S J, 1936. Rift Valley impressions. *Geol. Mag.* **73**, 307-312.
--------,1937. Rocks of the Kenya Rift Valley. *Geol. Mag.* **74**, 262-271.
Sherwood, P T, 1967. Classification tests on African red clays and Keuper Marl. *Q. J. Eng. Geol.* **1**, 47-53.
Sikes, H L, 1926. The structure of the eastern flank of the Rift Valley near Nairobi. *Geogrl J.* **68**, 385-402.
--------,1934. *The underground water resources of Kenya Colony.* London: Crown Agents.
--------,1939. Notes on the geology of the country surrounding Nairobi. *Rep. geol. Surv. Kenya* (not numbered).

Simpson, E S W, 1954. On the graphical representation of trends in igneous rocks. *Geol. Mag.* **91**, 238-244.
Smith, R L, 1960. Zones and zonal variations in welded ash flows. *Prof. Pap. U S G S* **354-F**.
Smith, W Campbell, 1931. A classification of some rhyolites, trachytes and phonolites from part of Kenya Colony, with a note on some associated basaltic rocks. *Q. J. geol. Soc. London* **94**, 507-553.
--------,1950. Note on the Kapiti Phonolites and kenytes of Kenya Colony. *Bull. Br. Mus. (Nat. Hist.) Min.* **1**, 1- 15.
Smith, J V and Sahama Th G, 1954. Determination of the composition of nephelines by an X-ray method. *Min. Mag.* **30**, 439-449.
Spencer, E, 1937. The potash-soda felspars. *Min. Mag.* **24**, 453.
Stephen, I, Bellis F and Muir A, 1956. Gilgai phenomena in tropical black clays of Kenya. *J. Soil Sci.* **7**, 1-9.
Suess, E, 1892. Die bruche des östlichen Afrika. *Denkschr. Akad. Wiss., Wien Math-nat.* **58**, 555-584.
Terzaghi, K, 1958. Design and performance of the Sasumua Dam. *Proc. Inst. geol. Engrs.* **9**, 369-376.
Thompson, A O, 1964. Geology of the Kijabe area. *Rep. geol. Surv. Kenya* **67**.
Thompson, A O, and Dodson, R G, 1963. Geology of the Naivasha area. *Rep. geol. Surv. Kenya* **55**.
Tilley, C E, 1954. Nepheline-alkali feldspar paragenesis. *Am. J. Sci.* **252**.
Van Bemmelen, R W, 1961. Volcanology and geology of ignimbrites in Indonesia, north Italy and the U.S.A. *Geol. en Mijb.* **40**, 399-411.
Walker, E E, 1903. Report on the geology of the East Africa Protectorate. *Africa* **11** (Cd.1769).
Walmsley, R W, 1957. Nairobi. The geography of a new city.
Williams, L A J, 1967. In *Nairobi: city and region.* 1-13 (W T W Morgan ed). London: Oxford University Press.
Willis, Bailey, 1936. *East African plateaus and rift valleys.* Washington: Carnegie Institute.