



Londiani caldera seen from across Kilombe caldera.

THE GEOLOGY OF THE LONDIANI
AREA OF THE KENYA RIFT VALLEY

Thesis presented for the Degree of Doctor of Philosophy
in the University of London

William Barry Jones

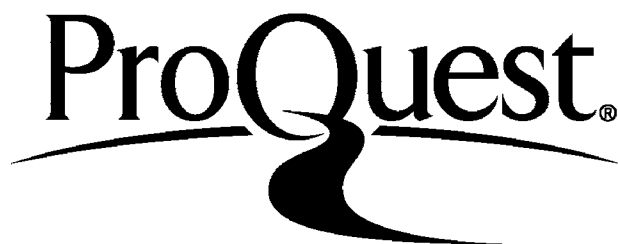
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ABSTRACT

An area of about 900 square miles (2300 km^2) at the junction of the Kenya and Kavirondo Rift Valleys was studied and a map of it on a scale of 1 : 50,000 is presented.

The formations present are alkaline lavas and tuffs ranging in age from 12 m.y. b.p. to recent and can be divided into a basanite to phonolite series older than 7 m.y. and a basalt to trachyte series younger than 7 m.y. The formations are grouped into four assemblages, each consisting of rocks derived from sources in about the same area. A series of trachytic ash flows about 4 m.y. old, the Eldama Ravine Tuff, and two trachyte volcanoes, Londiani of 3 m.y. b.p. and Kilombe of 2 m.y. b.p., together with their associated syenite bombs are described in detail.

The structure of the area is dominated by the Equator and Mau Monoclines which form the western margin of the Kenya Rift Valley. Faults are relatively unimportant but show three distinct trends which can be related to structures in the basement.

Chemical analysis was carried out on about 200 rocks, particularly concentrating on the Eldama Ravine Tuff and the Londiani and Kilombe Trachytes. This, with the petrography, showed that the rocks within the basanite to phonolite series and the basalt to trachyte series are related in general but not in detail by fractional crystallisation. It is also shown that in the trachytic rocks Na, Fe, Y and the Lanthanides are very mobile.

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Chapter I

INTRODUCTION

Situation and Access

The region mapped is on the western side of the Kenya Rift Valley around the area where it is joined by the easterly extension of the Kavirondo Rift Valley. Its boundaries are approximately $35^{\circ} 30'E$ in the west, $0^{\circ} 15'S$ in the south, $0^{\circ} 10'N$ in the north and $35^{\circ} 55'E$ in the east, with a south easterly extension to the edge of the Menengai Caldera north of Nakuru at $36^{\circ} 00'E$. The total area is about 900 square miles (fig. 1).

The main towns are Eldama Ravine in the north, Molo in the south and Londiani in the south west, each with several hundred inhabitants. Lesser centres are Rongai and Maji Mazuri, on the railway south east and north west of Londiani mountain respectively. Nakuru, the administrative centre of the Rift Valley Province, lies just outside the area to the south east. Other important centres situated just beyond the edge of the mapped area are Timboroa in the north west and Mogotio in the north east.

Because it lies astride the historic route to Uganda, this region is well served with roads and railways. The railway from Nakuru to Eldoret passes between Londiani and Kilombe volcanoes while that from Nakuru to Kisumu goes through the south. A good tarmaced road from Nakuru to Eldoret skirts the south west of Londiani Mountain and a branch from this leaves the south west corner towards Kisumu. Good murram roads connect the main centres to each other and to the main roads. Since the author was there a tarmaced road from Nakuru to Baringo has been built through the eastern extension of the area.

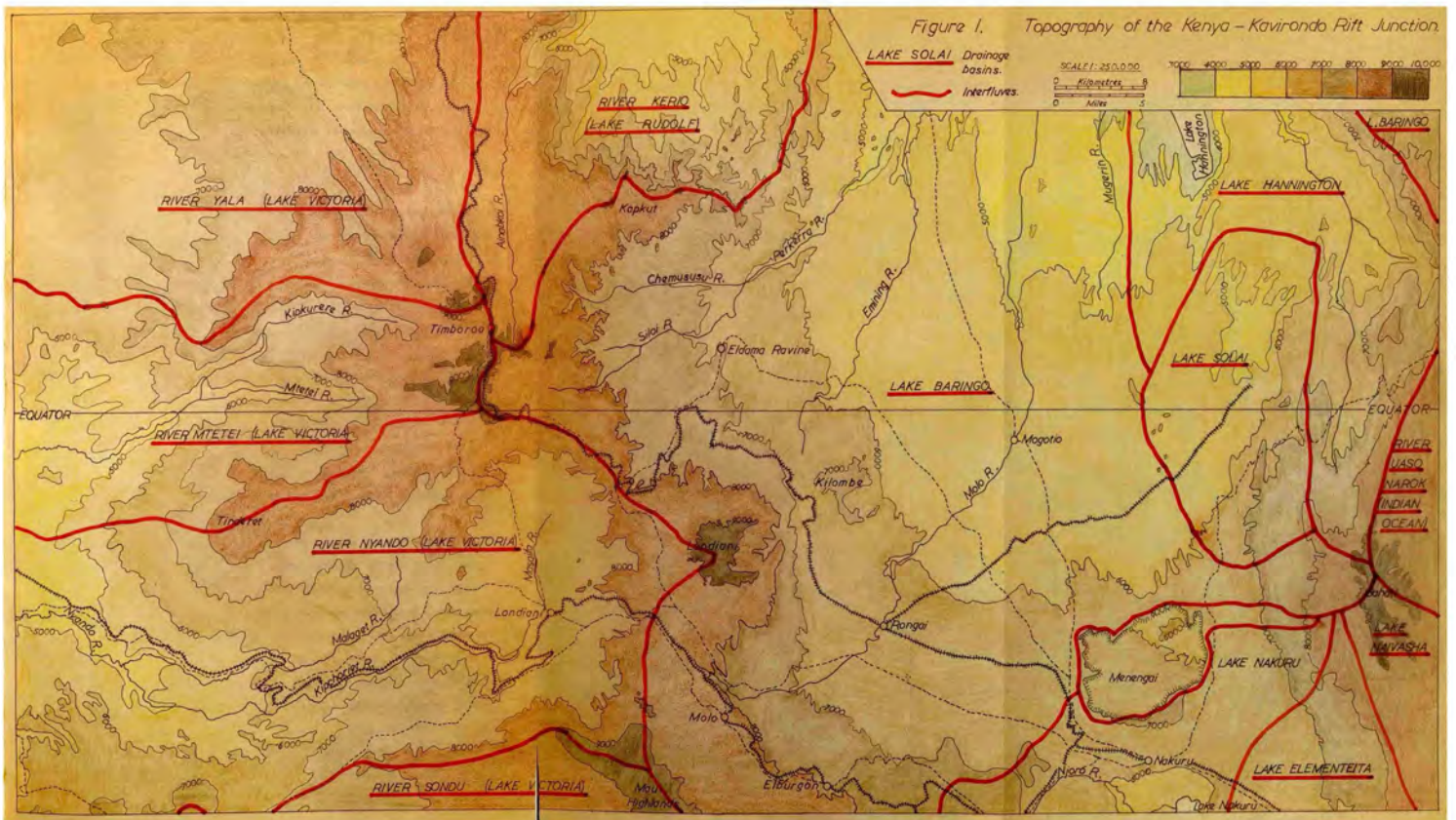
Topography

The area contains a ridge of high ground trending N-S in the south and NW-SE in the north, with the surface falling away from it on either side. This ridge separates the drainage basins of Lake Baringo to the east and Lake Victoria to the west (fig. 1). The area can be divided into seven parts as follows.

- 1) The Timboroa Highlands, a highland area rising gently to 9478 ft. near to Timboroa town. From here high ground encircles the north western margin of the area at 8000-9000 ft. ending as the Kapkut Highlands with Kapkut Summit at 9175 ft, north of which the ground falls precipitously into the head of the Keno valley. From Timboroa high ground continues SE to a col at 8100 ft. at Makutano and then rises onto Londiani Mountain.
- 2) Londiani Mountain. This rises gently from the north, west and south and steeply from the east to a circular ridge enclosing a caldera 5 km across, with its highest point at its western end at 9872 ft.
- 3) The Mau Highlands. This gentle ridge of high ground over 9000 ft. extends a long way in a NW-SE direction outside the southern boundary of the area and its northern end falls gently to meet Londiani Mountain at a col at Mau Summit at about 8300 ft. The north eastern side of the Mau Highlands is known as the Mau Escarpment.

These three highland areas form the backbone of the area at 8000 to 10,000 ft.

- 4) The Eldama Ravine Depression. This area rises gradually from the Rift Valley floor in the east at about 5500 ft. to the Timboroa Highlands in the west and is enclosed on the north and south by the Kapkut Highlands and Londiani Mountain respectively.
- 5) Kilombe Mountain. This is a smaller version of Londiani to the north east with its highest point, Eldalat, at 7850 ft.
- 6) The Rongai Plain. The plain is contained on the north west by Kilombe, on the west by Londiani Mountain and on the south west by the Mau Escarpment. It slopes down gently to the north east from about 7000 ft.



at the foot of the Mau Escarpment to 5200 ft. at Mogotio.

7) The Londiani Plain. This is a fairly flat area between 7500 ft. and 8000 ft. surrounded by high ground on all sides except the south west where the deep valley of the Kipchoriet leaves the area, having fallen to 6500 ft. at the boundary.

Drainage

East of the axis of the high ground the drainage is to Lake Baringo, via the rivers Perkerra and Molo. To the west it is to Lake Victoria via the river Nyando (fig. 1).

The Molo river begins near Mau Summit and flows to the south east down the valley between the Mau Escarpment and Londiani Mountain, turning east at the foot of the escarpment, then curving round to the north east until, near Mogotio, it turns to the north. The Molo river collects all the drainage of the area south of Londiani Mountain and Kilombe and its course is entirely consequent. It runs from the Mau Escarpment to Lake Baringo 50 miles to the north rather than to Lake Nakuru 15 miles to the east or Lake Hannington 30 miles to the north east. This is because of the generally northerly dip of the floor of the Rift Valley in this part of Kenya and of the barrier to east-west flow provided by the north-south block faulting in the centre of the rift.

On the Mau Escarpment parallel streams run to the north east to join the Molo. Londiani Mountain has a radial drainage pattern on its outer slopes. Within the caldera a dendritic stream pattern coalesces into a permanently running stream, the Visoi, which emerges through a deep gorge on the eastern side and ultimately joins the Molo. Similarly Kilombe has a radial outer and dendritic internal drainage, though the gorge which runs out of the eastern edge of the caldera is almost permanently dry. About four fifths of the radial drainage of Londiani ultimately goes to Lake Baringo and only one fifth to Lake Victoria. This is a result of Londiani lying on an eastward dipping slope.

In the Eldama Ravine Depression and adjacent highlands a dendritic drainage pattern feeds the river Perkerra. This river runs NE from Eldama Ravine through a straight gorge up to 1000 ft. deep, whereas the regional dip of the ground is to the east. The problem this poses is discussed later. The chief tributary of the Perkerra is the Chemususu which follows a straight east-west course.

The Londiani Plain is drained by the river Masaita while the NW slope of the Mau Highlands is drained by the Kedowa. These two join south west of Londiani Town as the Kipchoriet river which, skirting the south side of Tinderet, is the principal headwater of the river Nyando.

The drainage is very youthful. Waterfalls are common, the largest of which, 100 ft. high, is on the Masaita river one mile south west of Londiani town (plate 1). A mile north west of Eldama Ravine, the Siloi river drops 200 ft. in a mile in a series of cascades and rock pools in a very steep sided valley.

Climate, Flora and Fauna

The rainfall is markedly seasonal, the main wet season being March until August, with sometimes a lesser wet period in November. At these times it rains every evening and night and the rain clouds can be seen coming from the south east during the afternoon. However the area around Londiani Town is protected from the monsoonal weather by the high ground of the Mau and Londiani Mountain. Here the climate is controlled by Lake Victoria and the evening rain is brought by very low thundery clouds from the west.

Below about 6000 ft. the land surface is bare red brown sandy soil with sparse thorn bushes. Between 6000 and 7000 ft. the surface has a grass cover and the thorn bushes are replaced by thicker non-thorny Acacia bushes. Between 7000 and 8000 ft. thick forest alternates with grassy



plate 1: Waterfall cut in Kedowa Pillar Trachyte and the underlying Makutano Tuff south west of Londiani Town.
Note two figures at top.

meadows and at about 8000 ft. the forest was once almost continuous with occasional clearings, which have been suggested to be prehistoric forest clearances. The forests consist largely of cedar and podo, which have been extensively logged. Above 9000 ft. bamboo becomes dominant in the forest which thins out so that the highest ground around Timboroa and on the Mau is open grassland.

Some large animals live in the forest. Buffalo live on Londiani Mountain and on the Kapkut Highlands while a few rhinoceros live on Londiani and Kilombe mountains. A herd of zebra inhabit the south side of Kilombe. One band of baboons patrols Kilombe and the eastern side of Londiani mountain and another can be found in the Perkerra gorge. The Black and White Colobus, Vervet and Blue Monkeys are all found in the forests. Dikdik, Gazelle, Impala and antbears live on the higher ground. Leopards are said to lurk in the forests. The rock hyrax abounds in rocky places, especially the gorge coming out of Kilombe caldera. The author found the bones of a specimen of the rare Giant Forest Hog on Londiani. In about 1965, at a time of exceptionally high rainfall, a hippopotamus appeared in a swampy area, now dry, near the eastern foot of Kilombe. It must have come up the river Molo from Lake Baringo, only to be killed and eaten by the local inhabitants. Finally the bamboo forests are supposed to be the home of the terrible, but probably mythical Chemoisit.

Population

An Acheulean artifact site near to Rongai shows that this area was inhabited in early stone age times. On the higher ground amongst the forests small obsidian artifacts up to two inches long occur lying on the ground in great numbers. These artifacts are characteristic of the Wilton culture, which covers the period from 3000 BC until the recent

past (Cole 1963). The Iron Age is represented by slag heaps between Londiani and Kilombe, two of which are marked on the map. The best exposed of these is at 133933 where a roughly circular area of about 40 ft. diameter has abundant heaps of slag 3 ft. high containing many pottery cylinders, known as 'tuyères'. On the Mau escarpment clusters of depressions about 20 ft. across occur along the valleys. These 'Sirikwa Pits' are the sites of prehistoric huts, which differed from the modern huts of the area in being wider and having the floor dug some five feet into the ground. It is of interest that while the present inhabitants are aware of the true significance of the slag heaps, the purpose of the obsidian artifacts has been forgotten, they being considered as fallen pieces of the night sky.

In the late nineteenth century this region was sparsely inhabited by the Masai but since then they have not ranged so far north. Many place names are probably of Masai origin; for example Londiani, sometimes spelled Loldiani, may be a corruption of the Masai 'Ol doinyo' meaning 'the mountain'. Mau is a Masai word; Gregory (1921 p 130) states that the Masai divided that highland area into 'Mau Narok' meaning 'the black twin' and 'Mau Nyuki' meaning 'the red twin'.

After the Masai, the area north of Londiani mountain was occupied by the Tugen and that south of Londiani by the Kipsigis. These two tribes are closely related to the Suk and Elgeyo further north, all being Nilo-Hamitic peoples speaking Kalenjin languages. They were originally pastoral people keeping cattle, sheep and goats and living in scattered huts, but now they are increasingly growing maize, especially in the highlands.

European farms occupied about half the area, around the centres of Rongai, Molo, Londiani Town, Timboroa and Eldama Ravine. The European farmers mostly bred cattle. At the time of this survey few of them remained.

Recently, especially during the last ten years, many Kikuyu have moved into this part of Kenya. They live in large villages growing maize. Many live in villages in the forest called 'Forest Stations' as at Narasha, west of Eldama Ravine, and Makutano, near the Molo-Timboroa road. Some groups of Kikuyu occupy former European farms which are divided into numerous small holdings.

Much of the original forest has been cut down to make more agricultural land for the rapidly expanding population and much of it has been replaced by plantations of Pine and Cypress. Between the cutting down of the natural forest and the planting of the artificial, the forest department's workers are allowed to grow crops for 2-3 years, so that Londiani Mountain has natural forest at the top, surrounded by a belt of newly cleared land with maize patches, in turn surrounded by a belt of pine forest on the lower slopes. The main products of this area are timber, cattle and maize, with some coffee and pyrethrum.

Previous Geological Work

The first person to comment on the geology of this region was J.W. Gregory who visited Kenya in 1892-93. He mentioned the margin of the Rift Valley west of Nakuru as having a structure unlike the usual steep fault scarp, calling it a 'faulted synclinal'. He seems to have considered the valley between the Mau and Londiani Mountain as a syncline trending NW-SE and let down to the east by a series of parallel faults (1894 p 306).

In 1902 or 1903 E.E. Walker visited Kilombe, which he described as a good example of a volcanic cone (1903 p 6).

G.T. Prior described the petrography of rocks from East Africa collected by the Uganda Survey and by Gregory, amongst which were some nephelinites from the Nyando and Kedowa rivers. (Prior 1903 p 239 & 250)

In 1905-06 H.B. Maufe investigated the geology along the Kisumu railway and described the rocks seen in the cuttings. He noted that, west of Mau Summit, the railway descended over a succession of rocks dipping less steeply than itself to the west (Maufe 1908 p 45-48).

Gregory revisited Kenya in 1919 and in his book (Gregory 1921 p 120-130) presents a section along the railway from Kisumu to Laikipia. He regarded the oldest volcanic rocks of the area as phonolites of upper Cretaceous age, resting directly on the basement. West of Londiani town these phonolites were overlain by upper Pliocene nephelinites while on the higher ground around Mau Summit the phonolites were overlain by tuffs and then lower pliocene 'Phonolitic Trachyte'. The steep straight eastern edge of Londiani mountain was the rift bounding fault and its lack of topographical expression on the Mau Escarpment was due to the rapid weathering of the soft Mau Tuffs and an overlying blanket of tuff from Menengai.

Bailey Willis (1936 p 64, 265 & 270) visited East Africa in 1929-30. He saw the Mau Escarpment as a 'flexure', meaning a monocline, disagreeing with Gregory's idea of the rift margin here being faulted.

In 1952-53 G.J.H. McCall mapped the Nakuru area, including the south east corner of the present area (McCall 1957 A & B). He also wrote a brief description of Kilombe (McCall 1964). Working for the Kenya Geological Survey, J. Walsh mapped the part of the area north of the equator in 1959-60 and D.J. Jennings mapped the part south of the equator in 1962 while the region to the west was surveyed by F.W. Binge in 1949. and to the east by McCall in 1958-59. These surveys were published as reports of the Kenya Geological Survey with maps at a scale of 1:125,000 (Binge 1962, McCall 1967, Walsh 1969, Jennings 1971). Walsh's map is poor especially in that he did not recognise the Kapkut volcano.

Jennings considered the eastern side of Londiani mountain to be the rift bounding fault scarp, now faced with Londiani Trachyte lavas. He missed the Londiani caldera and could see no order in the tuffs but he made a sound contribution towards establishing the sequence of lava types.

During their fieldwork Walsh and McCall did a gravity survey which included the north east part of the present area. This survey first showed the gravity high along the central section of the Kenya Rift Valley and the pronounced low about Makutano. An improved gravity map of the central section of the Rift Valley, including the eastern part of this area, was published by Searle (Searle 1970).

In early 1970 S.J. Lippard, working as a member of the East African Geological Research Unit, mapped the area north of Eldama Ravine as part of his work on the south end of the Kerio valley. He was the first to recognise the Kapkut volcano. The present author, also a member of the E.A.G.R.U., did his fieldwork during October 1970 - June 1971 and November 1971 - May 1972. Where their work overlaps, this author's mapping, although more detailed, is in general agreement with Lippard's.

Chapter II

REGIONAL GEOLOGICAL SETTING

Introduction

Fig. 2 is a geological map of the area at the junction of the Kavirondo and Kenya Rift Valleys on a scale of 1:250,000 compiled by comparing the maps of Binge (1962), P.S. Griffiths (Ph.D in prep.), Jennings (1964 and 1971) and Lippard (1972) as well as the author's own work. The following account of the geology is taken from these sources and also from Martyn (1969), McCall (1967), Shackleton (1951) and Walsh (1969).

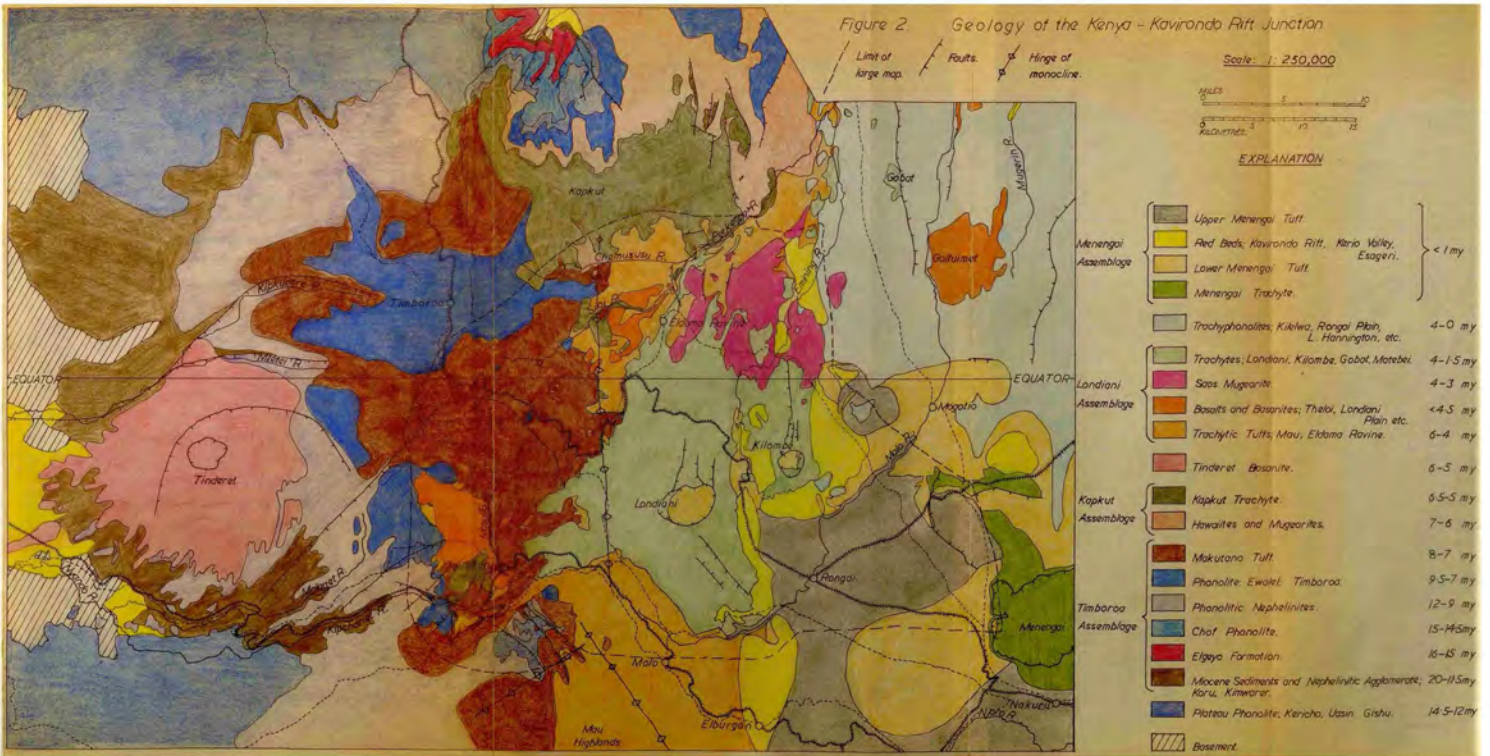
South of the equator the low ground of the Kenya Rift Valley floor in the east of the area rises gently to high ground in the centre which then falls away to the west into the eastern end of the Kavirondo Rift Valley, into which Tinderet is an extension of the high ground. In the north the floor of the Kenya Rift Valley is bounded on the west by the Kamasia Hills, a north-south trending range, west of which the Kerio Valley ends abruptly at its southern end against the Kapkut Highlands. The western side of the Kerio Valley is the steep eastward facing Elgeyo Escarpment, above which the Uasin Gishu Plateau slopes gently westward. The north side of the Kavirondo Rift is the steep Nyando Escarpment whereas the south side rises gently onto the High ground around Kericho.

Precambrian gneisses of the Basement System can be seen in the Kavirondo Rift north west and south west of Tinderet, in the Elgeyo Escarpment and on the lower eastern slopes of Saimo in the centre of the Kamasia Hills.

Pre-Plateau Phonolite Formations

The earliest Tertiary rocks at the eastern end of the Kavirondo Rift Valley are the Koru Beds, a series of shales and limestones with biotite

Figure 2 Geology of the Kenya - Kavirondo Rift Junction



bearing tuffs, sometimes carbonatic. These contain Miocene fossils at Koru, south of Tinderet, and Songhor, north west of Tinderet, at both of which sites they have been dated at 19-20 m.y. (Bishop et al. 1969). Shackleton (1951) has shown that at this time there was no fault scarp along the line of the present Nyando Escarpment and that the Koru Beds were deposited in a lake in a shallow depression on the basement surface. These sediments pass upwards into undersaturated agglomerates and tuffs, up to 1000 ft. thick, which can be traced all round the west and south of Tinderet. At Ft. Ternan, south of Tinderet, a fossiliferous site in the agglomerates has been dated at 14 m.y. (Bishop et al. 1969).

The section in the head of the Kerio Valley was examined by Lippard (1972). Here the Tertiary succession begins later than in the Kavirondo Rift. At about 16 m.y. a downwarp in the basement surface caused the accumulation of basement derived conglomerates, grits and shales, the Kimwarer Beds, which reach their maximum thickness of 200 ft. where they disappear under the Kapkut Highlands. The upper part of the Kimwarer Beds is transitional to the overlying Elgeyo Formation. This is a local accumulation of coarse basic agglomerates with subordinate basanitic flows. A specimen from this formation has been dated at about 15 m.y. (Baker et al. 1971). The Elgeyo Formation is followed by the Chof Phonolite, a series of thin lavas of unusual composition (Lippard 1972) again thickening to the south, reaching 1100 ft. thick.

In the central Kamasia Hills the basement rocks are overlain by a total of about 7000 ft. of phonolite flows with subordinate sediments and basanites (Martyn 1969). This succession was extruded during the period 16-7 m.y. and represents the infilling of the downsagging floor of the early rift valley. Only a small part of this succession is continuous onto the rift flanks (Lippard 1972). The phonolites are divided into three formations; the Sidekh Formation, the oldest, the Tiim and the Ewalel Formation, the youngest.

The Plateau Phonolites

The Plateau Phonolites, formed 13.5-11.5 m.y. ago, are correlatable over a very large area. They are known as the Uasin Gishu Phonolite north of Tinderet, the Kisumu Phonolite by the Kavirondo Gulf and the Kericho Phonolite south of Tinderet. They are represented in the Kamasia succession by the lower part of the Tiim Formation (Lippard 1972). Lippard considers that they are derived from a large central volcano now buried under the floor of the rift valley east of the Kamasia Hills. The Uasin Gishu Phonolite conformably overlies the Chof Phonolite (Lippard 1972) whereas, along the Nyando Kipchoriet river valley, the Kericho Phonolite can be seen to have flowed around the southern flank of a large pyroclastic cone (Binge 1962). Plateau Phonolites of this age are also found on the eastern side of the Rift Valley as the Rumuruti Phonolite in the north and the Kapiti and Yatta Phonolites in the south (Baker et al. 1971). They cover an area altogether 300-400 km across, which is about the same extent as the Columbia River Basalts, a classic example of plateau basalts (McDonald 1973). Lippard (1973) states that the total volume of phonolites in Kenya is 40,000-50,000 km³. The greater part of this volume consists of lavas 13.5 - 11.5 m.y. old.

After the eruption of the Plateau Phonolites, at about 12 m.y. ago, the first major movement on the Elgeyo Fault occurred forming a fault scarp which prevented any later flows from reaching the Uasin Gishu Plateau (Lippard 1972).

The Timboroa Assemblage

Eruption of pyroclastic rock at the eastern end of the Kavirondo Rift continued with increased vigour after the emplacement of the Kericho Phonolite, producing coarse nephelinitic agglomerates (Binge 1962). These

pass up into a series of nephelinites and phonolitic nephelinites 12-9 m.y. old. All the sediments and pyroclastic rocks beneath the phonolitic nephelinites, both above and below the Plateau Phonolites, are shown together on the map fig.2. It can be seen that they form a roughly semicircular outcrop, suggesting a centre of eruption about five miles west of Timboroa. In this context it is worth noting that the Chof Phonolite also seems to be derived from a source in the Timboroa Highlands.

South west of Londiani town the overlying lavas are called the Lumbwa Phonolitic Nephelinites, and here they are largely free of tuff. However north west of Timboroa the lavas are probably subordinate to tuffs (Jennings 1964). Phonolitic Nephelinites are not seen in the Kerio Valley section. They also have a semicircular outcrop, centred about ten miles south of Timboroa.

The next lavas are the Timboroa Phonolite, following immediately after the phonolitic nephelinites at about 9 m.y. They form the Timboroa Highlands and outcrop along the western edge of the Londiani Plain. Age dating evidence suggests that they are equivalent to the Ewalel Phonolite found in the Kamasia Range. At the southern end of its outcrop, in the head of the Kerio valley, the Ewalel Phonolite Formation thickens and contains a high proportion of tuffs. This led Lippard to suggest that it was derived from a centre underneath the Kapkut Highlands. This centre is probably also the source of the Timboroa Phonolite, which around Londiani Town, is seen to have flowed from the north.

The lavas of the Timboroa Phonolite are intercalated with and overlain by phonolitic tuffs. In the head of the Kerio valley tuffs, including welded tuffs form 70% of the Ewalel Phonolite Formation (Lippard 1972). In the southern Timboroa Highlands only those tuffs that overlie the phonolites can be seen and they are called the Makutano Tuff. These

phonolitic tuffs have an arcuate outcrop suggesting a central source about five miles north east of Maji Mazuri.

The nephelinitic agglomerates, the Chof Phonolite, the phonolitic nephelinites, the Timboroa Phonolite and the Makutano Tuff are all derived from centres around Timboroa. These formations can be grouped together as the Timboroa Assemblage. The Elgeyo Formation is included in it here for convenience although its source area is a long way north of Timboroa. It is evident that the centre of eruption for each formation has migrated eastwards with time.

The 7 m.y. Faulting Episode

A major period of faulting occurred in the Kamasia Hills at about 7 m.y. ago, downthrowing the floor of the rift valley and backtilting large blocks of phonolite away from it. This faulting coincided with a change in the chemistry of the magma types erupted from basanite and phonolite to basalt and trachyte.

The Nyando fault, on the north side of the Kavirondo Rift, branches at its eastern end into two faults which curve round to the north east and then back to the east. Erosion along these fault lines has produced the valleys of the Kipkurere and Mtetei rivers which cut across the regional dip. This faulting is later than the Koru Beds (Shackleton 1951). Jennings states that the faulting is later than most of the tuffs and his map implies that it is later than the phonolitic nephelinites (Jennings 1964). He also states that the Basanites of Tinderet, now known to be about 6 m.y. old, lap against the foot of the Mtetei fault scarp. This shows that the faulting occurred between 9 and 6 m.y. ago and can be tentatively correlated with the 7 m.y. faulting in the Kamasia Hills.

A period of faulting at about 7 m.y. ago, accompanying a change from phonolites to trachytes, has also been found in the Narok area, south of the Mau Highlands (R. Crossley and R. Knight pers. comm.). It seems that this 7 m.y. period of faulting is an event of major importance throughout the length of the Kenya Rift Valley.

The southern end of the Elgeyo fault and the eastern end of the Nyando fault are the only major faults in this region. The southern side of the Kavirondo Rift and the Mau Escarpment, which forms the south western margin of the Kenya Rift Valley south of Londiani, are both monoclinical. Smaller faults are however fairly common, especially south and south west of Londiani town, and show three distinct trends. This is because this area at the junction of the Kavirondo and Kenya Rifts is the meeting point of three provinces each with its own characteristic trend, i.e. the Kamasia Hills with a north south trend, the Mau Highlands where faults are north west - south east and the area south of Tinderet where the faulting is north east - south west.

The Kapkut Assemblage

After the faulting in the central Kamasia area, there were erupted onto the partly eroded phonolite surface in turn the Eron Basalt, the Kabarnet Trachyte, closely dated at 7 m.y., and finally the Kaparaina Basalt. In the Kapkut area basalts were followed by the build up of the Kapkut Trachyte central volcano. The Kabarnet and Kapkut Trachytes are separated by an area in which only basalt outcrops. The Eron and Kaparaina Basalts are indistinguishable in the field and Lippard considered the intervening ground to be Kaparaina Basalt. The Kapkut Trachyte, overlying the basalt, was therefore younger than the Kabarnet Trachyte. However since then K/Ar age dates have been obtained which are incompatible with this hypothesis. The dates of 6.6 and 7.6 m.y. obtained from Kapkut

suggest that the Kapkut Trachyte is equivalent to the Kabarnet Trachyte and not younger than it. Furthermore the dates of 6.7 and 6.9 m.y. for 'Kaparaina' basalts from the intervening area are older than the 5.3 and 5.4 m.y. dates of the Kaparaina Basalt in its type area (the 8.2 m.y. date is generally discredited) and would be more appropriate for Eron basalts. It now seems that the intervening ground in Eron Basalt and the Kapkut volcano is broadly equivalent to the Kabarnet Trachyte. Lippard himself now favours this second interpretation (pers. comm.).

The Kapkut Trachyte and underlying basalts and mugearites can be distinguished as the Kapkut Assemblage, which includes those rocks erupted in the Kapkut area, to distinguish them from the Timboroa Assemblage. In the Lembus Forest area to the west of Kapkut mugearites which underlie the Kapkut Trachyte are overlain by the Makutano Tuff, showing that the upper part of the Timboroa Assemblage overlaps in time the lower part of the Kapkut Assemblage. The Kapkut Assemblage is the local representative of Lippard's Baringo Group except that the Eldama Ravine Tuff and Londiani Trachyte are placed in the separate Londiani Assemblage.

The Kapkut volcano was affected by downtilting to the east accompanied by antithetic faulting at its eastern end. This faulting is probably a southern continuation of a major phase of faulting in the Kamasia Hills which affected all the basalts and trachytes and so must be younger than 5.3 m.y. Since the Eldama Ravine Tuff overlaps the eastern end of Kapkut and it not affected by the faulting, then the faulting must be older than 4.3 m.y. and so occurred between 5.3 and 4.3 m.y. ago.

The Londiani Assemblage

The eastern end of the Kenya-Kavirondo Rift junction is occupied by rocks of the Londiani Assemblage. This begins with the eruption

from the east of a series of ash flow tuffs up to 800 ft. thick. South of Londiani these are the Mau Tuff dated at about 6 m.y. and north of Londiani they are the Eldama Ravine Tuff at about 4 m.y. These are followed in a broadly conformable succession by the Saos Mugearite and two trachytic caldera volcanoes, Londiani at 3 m.y. and Kilombe at 2 m.y. There is a series of smaller trachyte centres of similar ages north east of the two volcanoes, along the western margin of the rift valley floor. In order north from Kilombe, these are the domes of Kiborit, undated, and Matebei at 3.6 m.y., the small centre of Gobat at about 2 m.y. east of Emining and finally, much farther north at $0^{\circ} 25'N$ the mugearite-trachyte centre of Ainapno at 1.9 m.y. Trachyphonolites outcrop east of Kilombe and along the western edge of the Rift Valley floor further north, including the Kapsalop Phonolite of 1.7 m.y. and the Kindonin Trachyphonolite of 4 m.y. both between Gobat and Ainapno. Eastwards the floor of the rift valley is covered by extensive flows of Lake Hannington Trachyphonolite which are less than 1 m.y. old (P.S. Griffiths pers. comm.). In the centre of the rift there are two basalt centres, the Kwaibus Basalt underlying the Hannington Trachyphonolite and the Goituimet Basalt overlying it.

The Tinderet Basanite was erupted about 6 m.y. ago to form a central volcano (Baker et al. 1971). Faulting then produced a caldera at the summit and a larger semicircular fault downthrowing the higher part of the volcano to the south. On the Londiani Plain eruption from scattered centres produced the Londiani Plain Basanites at an unknown time probably within the last 2 million years.

At the time of the eruption of the Eldama Ravine Tuff the ground sloped to the west. This westward slope still existed at the time of the Londiani Trachyte but since that time the tilt has reversed so that now there is a monocline running north south through the eastern half

of the area, displacing the floor of the Kenya Rift Valley relatively downwards. On the rift valley floor itself the trachyphonolites have been affected by recent north south block faulting (McCall 1967).

The Menengai Assemblage

In the centre of the rift valley just north of Nakuru lies the Menengai volcano. Here the building of a trachyte shield volcano was followed by piecemeal subsidence to produce a large caldera 35 square miles in area. The caldera subsidence was accompanied by extrusion of tuffs. Trachyte lavas have since largely filled in the caldera and a second tuff eruption has blanketed much of the surrounding country with black ash. The age of Menengai is unknown but is probably less than 1 m.y.

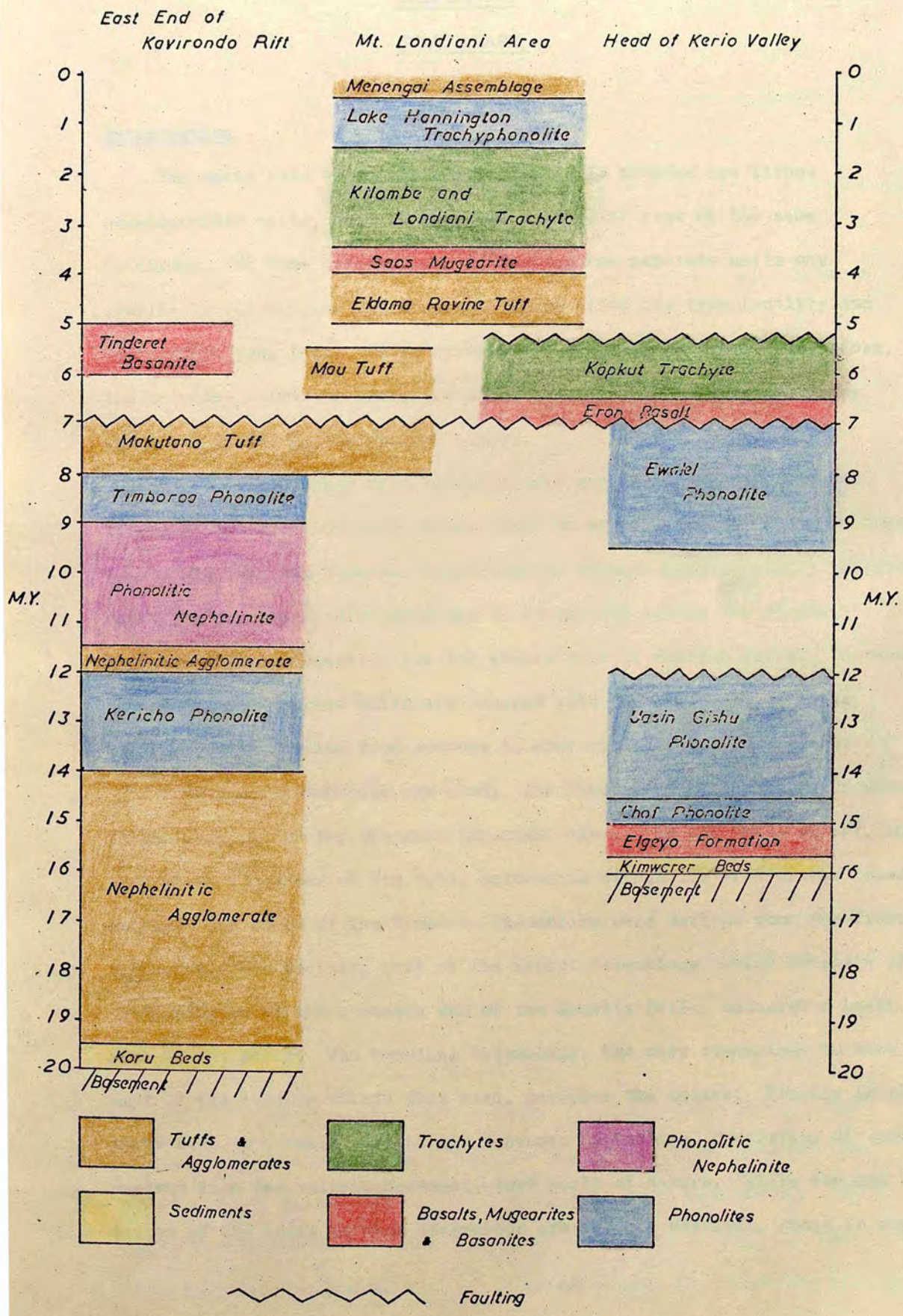
The south east corner of the present area extends onto the edge of the Menengai Assemblage. The two tuff horizons are separated by red beds exposed along the edge of the high ground, the Esageri Beds. These beds continue along the foot of the Mau Escarpment and are similar to the Kerio Valley Beds in the Kerio valley (Lippard 1972) and to the Kapthurin Beds in the Baringo Basin (Martyn 1969).

Summary

The development of the Kavirondo Rift, at least at its eastern end, began 20 m.y. ago. The junction of the two rifts was a focus for volcanic activity which migrated eastwards with time. The rocks older than 7 m.y. belong to a nephelinite to phonolite trend whereas those younger than this age belong to a basalt to trachyte trend.

Relevant K/Ar dates are summarised in Table 1 and comparative stratigraphical columns are shown in fig. 3 .

Figure 3. Stratigraphic Columns for the Kenya-Kavirondo Rift Junction



Chapter III

STRATIGRAPHY

Introduction

The units into which the stratigraphy is divided are lithostratigraphic units, that is they are volumes of rock of the same lithology. No time stratigraphy is implied and separate units may overlap in their ages. Each unit is named after its type locality and predominant rock type. Where stratigraphic names have been used before, the original author is indicated after the name. Otherwise the names are newly coined by the present author.

Each stratigraphic unit occupies only a part of the total area so that separate stratigraphic columns must be erected for different regions. This means that the temporal relationships between geographically isolated units are sometimes very difficult to ascertain, making one single stratigraphical succession for the entire area of dubious value. Instead the lithostratigraphic units are grouped into 'assemblages' of units believed to be derived from sources in approximately the same place.

Four such assemblages are used. The Timboroa Assemblage, outcropping in the west, is by far the most important areally in its total extent, but only about a quarter of its total outcrop is within the area of the present survey. The rocks of the Timboroa Assemblage were derived from the Timboroa Highlands. The southern part of the Kapkut Assemblage, which consists of units erupted at the southern end of the Kamasia Hills, occupies a small area in the north. The Londiani Assemblage, the only assemblage to have most of its outcrop within this area, occupies the centre. Finally in the south east is a small part of the Menengai Assemblage, consisting of rocks derived from the volcano Menengai, just north of Nakuru. While the age ranges of the rocks in each assemblage are largely distinct, there is some

interdigitation between the top of the Timboroa Assemblage and the bottom of the Kapkut Assemblage. The gross stratigraphy of these assemblages over the whole of their outcrop is described in Chapter II. The small outcrop of the Kericho Phonolite is not assignable to any of these assemblages, being part of the Plateau Phonolite, and is considered separately.

In this chapter descriptions of lithologies are as they appear in hand specimen.

Plateau Phonolite

Kericho Phonolite (Binge 1962)

The oldest formation exposed within the present area is a phonolite outcropping at the northern end of the Mau Highlands. Here erosion has cut deeply into the flanks of the high ground along the lines of three faults, revealing the deeper lying rocks not elsewhere exposed on the Mau. The Phonolite is a dark fine grained rock with phenocrysts of nepheline, sanidine and a few biotite, in variable but never abundant amounts. This is correlatable with the Kericho Phonolite further to the west because of its textural similarity and its position underneath the phonolitic nephelinites. A specimen of this phonolite gave a K/Ar date of 11.7 ± 0.3 m.y. (14/924), which is within the range of dates given by plateau phonolites elsewhere in Kenya. Although plateau phonolite is common to the north and south west, this is the only place where it outcrops within the area of the present survey.

Timboroa Assemblage

The Nephelinitic Agglomerate, which forms the lower part of the Timboroa Assemblage, is not exposed in the present area, although its outcrop begins around Lumbwa just outside its south west margin. Part of the Phonolitic Nephelinite is exposed south west of Londiani Town where it is known as the Lumbwa Phonolitic Nephelinite. The overlying Timboroa Phonolite and Makutano Tuff are well represented.

Lumbwa Phonolitic Nephelinite

These rocks are exposed on the sides of the Kipchoriet valley north west of Kedowa and on the slope of the Mau south east of Kedowa. They are named after Lumbwa railway station just outside the western margin of this area from around which rocks of this kind have long been known (Prior 1903). 700 ft. of these lavas are exposed on the fault scarp north of the river.

The great majority of this formation is phonolitic nephelinite. This is a green rock containing megascopic laths of sanidine, stubby nephelines and needles of pyroxene. The size and number of phenocrysts is very variable. On the Mau slope this overlies the Kericho Phonolite, being probably one flow about 100 ft. thick. A specimen from there, 14/957, gave a K/Ar date of 12.4 ± 0.3 m.y.

Glassy rock is exposed in two places. One is by a stream just north of the railway at 790803 where it is a black brittle rock showing abundant small nepheline phenocrysts. The other is on the south side of the Nyando valley at 793765 where it is aphyric. Each of these outcrops probably represents a thin flow intercalated within the phonolitic nephelinite sequence.

The phonolitic nephelinites are capped by a basanite flow. This is a heavy dark rock, usually with olivine and sometimes with feldspar phenocrysts, exposed in two places, 795823 and 805819, near the top of the scarp north of the Kipchoriet river, atop an isolated hill at the same height halfway south to the railway and in a downfaulted position by the side of the railway at its foot, 801796. At the last of these outcrops it shows columnar jointing, the sides of the joints being 3 ins. wide. It also forms a spur on the south side of the valley at 801784.

Timboroa Phonolite

This formation consists of phonolites erupted in the Timboroa Highlands area and is probably equivalent to the Ewalel Phonolite of the Kamasia Hills (see Chapter II). Only the southern part of its outcrop is seen in the area of this survey. It is exposed on the north eastern side of the Kipchoriet Valley, where it has been called the Nyando Valley Phonolite (Jennings 1971 p 21), and on the high ground around Timboroa. It is a dark fine grained lava with sparse phenocrysts of sanidine and sometimes of nepheline and biotite.

Along the Kipchoriet valley the basal flow of the Timboroa Phonolite is distinguishable from the overlying flows because it contains occasional pyroxene phenocrysts in addition to the sanidine, nepheline and biotite. This flow caps the scarp north of the Kipchoriet. Further south it reappears in the river and is traceable to the south forming a west facing scarp about 100 ft. high. The very intermittent outcrop of the basanite flow beneath it shows that there was a period of erosion between the phonolitic nephelinites and the Timboroa Phonolite.

The second phonolite flow also forms a west facing scarp on the south side of the Kipchoriet Valley, this time 150 ft. high. A mile east of this scarp the river has cut a valley through the phonolite showing it to be at least 300 ft. thick. Some phonolite boulders at 841733, at the north west foot of the Mau, may represent the most southerly outcrop of the Timboroa Phonolite. The phonolite is continuous from the Nyando valley northwards along the western limit of the area as far as poor outcrops on hills two miles north and three miles northwest of Limutet.

North of the equator, phonolite outcrops over a small area two miles west of Murungwa where the Siloi river has cut a valley down through the overlying Makutano Tuff. In the riverbed here the phonolite is mottled

in blue, green and brown, possibly as a result of weathering. The main outcrop north of the equator begins a mile north west of Murungwa where the phonolite emerges from under the Makutano Tuff and rises to form a high ridge whose summit is at Timboroa. On the lower eastern part of this ridge exposures are few while on the higher western part they are very rare and very weathered. This is because the higher ground is covered in a thick soil mantle. Small inliers of phonolite occur near the northern railway on hills at 875009, 880990 and 908967.

A specimen from 3 miles west of Murungwa in the north, 14/83, gave a date of 9.4 ± 0.3 m.y. while one from 3 miles north west of Kedowa in the south, 14/949, gave 8.9 ± 0.2 m.y.

Makutano Tuff

The Makutano Tuff covers much of the west of the area, being a series of phonolitic tuffs differing in character in different parts of its outcrop. It is well exposed only in the embayment in the north of the Mau uplands south east of Londiani town. It is named after Makutano, a small settlement on the Nakuru-Eldoret road, near to which it is exposed in deep road cuttings. Its outcrop can conveniently be considered in three areas.

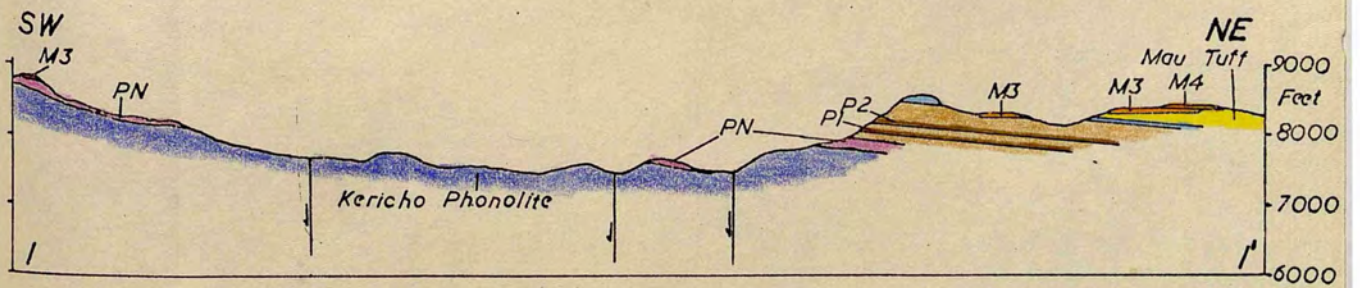
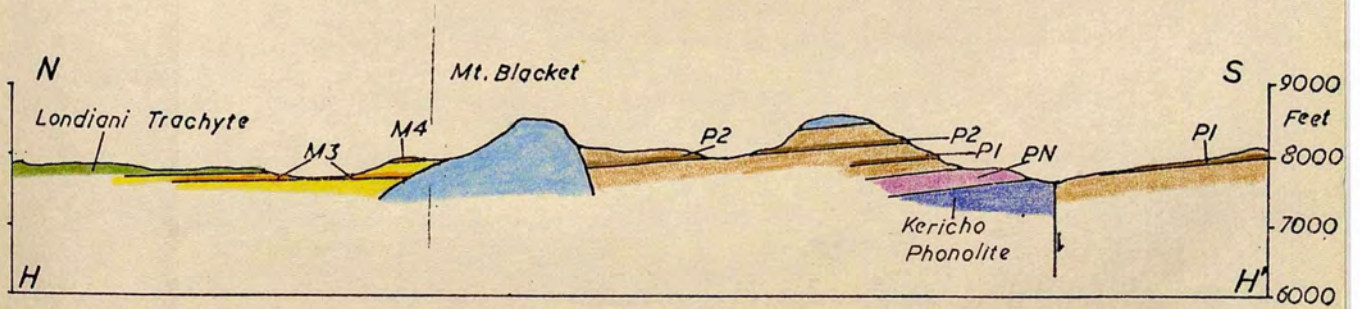
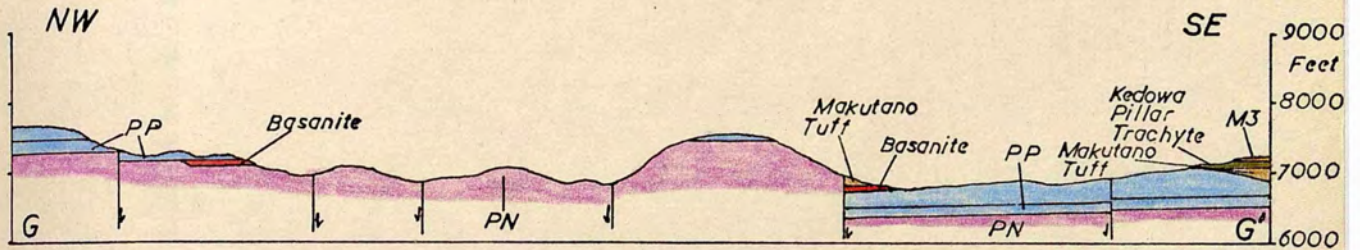
1) The Mau.

On the hill $1\frac{1}{2}$ miles south of Mt. Blakett 600 ft of these tuffs overlie the phonolitic nephelinite (fig. 4). The tuffs are cream, pale green or pink and contain a few pumice lumps and phenocrysts of sanidine, nepheline and occasional biotite. On this hill there are two massive resistant pink horizons P1 and P2, each probably an ash flow tuff. The lower of these ash flows P1 has a welded zone about 15 ft. thick of dark fine grained lava-like rock with common small waxy nepheline and glassy feldspar phenocrysts. This welded tuff is traceable on hills for two miles further south. It also occurs three miles south west of Londiani town. A specimen of P1, 14/898, gave a date of 7.9 ± 0.2 m.y.

Figure 4. Sections across the North of the Mau Highlands and West of Londiani Town

Vertical Exaggeration ≈ 1.5

1 Km
1 Mile



Makutano Tuff

Phonolite
Timboroa & Mt. Blacket

PP = Pyroxenephyric Phonolite

PN = Lumbwa Phonolitic Nephelinite

Mt. Blackett is a conical hill of about $\frac{1}{2}$ mile basal diameter rising about 600 ft. above its surroundings to a flat top (plate 2). No outcrops were found on it but a few loose blocks of weathered phonolite occur on its steep slope and fresh boulders of phonolite with feldspar and nepheline phenocrysts can be found in the track by its southern foot. A hillock at the western foot of Mt. Blackett at 922795 has an outcrop of phonolite which gave a date of 7.6 ± 0.2 m.y. If this hillock is continuous with the rock of Mt. Blackett then the latter is of approximately the same age as the surrounding Makutano Tuff. The tuffs do not undergo any change of dip near the hill, showing that they do not postdate and mantle it. Therefore Mt. Blackett is probably a phonolite plug intruded into the tuffs. That it is at a previous site of eruption of Makutano Tuff is suggested by the presence of an agglomerate horizon of blocks of glassy phonolite at 938781 on the hillside 1 mile south of Mt. Blackett and a nephelinephyric glassy phonolite flow which is the highest member of the Makutano Tuff, capping the hill $1\frac{1}{2}$ miles south of Mt. Blackett and on the hillside $\frac{1}{2}$ mile south east of Mt. Blackett.

Lying on the surface of the Makutano Tuff on the Mau are boulders of phonolite and quartz trachyte, especially at 939764. It is reasonable to suppose that these boulders have weathered out of the tuff, in which case they show that an oversaturated trachyte formation exists under the Makutano Tuff which is not exposed at the surface. Pieces of wood mineralised by quartz and, at 917755, a boulder of carbonate rock, possibly carbonatite, were found weathered out of the tuff.

2) The North West.

In the north west Makutano Tuff laps against the Timboroa Phonolite. It is different from the tuffs on the Mau, being generally yellow and pumiceous. It is well exposed in cuttings for the road and railway north



plate 2: Mt. Blackett from the south west.



plate 3: Thick soil profile on Makutano Tuff along the road north west of Makutano.

west of Makutano where it has weathered to a thick soil (plate 3). Feldspar phenocrysts are common, biotite is rare and nepheline is absent. It is difficult to distinguish from the younger Eldama Ravine Tuffs which overlap it from the east, the critical difference being the presence of rare biotite phenocrysts in the Makutano Tuff. Fine grained bedded tuffs are common and at 911019 on the Siloi river mm scale bedding suggests deposition from water. An uncommon but characteristic type is a yellow tuff containing small patches of glass about 5 mm wide, often altered to a brown toffee like appearance.

In this northwestern area there are three recognisable ash flow tuff units. The earliest, P3, a greenish grey ignimbrite with darker fiamme and biotite phenocrysts, is found on the sides of a stream valley in Maji Mazuri forest at 944020 and also in the Siloi riverbed where it passes through Murungwa three miles to the north east at 976066. P5, a dark blue gritty tuff with flattened green pumice, is quarried near the sawmill at Arama (956062). P4, a blue grey slightly welded tuff immediately underlies P5 and outcrops on hilltops to the west as far as 936069.

The tuffs lap against the phonolite forming the highest ground in the north west. The junction between the tuff and the underlying phonolite, as seen two miles west of Murungwa, is very irregular. This shows that the tuffs drowned the lower lying part of a mountainous topography of phonolite.

The railway cutting at 898981 exposes a gritty yellow tuff showing cm scale bedding which contains lumps of augitephyric basic lava up to 6 inches long. This tuff grades upward into 15 ft. of lateritic soil. Lumps of very weathered basic lava can be found occasionally in the soil in the railway cuttings north west of Makutano and in roadsides north west

of Maji Mazuri. It seems that the phonolitic tuffs are overlain in places by basic tuffs of a similar age. A small dome of basanite forming a hill at 948076 may be correlated with these basic tuffs.

3) The Londiani Plain

Most of the Londiani Plain is covered with tuff. Some tuffs occurring on hills on the plain are attributable to the Mau Tuff but the age of the tuffs forming the floor is indeterminable as they are poorly exposed. South west of Londiani town Makutano Tuff occurs along the river valleys and this is probably laterally equivalent to the tuffs of the plain. In a small gulley $\frac{1}{2}$ mile west of Lessotet, biotite flakes were found in the tuffs. Those forming the floor of the Londiani Plain are therefore placed in the Makutano Tuff.

Tuffs are exposed along the road from Londiani Town where it climbs up to Timboroa, including a welded horizon P6. This welded tuff is a massive homogeneous rock with abundant feldspar, nepheline and a few biotite phenocrysts. It is traceable for two miles in an east west direction and dips gently north eastwards.

A basanite flow can be seen at 840791 and 845781 south west of Londiani town which is probably intercalated in the Makutano Tuff.

Kapkut Assemblage

The rocks of the Kapkut Assemblage which are exposed in the present area consist of small scattered inliers of hawaiite and mugearite and part of the overlying Kapkut Trachyte volcano. A trachyte flow south west of Londiani town, the Kedowa Pillar Trachyte, is included in the Kapkut Assemblage because of its lithology and stratigraphic position.

Hawaiites

Hawaiites of the Kapkut Assemblage are exposed in three places. The Perkerra Valley Hawaiite outcrops underneath the Kapkut Trachyte in a small valley at Sigoro on the eastern end of Kapkut and also where the

valley meets the Perkerra Gorge below (fig. 5). It has a very distinctive appearance with abundant 1 cm long plagioclase laths. By the river Perkerra the upper and lower surfaces of a flow in the hawaiite can be seen which is twenty feet thick. The Perkerra Valley Hawaiite also outcrops at the bottom of the gorge below Kokwamanik Hill and is clearly the southerly continuation of a large area of similar rocks further north in the Kamasia Hills mapped by Lippard as Kaparaina Basalt (Martyn 1969).

The Chemususu Hawaiite occurs at Chemususu Old Sawmill Site in the Lembus Forest. This also has large platy plagioclase phenocrysts. It outcrops for about 50 ft. vertically along the end of a spur (939103). Tuff outcrops a few yards to one side of the hawaiite and so the hawaiite is probably an inlier surrounded by Makutano Tuff.

The Murungwa Hawaiite outcrops along a stream on Murungwa at 981062 underlying the Kapkut Trachyte. It is a vesicular rock with abundant stubby plagioclase phenocrysts.

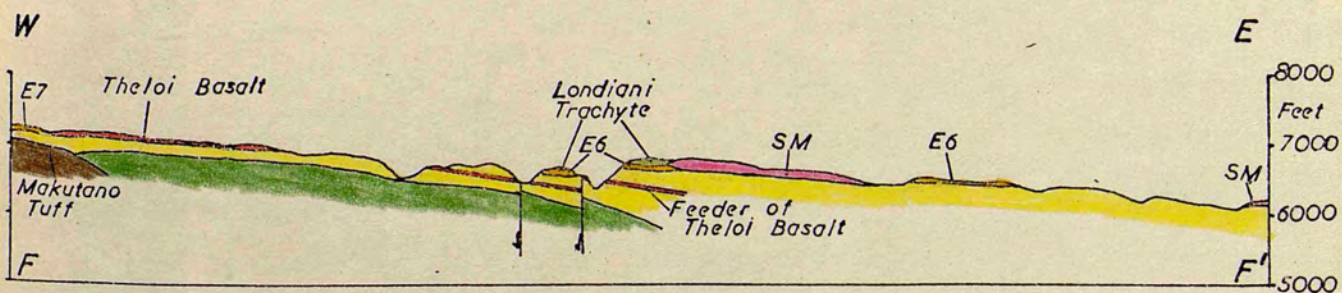
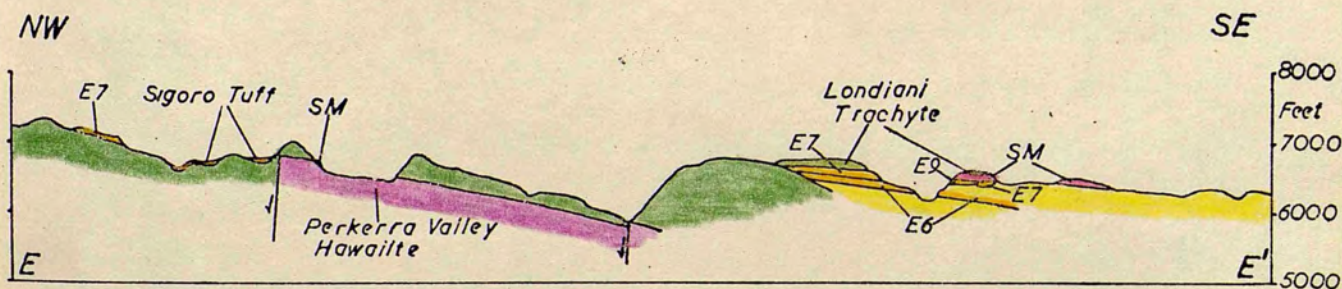
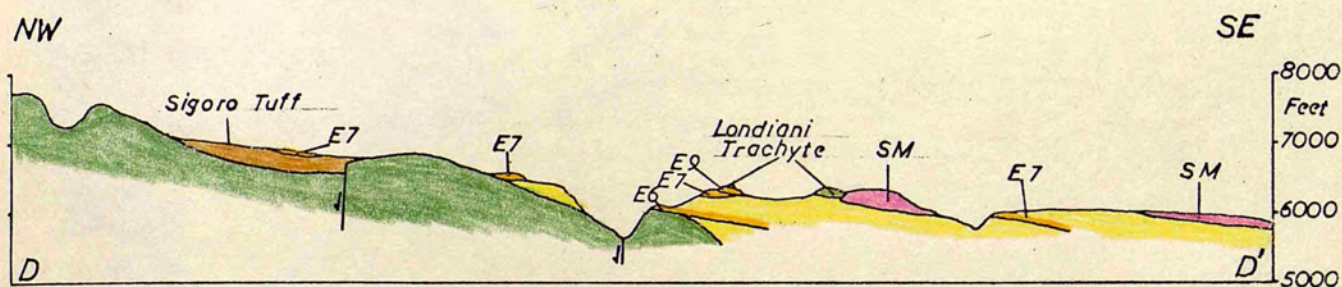
Lembus Mugearite

In the Lembus Forest to the west of Kapkut is an area where the interfluves form a fairly uniform surface dipping gently to the south east below the level of the more irregular hills around them. In this area there are occasional outcrops of blue weathered mugearite. On the south side of the Chemususu valley mugearite outcrops up to near the top where it is replaced by micaceous tuff but it is not clear whether it laps against or is overlain by the tuff. However mugearite was seen to outcrop in the valley bottom in three places and nothing was seen to underlie it so it is assumed to be older than the adjacent tuff. It is also assumed to be older than the Kapkut Trachyte which forms the high ground on the north, west and east sides. The thickness of mugearite cut by the Chemususu river is 300 ft. A small outcrop occurs in a stream valley at 967087 a mile south of the main exposure.

Figure 5. Sections across the Perkerra Gorge

Vertical exaggeration ≈ 1.5

1 Km
1 Mile



Kapkut Trachyte
 Eldama Ravine Tuff
 SM = Saos Mugearite

A fresh boulder of mugearite was found in a valley leading from Kapkut into the Pekerra Gorge which gave a date of 7.6 ± 0.2 m.y. (14/678). This suggests that the Lembus Mugearite is continuous under the Kapkut Trachyte.

The Lembus Mugearite and the Chemususu Hawaiite both underlie the Makutano Tuff while the Kapkut Trachyte overlies it. This is the only occasion in the present area where different assemblages are interdigitated.

Kapkut Trachyte

This forms the Kapkut Highlands bounding the north of the area. Its most easterly outcrop and best exposure is along the Perkerra River where flows uniformly about 50 ft. thick dip to the south east (O64119). The western end of the trachytes seems to be about two miles west of Chemususu Old Sawmill Site where trachyte overlaps onto Timboroa Phonolite. In the west the trachyte also overlies the Makutano Tuff. The maximum vertical thickness of trachyte lavas seen is 900 ft. on the hill at O66167 on the south east side of the Perkerra Gorge.

The trachyte is nearly always very weathered so that no fresh specimens were obtained. Along the lower part of the Perkerra Gorge the trachytes contain few feldspar phenocrysts whereas along the top of the gorge and on the main mountain mass to the west they are abundantly feldsparphyric and sometimes show large white anorthoclase phenocrysts with clear glassy rims. The trachytes also contain small red needlelike phenocrysts and sometimes xenoliths of coarsely feldsparphyric mugearite.

The Kapkut Highlands do not have the form of a cone. Instead there is a semicircle of hills. In order from the west these are Kokwe, Koisamo, Kapkut Summit and Chemorgong. This ring is suggestive of a caldera but there is no inward facing scarp along which to draw a ring fault. Perhaps this semicircle of hills represents a curved fissure from which the lavas were erupted.

At Sigoro is a plateau a mile wide on which are exposed fine grained sediments, the Sigoro Tuff, showing mm scale graded bedding and containing some diatomite. The Sigoro Tuff contains a few horizons of agglomerate consisting of fragments of trachyte and Perkerra Valley Hawaiite. The tuffs wedge out to the north east, overlying Kapkut Trachyte and overlain by Eldama Ravine Tuff. These tuffs are very disturbed, showing slumping and small scale faulting.

The plateau is bounded on the south east side by low hills of trachyte and the sediments were laid down probably in a lake between these hills and the higher ground in the north west. This depression was caused by a northwest downthrowing fault, the line of which is shown in the valley at Sigoro by the steep contact of the trachyte with the Perkerra Valley Hawaiite.

At O49143 in the road at Sigoro a thin flow of quartz trachyte is interbedded with the Sigoro Tuff. This rock type is also exposed at O52139 where it is banked against the Kapkut Trachyte of the valley side and at O63129 on the north west side of the Perkerra Gorge about 400 ft. above the river. This shows that between the ending of the main period of eruption of Kapkut and the extrusion of this flow, which happened while the Sigoro Tuff was being deposited, considerable erosion had taken place to produce the Perkerra Gorge and the valley leading into it from Sigoro.

Along the north west side of the Sigoro Plateau there is a series of hills of trachyte characterised by the presence of xenoliths of coarsely feldsparphyric mugearite, which occur only rarely elsewhere in the Kapkut Trachyte. A good exposure at O59149 shows this xenolithic lava overlying Sigoro Tuff, while at O59145 in the roadside this xenolithic trachyte can be seen cutting through the Sigoro Tuff and passing up into a flow.

Trachyte outcrops along the bottom of the Perkerra Gorge four miles north of Eldama Ravine and is probably continuous under the Eldama Ravine Tuffs north of that town. The trachyte again outcrops in the Siloi river west of Eldama Ravine and forms the high ground of Murungwa. The hill at 923016 four miles south west of Murungwa has a few weathered blocks of trachyte and is considered an outlier of the Kapkut Trachyte. A hill 300 ft. high 2 miles west of Maji Mazuri is an extruded dome of trachyte with the Eldama Ravine Tuff lapping round it.

The Kedowa Pillar Trachyte, named after a triangulation point standing upon it, is a trachyte flow with common feldspar phenocrysts which mantles the fault escarpment west of Londiani town. The most northerly outcrop of this flow is at the western foot of Limutet where very weathered trachyte is exposed. The Kedowa Pillar Trachyte is overlain by Mau Tuff and is therefore correlated with the Kapkut Trachyte rather than with the nearer Londiani Trachyte because the latter overlies the Mau Tuff. However it is at such a distance from Kapkut that Kapkut is unlikely to have been its source.

Highly porphyritic flows are not seen in any of these outcrops south of the Kapkut Highlands and are confined to the Highlands themselves. This suggests that in the earlier part of the history of the Kapkut Trachyte, eruption of sparsely porphyritic lavas was widespread and that later the lavas were concentrated in the Kapkut Highlands and became very porphyritic. However it cannot be disproved that some of the poorly porphyritic lavas away from the Kapkut Highlands are the same age or even younger than the very porphyritic flows.

In summary the history of the Kapkut volcano began with eruptions of mugearite, the Lembus Mugearite. This was followed by eruptions of trachyte ending with a coarsely feldsparphyric, possibly from an arcuate

fissure. Then the south east side of the volcano was affected by faulting producing a basin in which tuffaceous sediment accumulated and by vigorous erosion forming the Perkerra Gorge. Activity ended with the extrusion onto the tuffs of small flows containing xenoliths of mugearite.

Londiani Assemblage

The Londiani Assemblage begins with a trachytic ashflow tuff succession with subordinate basalt flows called the Eldama Ravine Tuff in the north and the Mau Tuff in the south, the Mau Tuff being the older. This is followed first by the Saos Mugearite and then by trachytes and trachyphonolites of which the most important are the Londiani and Kilombe trachyte volcanoes. Some basanites on the Londiani Plain are included in this Assemblage.

Trachytic Ash Flow Tuffs

A) Mau Tuff

The Mau Tuffs are a series of trachytic tuffs exposed on the high ground north west of Molo town and around Londiani town. On the Mau, exposures are few and are mostly of two welded tuffs. Where exposed the unwelded tuffs are yellow or grey pumiceous tuffs with lithic fragments. The best exposure of unwelded tuff is in the road cutting at O70753 north east of Molo town where the tuffs are capped by Londiani Trachyte. At 995768 on the Mau a crag of yellow tuff is agglomeratic with lumps of trachyte and phonolite.

At 121806 at the south eastern end of Londiani Mountain an outcrop of dark blue grey welded tuff with flattened pumice, surrounded by Londiani Trachyte, is probably an inlier of Mau Tuff.

Four ash flow tuffs can be identified:

I) M1

This is a blue grey welded tuff, usually with fiamme, which is characterised by an abundance of round lithic fragments a few mm in diameter. It outcrops along the Molo river, sometimes in the river bed

and sometimes a few feet above it. It continues over the pass at Mau Summit and along the Kedowa river as far as a point 3 miles south of Londiani Town. It can be traced from the Molo river for up to three miles in streams coming down off the Mau. M1 rises onto the Mau where the southwestern edge of its outcrop is not exposed except at 974762 which is its highest exposure.

2) M2

West of Kedowa some outcrops of massive yellow tuff with glassy pumice in various states of collapse are grouped together as one unit and placed in the Mau Tuffs, although their relationship to the other units is not seen in the field. Boulders of welded tuff with glass fiamme up to 6 inches long occur $1\frac{1}{2}$ miles south west of Londiani Town at 861805 and may represent another outcrop of M2.

3) M3

This is a pale glassy welded tuff with abundant 3 mm long feldspar phenocrysts. It outcrops mostly on the Londiani Plain and around Kedowa where it is extensively quarried. It occurs on the Mau just south east of Mt. Blackett and its highest and most southerly outcrop is at 890728. Its most northerly outcrops are at Mlima ya Simba at 868967 and 876960. Boulders of abundantly feldsparphyric welded tuff in the stream at 943868 show that this unit outcrops somewhere upstream of there.

4) M4

This is seen on the Londiani Plain and on the Mau. On the Mau it caps hills and dips generally away from the highest ground. It is a blue grey welded tuff with fiamme in which an axiolitic devitrification structure is visible in hard specimen. On the Londiani Plain the axiolitic texture is less often developed and the tuff is more granular but the presence of intermediate types shows that they are all one unit. This horizon is also extensively quarried at Kedowa, where it can be seen to overlie M3.

A specimen of M3, 14/958, gave a date of 5.8 ± 0.2 m.y. while a specimen of M4, 14/843, gave a date of 6.0 ± 0.2 m.y.

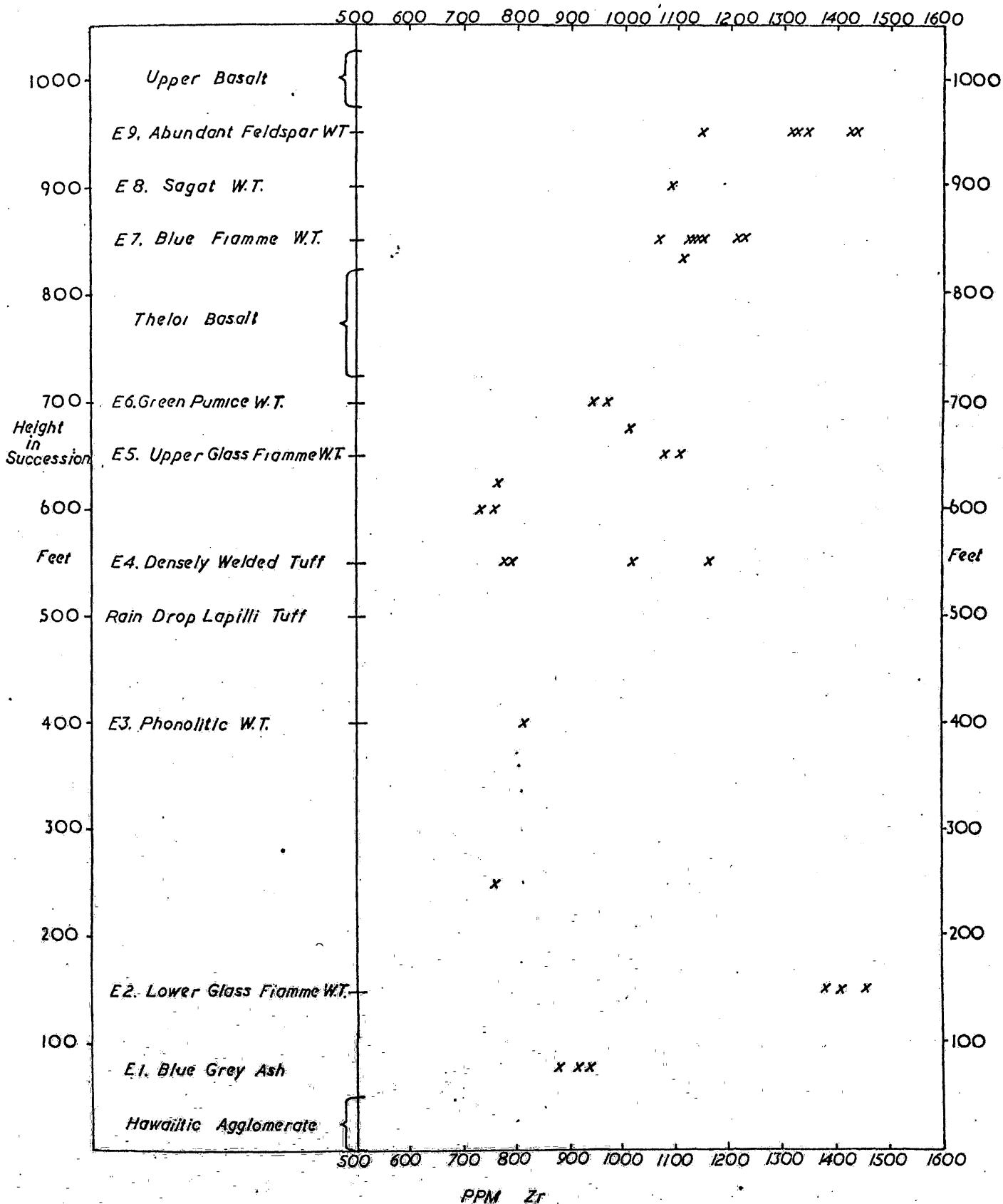
B) Eldama Ravine Tuff (Walsh 1969)

The Eldama Ravine Tuff is a series of predominantly trachytic ash flows with subordinate ash fall tuffs, agglomerates and interbedded basalt flows. The maximum thickness of tuff seen is 800 ft. in the Perkerra Gorge below Kokwamanik Hill. Some ash flows exposed elsewhere are not seen in the section below Kokwamanik; so it is suggested that the total accessible thickness of the tuffs is about 1000 ft. The tuffs thin out to the west and probably continue to thicken to the east so that the thickness of the Eldama Ravine Tuff under the Hannington Trachyphondite in the east may be much greater than 1000 ft. The average thickness of the cooling units is about 50 ft; for example five cooling units are seen on the eastern side of the spur on the south side of the Chemususu Perkerra junction in a thickness of about 300 ft. This means that about 20 cooling units are exposed in this area. In general, apart from the Chemususu and Perkerra sections, only the upper part of the Tuff is exposed so that the stratigraphy within the upper part of the Eldama Ravine Tuff succession is better understood. The cooling units generally form scarps which can be traced on air photographs. The unwelded cooling units are usually yellow while about half of the total show welding and are dark coloured, grey, blue or purple. Nine of the welded tuffs are traceable or correlatable over some distance and are shown on the map. Other ash flows which can be seen in one outcrop only are not shown. The stratigraphy of the Eldama Ravine Tuff is shown in fig. 6.

Hawaiitic Agglomerate

The lowest member of the Tuff is seen in the Chemususu riverbed at O23115 where tuff is exposed containing abundant lava fragments, many of which are round lumps of hawaiite. One olivinephyric hawaiite bomb is four feet long and has a breadcrust surface showing that the hawaiite bombs are

Figure 6. Stratigraphy and Zr Content of the Eldama Ravine Tuff



cognate. A few yards upstream of here Lippard found a Kapkut trachyte outcrop (pers. comm.) so this hawaiitic agglomerate is the basal member of the Eldama Ravine Tuff in this locality.

E1, Blue Grey Ash

A blue grey compact ash forms a feature a few yards from the river on the north side at the above locality. Another blue grey compact ash occurs on the north west side of the Perkerra river just below its junction with the Chemususu and these two are correlated.

E2, Glass Fiamme Welded Tuff

This is a welded tuff with abundant thin lenses of black glass about an inch long in a fine grained brown matrix. It outcrops just above E1 by the Perkerra and rises to the north west where it is seen around Sigoro. Outcrops occur near the bottom of the Perkerra Gorge further downstream at O98138 and at 116157 below Kokwamanik. The most westerly outcrop is at 969119 in the Lembus Forest.

Above E2 there is a gap of about 500 ft. before the next widespread welded tuff E6. In this gap three welded tuffs have been mapped but their mutual relationships are not known.

Rain Drop Lapilli Tuff

This is an unwelded massive tuff with a few pumice lumps about 1 cm long. It is recognisable in different places because it contains structures which have been called 'rain drop lapilli'. These are spherical bodies of tuff about 1 cm in diameter. The centre of these bodies consists of tuff exactly the same as the rock matrix and they have an outer skin of concentric shells of finer material 1 or 2 mm thick. This can be seen north of Eldama Ravine at O36094 by the stream, at O22101 on the north west side of the valley and at 993114 in the roadside by the Chemususu river.

E3, Phonolitic Welded Tuff

This occurs half way down the south side of the Perkerra Gorge below Kokwamanik. It is a hard, fine grained, blue black rock with a few feldspar phenocrysts indistinguishable in hand specimen from plateau-type phonolite. However in the field it grades into unwelded tuff. A small outlier of this tuff outcrops on a spur of Kapkut Trachyte at O91139.

E4, Densely Welded Tuff

The Densely Welded Tuff can be seen on both sides of the Siloi river exposed in the path which crosses the river at the north west end of the Poror Spur. On the north side at O42091 a blue purple welded horizon with very flattened green pumice is 5 ft. thick and grades rapidly over a few inches into unwelded tuff above and below. On the south side the welded horizon is about twice as thick and a sedimentary junction, representing the top of the ash flow is about 20 ft. above the most densely welded part. This welded tuff outcrops west of Eldama Ravine at O05065 and 996034.

E5, Upper Glass Fiamme Welded Tuff

At O60114 near the top of the south east side of the Perkerra Gorge there is a welded tuff which looks exactly the same as E2, outcropping 500 ft. below it. Welded Tuff outcrops with glass fiamme which occur south east of the Perkerra Gorge are assigned to this Upper Glass Fiamme Welded Tuff since they belong in the upper part of the Eldama Ravine Tuff succession. One such outcrop is at O43039 1 mile south east of Eldama Ravine. Here the welded tuff forms a 10 ft. high overhanging outcrop with glass fiamme up to nine inches long and grades down over three feet into creamy pumice tuff. Another outcrop is at 174127 near Matebei. The straight eastern edge of this outcrop has been undercut and its top potted by stream erosion (plate 4) although it now stands above its surroundings. An outcrop of glass fiamme welded tuff west of Murungwa at 958052 is assigned to E5 rather than to E2 because it fits better with the extrapolated form lines of the former



plate 4: Potholing and undercutting of E5 by water erosion.



plate 5: Tumulus on surface of Saos Mugearite flow.

E6, Green Pumice Welded Tuff

When fresh this is a purple gritty welded tuff with green pumices up to 3 inches long but usually about $\frac{1}{2}$ inch showing various stages of collapse. This fresh welded tuff is well exposed in a line of quarries on the top of the east side of the Perkerra Gorge two miles NNE of Eldama Ravine. Further north east along the gorge a pink or grey welded tuff half way down the south east side is believed to be its continuation because it contains flat green pumice enclaves. Outcrops $1\frac{1}{2}$ miles south east of the gorge and on the south side of the Chemususu are assigned to this welded tuff for the same reason.

Murungwa Agglomerate

The Murungwa Agglomerate outcrops at the western foot of Murungwa and is best seen in Sclater's road at 966054. Here a basaltic matrix contains blocks of trachyte, phonolite, welded and unwelded tuff and one of finely graded bedded tuff. There are also cognate clots of basalt with augite and feldspar phenocrysts. The matrix is gritty yellow brown tuff, much altered to clay, with tiny fragments of black glass and phenocrysts of augite and feldspar. Some of the blocks are of welded tuff with black glass fiamme and so come from E5, which outcrops nearby. However no blocks of E7, which also outcrops nearby, were found. The Murungwa Agglomerate therefore probably belongs between these two horizons.

Four isolated outcrops of bedded gritty tuff with augite phenocrysts and sometimes basalt bombs up to $1\frac{1}{2}$ miles to the west are correlated with the Murungwa Agglomerate. These are at the roadside 953063, on the hilltop 941042, in the track 947051 and in the road 945047.

The abundance of blocks in the agglomerate at the foot of Murungwa and their rarity in the outcrops further west suggests that the agglomerate is derived from somewhere on Murungwa but the source cannot be more closely identified.

Theloi Basalt (Lippard 1972)

This is a flow with variable amounts of augite and lesser olivine phenocrysts. It is usually black but sometimes purple, especially in its feeder dyke. Its source can be seen in the sides of the Perkerra valley where it passes round the Poror spur as a dyke about ten feet thick rising at a shallow transgressive angle through the tuffs. On the south side of the river the feeder is seen as it passes into the flow (O39086) but on the north side the connection has been eroded away. It flowed to the south west, was halted by the Kapkut Trachyte mass of Murungwa and continued around its southern flank for another two miles. The south eastern extension of the flow is hidden under later tuffs except at OOOO08 where the base of the flow is exposed and it may be only about ten feet thick, showing that the flow pinches out rapidly to the south east. Two small outliers of the basalt perched on the south east side of the Perkerra Gorge at O50115 and O69126 show that the Theloi Basalt flowed down this gorge. The flow becomes thicker to the west; at Siloi Old Sawmill Site it is about 100 ft. thick while on Murungwa it is about 200 ft. thick. The base of the flow can be seen near Eldama Ravine at O25068 and O21066 where the top foot of the underlying tuff is reddened. Concentrations of boulders of augite phyric basalt occur on the top of the south east side of the Perkerra Gorge in three places, O60113, O65115 and 115146. These are probably derived from erosion of the basalt by the Siloi river.

E7, Blue Fiamme Welded Tuff

E7 is a very inhomogeneous rock with a blue grey matrix containing fiamme up to three inches long of a darker material. At O99104 in the valley just west of the Eldama Ravine - Emining road it emerges out of the east side of the valley as a solid horizon 5 ft. thick with the appearance of a trachyte lava, passing up into 10 feet of agglomerate of boulders up to 1 ft. long. This is probably close to its source. Outcrops extend

onto the high ground of Kapkut and far to the west, the furthest west being by the railway at 905973. In the eastern outcrop the fiamme are large and irregular and there are many lithic fragments, while to the west the fiamme became smaller and flatter and the lithic fragments disappear, showing that the tuff was derived from the east.

E8, Sagat Welded Tuff

This is a blue welded tuff with flattened pumice enclaves seen outcropping just below the mugearite about two miles south of Saos. A reddened horizon comes between it and the overlying mugearite. Its relationship to the other welded tuffs is not apparent.

E9, Abundant Feldspar Welded Tuff

The last of the Eldama Ravine Welded Tuffs is a blue grey welded tuff with small indistinct fiamme which differs from all the other welded tuffs in containing abundant feldspar phenocrysts. This occurs mostly along the top of the Perkerra Gorge and on the low ground to the south east. It also outcrops west of Murungwa at 955050 and at 911020. E9 often contains moulds after pieces of vegetation, especially at 115116 in the roadside near Saos.

E9 lies unconformably on the tuffs below it. This is well illustrated along the Eldama Ravine - Emining road. At 104102, E9 lies on the top of a ridge while E7 outcrops in the stream bed 200 ft. below. Halfway down the hillside a small patch of E9 dips conformably with the hillside. A mile and a half upstream at 094079 and $1\frac{1}{2}$ miles to the west at 080102 E9 rests directly on E7. This shows that E9 flowed from the east, over a scarp and down 200 ft. onto E7.

Over a large area around Saos the surface of the Eldama Ravine Tuff is reddened for the top two feet. This red surface is overlain by Saos Mugearite but at 121124, 1 mile west of Saos, E9 can be seen to overlie it. The reddening of the surface of the Eldama Ravine Tuff thus occurred before the deposition of the last welded tuff.

Upper Basalt

Boulders of basalt occurring in a few places west of Murungwa, marked B on the map, are remnants of a basalt flow at the top of the Eldama Ravine Tuffs. As can be seen at 948055 and 955058, these boulders overlie E7 and so are distinguishable from the Theloi Basalt which underlies it. These boulders are sparsely porphyritic with feldspar, olivine and augite. Three outcrops of basalt 4 miles west of Maji Mazuri, one of which overlies E7, one outcrop 1 mile south of Maji Mazuri and one at Makutano (956930) probably belong in the Upper Basalt, though not all being one flow.

A basalt flow is exposed in two places in stream beds a mile south of Saos. In both exposures quartz infills vesicles. As it is immediately overlain by Saos mugearite it is placed at the top of the Eldama Ravine Tuff.

Agglomerates

Lithic fragments up to one inch long are common in the tuffs but agglomerates are uncommon. An example is at O46100 in Poror where a tuff matrix has abundant pumices about one inch long, fragments of lava up to six inches long and a few fragments of glass. Agglomerates are found more commonly in the east than in the west. The fragments in the agglomerates are trachyte, phonolite and glass. Syenite was not found in situ in the Eldama Ravine Tuff although coarsely mottled trachyte was found in situ and a syenite boulder lay on its surface at 117123.

Air Fall Tuffs

Air falls tuffs are subordinate in the Eldama Ravine Tuff and are only found in the stream beds around Saos. They are tuffs bedded on a scale of a few inches containing variable amounts of pumice. They can be seen two miles west of Saos at O99110 where they unconformably overlie E7. Horizons of agglomerate can be seen in the bedded tuffs $\frac{1}{2}$ mile north of

Saos along the stream. These air fall tuffs probably represent the waning stages of the Eldama Ravine Tuffs, since they are found only at the top of the succession.

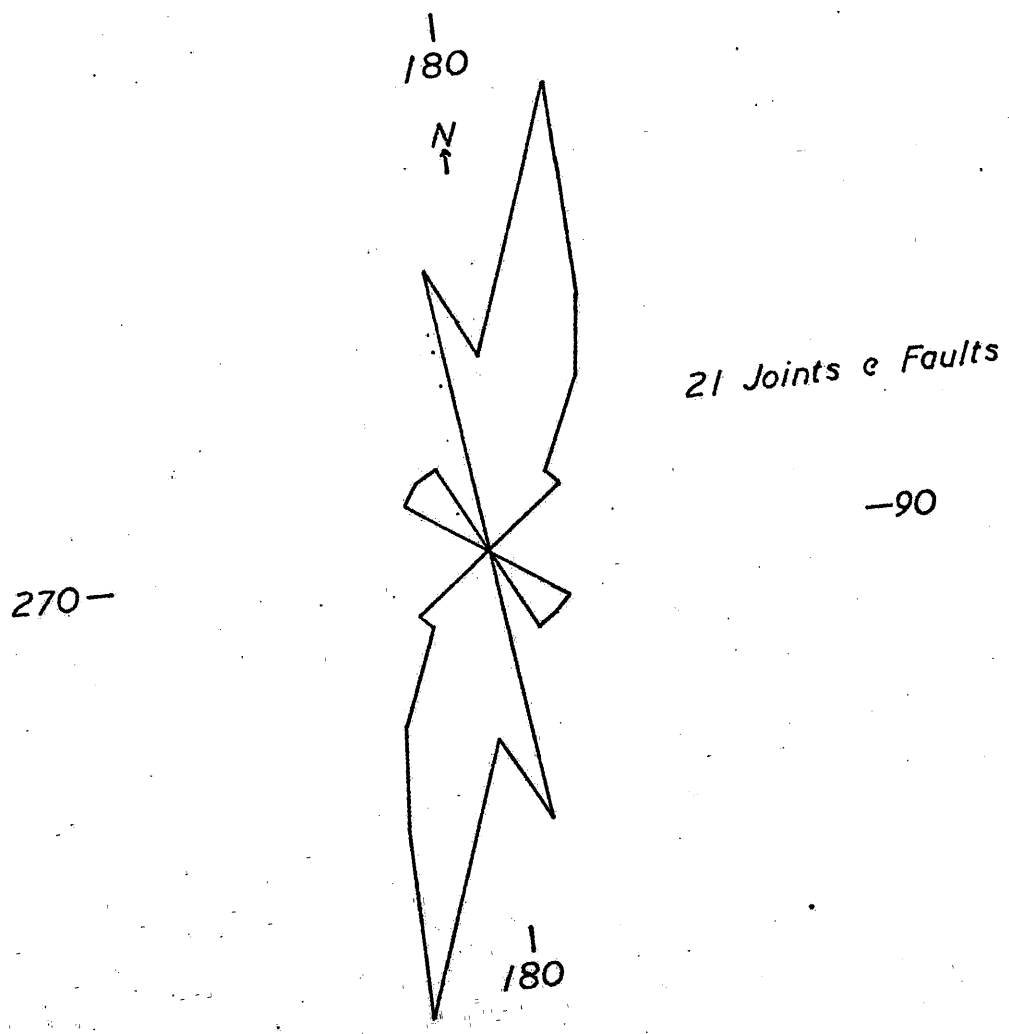
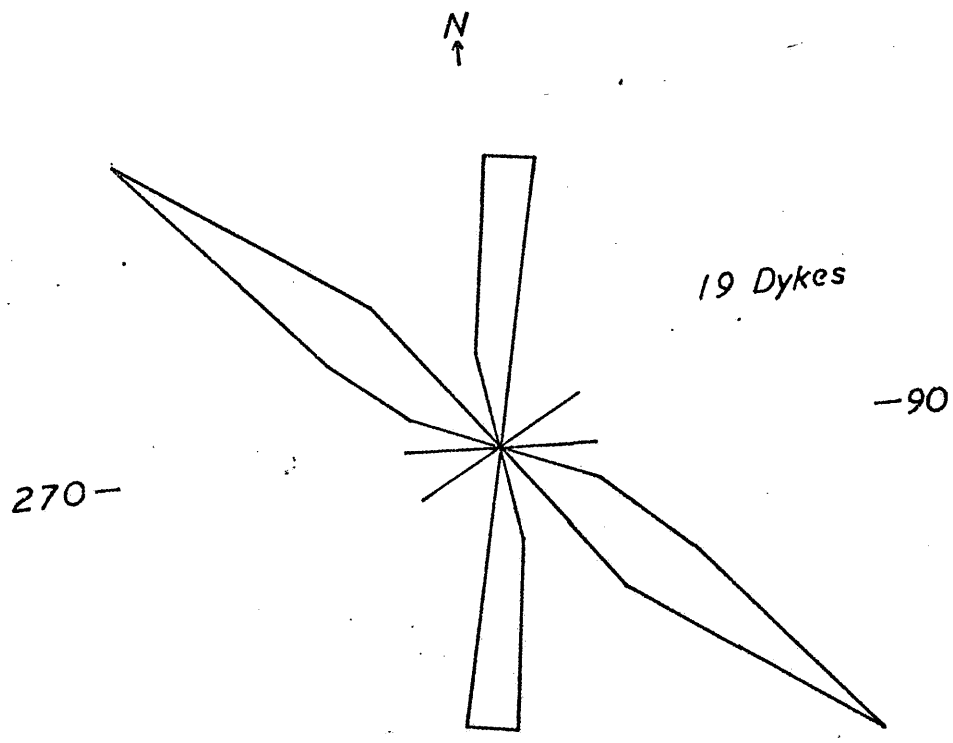
Tuff Dykes

In the eastern part of the Eldama Ravine Tuff outcrop, and especially in the stream sections $\frac{1}{2}$ mile and 1 mile south of Saos, tuff dykes occur cutting the tuffs. They are usually a few inches wide, the greatest width seen being 2 ft. The trends of 19 of these were measured and are shown in the rose diagram fig. 7. The distribution is bimodal, the dominant directions being 010° and 135° . They dip nearly vertically, two measured dips being 70°SW and 80°E . One dyke seen in vertical section dips vertically at the top but curves to dip at 50° at the bottom.

At 094111, 3 miles west of Saos a composite tuff dyke is well exposed. It is 6 ins. wide, sinuous and with angles where it crosses joints in the host rock. The two sides of the dyke are a perfect fit, showing that intrusion was as a result of extension at right angles to the length of the dyke. It can be followed for 50 ft. on a general trend of 180° , the thickness remaining fairly constant. It has a fine grained first stage and a coarser second stage, usually down the middle but sometimes winding through the first stage. At one end of the exposure a vertical section shows that the dyke dips steeply to the east and is sinuous vertically as well as horizontally. Near this end the two phases separate as two smaller dykes 2 ft. apart.

Another possible composite dyke is at 131129 $\frac{1}{2}$ mile north of Saos. It is $1\frac{1}{2}$ ft. wide consisting mostly of massive pumice tuff the same as the adjacent country rock and has margins of finer pumice tuff 2-3 ins. wide. The whole dyke forms an upstanding feature but it is possible that the central part is a screen of country rock protected between two thin dykes.

Figure 7. Rose Diagrams of Dykes and Faults in the Eldama Ravine Tuff



These dykes are probably feeders for the late ash fall tuffs. None of them show welding and they may have no relationship to the sources of the ash flow tuffs.

Age of the Eldama Ravine Tuff

The lithological and stratigraphic similarity between the Eldama Ravine Tuff and the Mau Tuff, they both overlying the Makutano Tuff and underlying the Londiani Trachyte, suggests that they may be different areas of the same formation. In particular the Mau Tuff M3 and the Eldama Ravine Tuff E9, which show a striking resemblance, even to them both containing moulds after plant material, may be the same ash flow. However, the K/Ar dating evidence shows that this is not so. A specimen of E4, 14/125, gave a date of 4.3 ± 0.1 m.y. and a specimen of E3, 14/570, also gave a date of 4.3 ± 0.1 m.y. whereas dates of 5.8 ± 0.2 m.y. and 6.0 ± 0.2 m.y. were obtained from the Mau Tuff.

Trachyphonolites

These are rocks outcropping in the east, intermediate in appearance between trachyte and the older phonolites in the west. Trachyphonolite flows cover most of the floor of the rift valley north east of the present area. The oldest of these are along the western margin, going back to about 4 m.y., while in the east by Lake Hannington they are less than 1 m.y. old (P.S. Griffiths pers. comm.). The younger part of these trachyphonolites is called the Lake Hannington Trachyphonolite (P.S. Griffiths, Ph.D. in prep.).

In the present area trachyphonolite outcrops in three areas, all probably belonging to the older part of the trachyphonolite sequence.

Emining Trachyphonolite

In the north a convenient eastern boundary to the area is provided by the edge of the outcrop of the trachyphonolites which cover the floor of the rift valley to the east. The edge of the trachyphonolite outcrop is a line running north-south from just east of Matebei. East of this line the country consists of low undulating hills. The trachyphonolite is

feldsparphyric and is similar to the Londiani Trachyte but often finer grained. The most westerly outcrop of this unit is probably in the stream-bed just south east of Kiborit Hill (154072) where very rotten trachytic rock is exposed. South east of this three inliers of trachytic rock projecting through the Saos Mugearite are assigned to the Emining Trachyphonolite.

The Emining Trachyphonolite underlies the Saos Mugearite but its relationship to the Eldama Ravine Tuff is not seen in the field. However the trachyphonolite certainly overlies the tuff since the tuff is very thick and is not seen anywhere above the trachyphonolite.

Kilelwa Hill Trachyphonolite

Kilelwa Hill, north east of Kilombe and just south of the equator, consists of trachyphonolite with common feldspar phenocrysts. There are two flows; one, about 100 ft. thick and less porphyritic, oversteps the other from the east. Since it stands above its surroundings Kilelwa Hill is probably an eruptive centre.

Rongai Plain Trachyphonolite

Trachyphonolite forms a low ridge running NW-SE for two miles on the south east side of Kilombe. It is a fairly fine grained blue grey rock with a few feldspar phenocrysts. Although so close to Kilombe it is probably not derived from that centre as it does not have a substantial dip away from it, and what little eastward dip it has is due to later tilting. A specimen of this trachyphonolite gave a date of $1.7 \pm .05$ m.y. (14/369). It is not possible to tell if it passes under the Kilombe Trachyte.

Saos Mugearite

This is a series of flows intermediate in appearance between basalt and trachyte. The earlier flows, exposed in the northern part of the outcrop, are hawaiites which when fresh are difficult to distinguish from basalt while the later flows are mugearites distinguishable only with difficulty from the overlying trachytes. However the Saos Mugearite has

two characteristic weathered forms by which it may be recognised. One is a pale blue rock in which abundant tiny white feldspar crystals are clearly visible; the other, less common, is a mottled orange brown rock. The flows vary from being aphyric to being abundantly porphyritic with platy feldspar phenocrysts. They also sometimes contain square white decayed feldspar phenocrysts up to 1 cm. long.

The internal structure of the flows is sometimes well displayed, as in the streambed 1 mile south of Saos. Here a flow shows columnar jointing, the columns being about 2 ft. in diameter. Five sided columns are the commonest, followed by six sided columns. It has a well developed horizontal fissility, breaking into slabs an inch thick. Further down this streambed, at 138105, a flow can be seen to overlie Eldama Ravine Tuff and here columnar jointed lava lies directly on the tuff in some places while in others up to six feet of scoriaceous vesicular lava intervenes. This intermittent basal scoriaceous layer is characteristic of aa flows (Macdonald 1972). In the streambed about two miles west of Matebei a series of three or four flows can be seen dipping gently eastwards. They are about forty feet thick and in one place there is five feet of yellow tuff between two flows.

At 175980 just south of the equator an inlier of mugearite is surrounded by hills of trachyte which have protected the surface of the mugearite. It is highly vesicular with spherical vesicles. A small tumulus 5 ft. by 4 ft. by 1 ft. high (plate 5) and a cylindrical block with parallel grooves on its surface were seen. These are all characteristic of pahoehoe flows (Macdonald 1972). The Saos Mugearite thus contains flows of both aa and pahoehoe types.

The Saos Mugearite generally thickens southward and passes under the Londiani and Kilombe Trachytes. The exposure at 175980 mentioned above is the most southerly outcrop of the Saos Mugearite. However fragments of mugearite occur in the early tuff in Kilombe Gorge showing that mugearite

underlies the trachyte in the area of the caldera. The Saos Mugearite probably represents the early stages of eruption of Londiani and Kilombe and for the most part flowed northwards.

$2\frac{1}{2}$ miles west of Saos mugearite forms a hill on the north west side of a valley in the underlying tuffs. At the northwest end of the hill the mugearite is 50 ft. thick and at the south east end is about 200 ft. thick. This is probably a remnant of a mugearite flow which ponded in a valley in the Eldama Ravine Tuff. The valley has now been reexcavated. This shows that there is in places a slight unconformity between the Eldama Ravine Tuff and the Saos Mugearite and that the surface of the Eldama Ravine Tuff during the eruption of the Saos Mugearite was, at least in places, much the same as now.

Two small outliers of Saos Mugearite at O51140 and O52136 on the sides of the valley at Sigoro show that the Saos Mugearite penetrated along the Perkerra Gorge and its side valleys but only in these two small outcrops has it been preserved.

Sources of Saos Mugearite were identified in two places. Sagat Hill, north west of Kiborit, is a spine of mugearite trending NNW-SSE about 200 ft. high. This is clearly a fissure vent of the mugearite. At 174044, three miles north east of Esageri, a hill of mugearite has a circular depression about 100 yards wide on its flat top. This depression may be a small crater on the site of an eruptive vent.

Trachytes

Included here are the two caldera volcanoes Londiani and Kilombe and the two domes Matebei and Kiborit. K/Ar dates of 3.6 ± 0.1 m.y. for Matebei (14/576), 3.1 ± 0.1 m.y. for Londiani (14/769) and 1.9 ± 0.05 for Kilombe (14/1) were obtained. The Londiani Trachyte covers an area of about 400 km^2 and has a volume of about 60 km^3 . The comparable figures for the Kilombe Trachyte are 80 km^2 and 15 km^3 .

On these trachytes the amount of exposure varies with altitude. On the higher slopes of Londiani, above 8000 ft., there is almost no exposure because of a thick soil cover and extensive forest. Only on the eastern side of Londiani Mountain is there fairly good exposure. Kilombe, being on lower ground, is better exposed than Londiani; so it has been possible to map Kilombe in much greater detail. The trachyte has been eroded to the extent that it is not possible to infer flow boundaries directly from air photographs. However the trachyte varies much in megascopic characteristics and variation between flows is usually greater than variation within flows. Thus flow boundaries can be found on the ground on the basis of lithological differences and often a corresponding feature can be made out on the air photographs. In this way about half of the lower, better exposed part of the trachyte can be divided into its component flows with moderate confidence. On Londiani the flows cannot be followed on the air photographs onto the higher ground because here erosion has cut steep sided valleys and all trace of the original flow boundaries is lost.

The trachyte is usually massive, dark blue green and fairly hard. On the weathering which tends to originate along distinct planes of fissility, it goes to a pale blue green softer rock. In outcrop the fresh dark blue and the paler blue green rock are about equally common. The junction between fresh and weathered rock is usually quite sharp, grading over about $\frac{1}{2}$ cm. Rarely the weathered rock may be red or brown.

The lavas vary in the field in the grain size of the groundmass, in the nature of the phenocrysts and in the nature of the xenoliths. Normally the rock is coarse to the touch but with the individual grains not visible. It can vary from being fine grained and grading into glass to being so coarse grained that the individual plates of feldspar in the groundmass are just visible to the naked eye.

Two kinds of phenocrysts are visible in hand specimen, alkali feldspar and 'hydrobiotite'. The feldspar phenocrysts vary in size from a few mm to 2 cm and in abundance from being completely absent to forming perhaps 30% of the volume of the rock. There is a tendency for size and abundance of the feldspar phenocrysts to vary sympathetically. The feldspar phenocrysts divide into two kinds; small euhedral clear plates, seen in thin section to be sanidine, and larger stubby rounded powdery white crystals which thin sections show to be anorthoclase. In the field the largest sanidines seen are about 1 cm long while the smallest anorthoclases are about $\frac{1}{2}$ cm long. Occasionally the white anorthoclases have clear rims. A few flows have both types of feldspar phenocrysts, e.g. L3, the sanidines being dominant.

The 'hydrobiotite' forms needles up to $\frac{1}{2}$ cm. long. In hand specimen they are sometimes red and glassy with good outlines suggestive of pyroxene and sometimes they are orange and powdery. Phenocrysts can be found with red glassy centres and orange powdery rims while others can be found with orange powdery centres and red glassy rims. These 'hydrobiotites' are smaller and rarer than the feldspars and vary in abundance with them.

Xenoliths are of three kinds. Angular lumps of trachyte, usually very rotten, are sometimes very common. These may be in part autobrecciated fragments of flow tops. Syenite occurs in some of the later flows. A few flows contain xenoliths of very porphyritic mugearite, which are also seen in the Kapkut Trachyte.

On Londiani and Kilombe the flows which can be made out can usually be related to adjacent flows but it is not possible to correlate all over the volcanoes. The numbering of the flows is therefore intended to have no stratigraphic significance and is simply the order in which they are met in traversing clockwise around each volcano starting in the north.

Descriptions of individual flows are given in Table 2 .

A) Londiani Trachyte

Early Tuffs

Tuffs with intercalated fine grained flows can be seen underlying the lavas in the gorge where the Visoi stream comes out of the caldera (O89983) and in a steep sided valley about a mile and a half south of these (O98876), the latter being the better exposure. On the south side at the head of this valley is a cliff in which fine grained bedded tuff dipping eastward is conformably overlain by a 50 ft. thick agglomerate of lumps of fine grained vesicular trachyte up to 2 ft. long, in turn overlain by a fine grained trachyte flow. On the north side of this valley a 30 ft. thick trachyte flow can be seen to have flowed down a valley cut in the tuff. Lower down the valley the tuff is usually massive and contains blocks of trachyte exceptionally up to 15 ft. long. Tuff with trachyte boulders also outcrops on the inward facing wall of the caldera adjacent to the head of the valley.

In the Visoi stream's gorge just below a waterfall close to the ring fault (O89983) tuff with trachyte boulders up to 2 ft. long is exposed. The maximum thickness of tuff seen is 20 ft. and the junction with the overlying trachyte flow dips to the east at about 20° .

These tuffs are seen only where erosion has cut deep into the flank of the volcano in the vicinity of the caldera. Locally they underlie the lavas but it is not possible to tell whether they are older or younger than the flows which outcrop away from the caldera. The base of the tuffs was not seen but the large number of trachyte blocks they contain shows that they are underlain by trachyte lavas. The possibility that these trachyte blocks are derived from an older horizon equivalent to the Kapkut Trachyte can be discounted because they are not accompanied by blocks of welded tuff equivalent to the Eldama Ravine and Mau Tuffs which would almost certainly overlie them underneath Londiani. So although the tuffs are the earliest activity now exposed in the area of the caldera, they were preceded by lavas and their relationship to the lavas farther out on the flanks of the volcano is unknown.

The Lavas

Of the flows of Londiani Trachyte none can be traced back to the edge of the caldera. Those flows whose sources can be tentatively identified began lower down the mountain. However it is reasonable to suppose that more flows originated on the higher ground where the lava pile is thicker than on the lower slopes.

The flows on the east facing slope south east of the caldera came from the west as their flow edges are aligned approximately east-west. The hill O96086 seems to be the source of L13 while L11 is a short flow only $\frac{1}{2}$ mile long which erupted onto the east facing slope. On the high ground above the southern end of this slope there is a graben trending north west - south east with throws of up to 100 ft. This is the source of L13 and L14.

On the north east side of the mountain L6 has its source low down the mountain side on the hill O83940. L4, which can be traced in all its outcrop, erupted on the low ground, its source being represented by a steep sided hillock on its surface 50 ft. high at O97002. L1 has been cut in two by stream erosion.

A small dome of trachyte at O97943, L7, has a well bedded agglomerate dipping off it which is well seen by the railway at O98942 (plate 6). It may be a crumble breccia formed as the dome grew, although crumble breccias are not known to be well bedded (Macdonald 1972 p 111).

On the west side of the mountain L16 and L17 have flowed a long way onto the Londiani Plain, their flow fronts forming scarps up to 300 ft. high as just north east of Londiani town. They are very similar in texture and may be two lobes of the same flow. The Molo-Makutano road runs just west of a break of slope and these two flows extend back at least as far as this. Assuming that they have an average thickness of 150 ft. then these two flows combined have a minimum volume of about $2\frac{1}{2}$ km³. The steep sided hills at O26820 and O25826 are domes of trachyte rising about 400 ft. and 200 ft. respectively above their surroundings.



plate 6: Bedded agglomeratic tuff dipping off trachyte dome L7.

In the north the trachytes have been strongly eroded so that there is a mass of trachyte west of Esageri which has been separated from its source by the downcutting of the Esageri river. North of Kabimoi trachyte outcrops along a river valley but not on the higher ground to the south east. This trachyte flow probably flowed down a preexisting valley cut in the Saos Mugarite.

The farthest travelled flow, L18, forms a series of outliers along the top of the east side of the Perkerra gorge, at least as far as Kokwamanik, a distance of about ten miles from the most southerly point at which it is distinguishable.

Flow tops are often strongly vesicular with vesicles uniformly spheroidal and about $\frac{1}{2}$ cm in diameter, e.g. on the ridge on which Eldama Ravine stands where the vesicles contain a waxy green material.

Some exposures on the west side of Londiani Mountain show autoliths, that is cognate fragments of lava embedded in the lava. These may be seen at 980872, 984878 and at 026846. They appear to be concentrated in the tops and bottoms of flows and form up to 80% of the rock in the last outcrop. The autoliths are probably fragments of the solidified top and bottom of the flow broken up and carried along by the still moving lava. They are most distinctly visible in weathered exposures.

Late Tuffs and Syenite Bombs

Syenite boulders are found on Londiani, especially on the scarp on the south east side on the flows L10 and L12. Here in an area about a mile across the syenites occur with abundant boulders of various types of trachytes. A small outcrop at 096845 shows tuff containing these. The flow L11 does not show any boulders on its surface showing that the trachyte and syenite boulders were emplaced in a thin sheet of tuff onto the surface of L10 and L12 before the eruption of L11. Erosion has since removed the tuff matrix except in sheltered spots and only the boulders remain.

The road cutting 980854 on the western side of the mountain shows bedded pumice tuffs with agglomeratic horizons. At 035808 on the south west side of the mountain there is an exposure of yellow brown pumice tuff. These two tuff outcrops are probably derived from Londiani and are the only tuff outcrops assignable to the late stages of the volcano. However the thick red soil cover of the higher ground may in part be derived from an easily weathered mantle of tuff.

At the summit there are no outcrops but in the track by the radio station there are lumps of various unidentifiable welded and unwelded tuffs and trachyte. One piece of micaceous quartzite was found but this was probably brought from elsewhere - it is ideal for sharpening pangas.

Sediments of the Caldera

The caldera is completely inaccessible except at its eastern end where the Visoi stream comes out and only here can the sediments which infill the caldera be examined. At the point where the Visoi stream leaves the caldera, 088892, the rocks on the west of the stream are finely laminated tuffs dipping eastwards overlying a very inhomogenous tuff with abundant boulders of trachyte with interstitial clay. In the valley north of there (085899) there are tuffs which are sometimes yellow and sometimes shaley grey and cream tuffs with graded bedded units 1 mm - 10 cm thick. (plate 7)

Within the caldera the interfluves are flat topped and together form a surface dipping to the east. From the air outcrops of pale coloured tuffs can be seen along the valleys and it is clear that the caldera was infilled by fine grained tuff, the flat tops of the interfluves being the remnants of the original top surface of the infill. Around the edge the tuffs are interbedded with agglomerates of boulders fallen from the caldera wall as in the outcrop at 088892 described above. (plate 8)



plate 7: The Visoi gorge seen from the outside



plate 8: Aerial view of the Visoi gorge inside Londiani caldera.
The northern part of Kilombe is visible in the distance.

B) Kilombe Trachyte

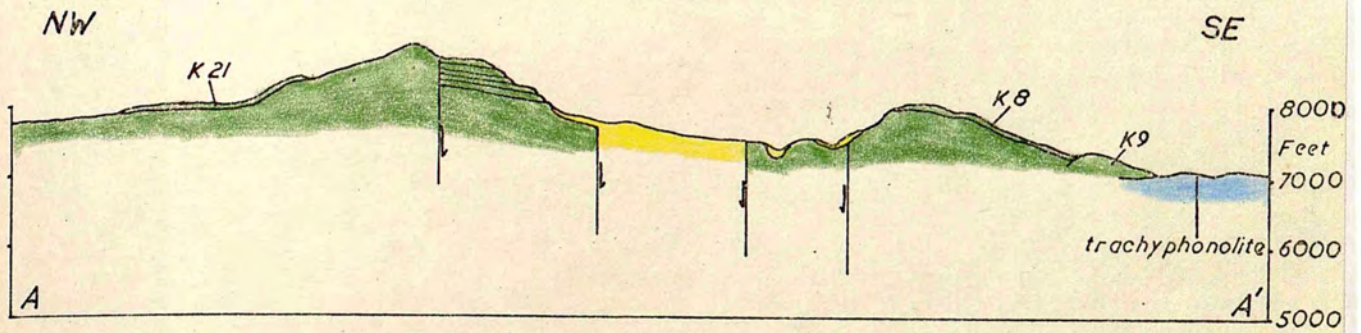
The Caldera Area (plate 9)

Early pyroclastic activity at Kilombe is seen where the stream that leaves the caldera has cut a gorge on the eastern side. Pumice tuff outcrops for 200-300 yards along the bottom of the gorge underlying the trachyte flows, the maximum thickness seen being about 100 ft. (fig. 8). The tuff contains angular blocks of mugearite up to 1 ft. long. The dip decreases outward from 40° at the inner end of its exposure where it is cut out by the ring fault to near horizontal at its outer end. There is one thin fine grained trachyte flow within it. The lava fragments in the tuff seem to be all mugearite showing that the tuff rests directly on the Saos Mugearite. However, as with the early tuffs of Londiani there is no knowing whether the tuff is earlier than lava flows elsewhere on the volcano.

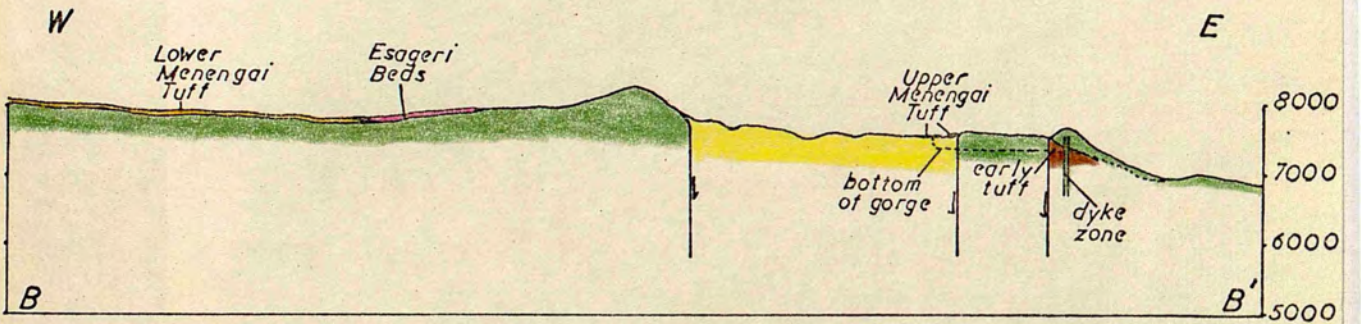
In the gorge four flows overlies the tuff. They are all medium grained with few or no small feldspar phenocrysts. Along the hillside north from the gorge several flows dip downhill at an angle slightly less than the slope of the ground so that three or four flows are exposed on the hillside, their distal ends having been removed by erosion. On the north west wall of the caldera four flows can be made out on the air photographs. They appear from their outcrop pattern to dip in towards the caldera (plate 10). This is also suggested by the fact that if they do dip inwards they would have thicknesses similar to the other early flows while if they dip outwards they would be abnormally thick. These early flows with few small feldspar phenocrysts are fairly uniformly about 40 ft. thick and wherever a section through them can be seen it is notable that the concentration of phenocrysts increases upwards through a pile of flows.

Pyroclastic activity continued during the time of eruption of the lavas. On the outer slope just north of the gorge an exposure shows 4 ft. of tuff between two flows. In a valley on the south east side of the mountain at 175901 a poorly exposed tuff contains large boulders of fine grained trachyte.

Figure 8. Sections across Kilombe



1 Km
1 Mile



trachyte

tuffs and sediments infilling caldera



plate 9: Aerial view of Kilombe from the south west.
The south east edge of Londiani is in the
foreground.



plate 10: Kilombe caldera seen from the firetower on the south west rim.

In the gorge just east of the outer ring fracture is a zone 150 ft. wide with several north south trending trachyte dykes, often multiple, which cut nearly vertically through the tuff and disappear where they meet the overlying flows. These dykes are clearly the feeders for the lavas along the gorge.

On the south east rim of the caldera and on the south east flanks there is a flow, K8, containing large anorthoclase phenocrysts up to 2 cm long (plate 11). These vary greatly in abundance from being absent to forming 30% of the rock. This was followed by only one more flow, K10, before the formation of the caldera.

Between the inner and outer ring fractures the trachyte exposed in the gorge is approximately horizontal. The flows on the flank on the north east side of the caldera are turning over to become horizontal at the top of their outcrop where they are cut out by the ring fracture. These observations, together with the suggestion that the flows in the north west caldera wall are dipping inwards, show that before the formation of the caldera the area inside the ring fault was approximately flat and not conical. The lavas were erupted not from the centre of the hill but from the edges such as the dyke zone seen in the gorge and possibly also from sites within the area of the present caldera.

In the south of the caldera is a hill which slopes gently in towards the centre. At the base of the hill are cliffs composed of trachyte with abundant feldspar phenocrysts 5 mm long, flow K12. On the slope above the cliffs is exposed yellow brown granular tuff with the same phenocrysts. This occurs also as thin patches on the southern slopes of the mountain. At the rim of the caldera, overlying K8, is an area 100 yards across with a thin layer of this tuff containing lumps of lava the same as K12. This represents an eruption which extruded a lava flow onto the floor of the caldera, probably from a source along the ring fault, and ended with a phase of tuff eruption.



plate 11: A block of the trachyte flow K8, showing large anorthoclase phenocrysts.



plate 12: An outcrop of K13 showing abundant xenoliths including syenite (S) and mugearite (M).

K13, the last flow to be extruded from the Kilombe caldera area, was abnormally fluid. It overlies K12 inside the caldera and most of the south west slope of the mountain outside; so it was erupted along the ring fault and flowed both inwards and outwards. Along the caldera rim it forms a crag where it is only 15 ft. thick. It contains abundant xenoliths of rotten trachyte; many of syenite up to 1 ft. long, the smaller ones angular; some of a glassy green rock and some of coarsely porphyritic mugearite up to 2 ins. long (plate 12). The ground mass is fine grained trachyte with fairly common feldspar phenocrysts 3 mm long and a few white feldspar phenocrysts 1 cm long which may be xenoliths from the mugearite.

The Northern Rift Zone

North of the caldera a ridge runs north as far as the road, a distance of five miles. Many flows originated along this ridge, including K21, K23, K2, K3, K4 and the smallest flow identified K5, which is only 100 yards across. K21 began on the hill 155949 and flowed 4 miles to the north west. It contains abundant feldspar phenocrysts which vary in average length from 3 mm to 1 cm in different parts of the flow. The eastward tilting of the volcano since its formation has caused the edge of K21 on the hill 135946 to be higher than the ground to the east from which it flowed.

The top of this ridge is downfaulted to form a graben. K2, a flow with abundant 5 mm long feldspar phenocrysts, is confined to the top of the ridge and so it erupted after the formation of the graben. This is analogous to K12 which was erupted into the caldera.

On the low ground between Kilombe and Londiani there is a flow, K17, which contains xenoliths of vesicular purple fine grained mugearitic rock with abundant feldspar phenocrysts up to 5 cm long. The xenoliths also contain the same small red hydrobiotite needles as are to be found in the

trachyte. The size and abundance of the xenoliths varies greatly in different parts of the flow, being greatest in the stream by the railway 119909 where they reach 1 ft. long (plate 13). This flow is approximately horizontal which shows that it came from the direction of Kilombe since this area has been subsequently tilted down to the east. There is another flow on the south east side of Kilombe, K6, which also contains a few small xenoliths of this mugearite and may have erupted at the same time. Apart from these two the only other flow containing mugearite xenoliths is the last one, K13.

Syenite Bombs

Syenite was erupted only after the formation of the caldera. A few small syenite xenoliths occur in K12 and larger ones are common in K13. Large boulders were ejected after the last flow and occur all around the rim of the caldera and as far away as the hill 155949, 1 mile from the caldera. They are largest and most abundant on the southern flank of the volcano, where in one place there are four boulders, each about 5 ft. long, lying next to each other and obviously once all part of one very large boulder (plates 14 & 15). Syenite bombs also occur in the tuffs within the caldera at its eastern end.

The Caldera Sediments

At the eastern end of the caldera, between the inner and outer ring faults, sediments occur in a north east - south west valley cut in the trachyte (171919). These are mostly tuffs, usually fine grained and sometimes with blocks of trachyte up to 1 ft. long, with subordinate horizons of agglomerate and fine grained graded bedded sediment. High on the south east side of the valley is a cliff exposure of creamy yellow tuff containing angular lumps of trachyte up to 1 ft. long and syenite up to 6 ins. long dipping at $5-10^{\circ}$ towards the centre of the caldera. This is where the greatest variety of



plate 13: One of the coarsely porphyritic mugearite xenoliths from K17



plate 14: A group of Syenite blocks on the south flank of Kilombe.



plate 15: A close up of one of the Syenite blocks in plate 14.

syenite types is found. Below this outcrop and about 20 yards from the end of the spur 172919 another cliff exposure shows tongues of pumice tuff intruding up into horizontally laminated pale grey tuff and only slightly disturbing the lamination. This is due to slumping and is strong evidence that the tuffs were laid down in water. Lower down the valley in the path there is a horizon of diatomite 1 ft. thick and a brecciated trachyte flow 7 ft. thick within the tuffs.


The sediments in this valley are continuous with tuffs lining the bottom of the gorge between the inner and outer faults while the trachyte is exposed along the top of the gorge. The tuffs cannot have been laid down in the gorge in its present form as they would have been washed out. It must be that there was a valley along the line of the present gorge before the formation of the caldera, and the NE-SW side valley was a tributary of it. After the formation of the caldera the part of the valley between the two faults was an embayment of the caldera lake.

Inside the inner fault about 250 ft. of tuff is exposed. The lowest part of this succession is seen in the 80 ft. waterfall at the western end of the gorge (167923) (plate 16). Here the lower 30 ft. is finely bedded yellow grey tuff with a slight dip to the east. The upper 50 ft. is more massive pumice tuff. The higher part of the succession is exposed on the hills on the caldera floor and consists of well bedded pumice tuff, some horizons consisting entirely of pumice and others of apumiceous tuff. There is much interstitial clay in the pumice rich horizons and some horizons a few inches thick consist entirely of clay. These clay rich pumice tuffs can be seen to overlie the sediments in the NE-SW valley at 168915. The clay may have formed by the alteration of the finer part of the tuffs in a lake.



plate 16: Finely bedded tuff exposed at the waterfall
at the inner end of the Kilombe gorge.



plate 17: Matebei,  from the south west.
To the right is Gobat and to the left Sorte.

The sediments of the eastern end of the caldera were clearly derived from Kilombe itself because of the fragments of trachyte and syenite and the trachyte flow they contain. A tuff dyke 9 ins. wide was seen on the south side of the gorge just inside the outer fault. However the source of the tuffs in the centre of the caldera is not clear. They appear to have been deposited periodically in a lake so they postdate the main activity of Kilombe and probably belong to the lower Menengai Tuff.

C) Minor Trachyte Centres

Matebei

This is a hill 3 miles south west of Emining (plate 17). It is steep sided, about 200 ft. high, half a mile across and with a fairly flat top. A ridge along the eastern side of the top of the hill is continued to the north as a spur for a few hundred yards. A similar smaller ridge runs along the west of the top of the hill. Matebei consists of trachyte without phenocrysts but with visible ground mass feldspar laths. There is jointing perpendicular to the surface of the hill and parallel to its edge. At the north west end of the hill a near vertical outcrop of tuff has trachyte outcropping continuously around it from top to bottom. This may be a block of the underlying Eldama Ravine Tuff rafted up by the trachyte. Below it a ledge of trachyte 10 ft. high extends outwards a few yards. This ledge continues around the western side of the hill, being at its widest, about 200 yds, on the south west side. It does not continue around the south side. Matebei was probably formed by extrusion of viscous trachyte from two parallel north south fissures represented now by the two ridges on the top of the hill, a less viscous batch of magma flowing outwards a short way to form the skirting ledge.

Kiborit

Kiborit is a dome shaped hill 4 miles north of Esageri. It stands on Saos Mugearite which dips to the east and is 300 ft. high above its eastern base. It is made of aphyric trachyte which shows an approximately horizontal fissility on both the top and flanks of the hill. This is a dome of trachyte formed by eruption probably from a single source at the centre. North of the hill a trachyte flow originating from a fissure at Sagat from which a mugearite flow had issued previously, banked against Kiborit. This flow shows a horizontal fissility except on Sagat where it is parallel to the hillside. This fissility parallel to the direction of flow is probably due to laminar flow in the lava.

Londiani Plain Basanite

On the Londiani Plain there is an extensive basanite field and some hills of basanite which overlie Mau Tuff. In the west basanite from the hill Limutet and from some hills $1\frac{1}{2}$ miles north west of it flowed to the south east for about 9 miles. This appears to be one single flow with olivine and augite phenocrysts. At 867868 a giant feldspar phenocryst 5 cm. across was seen. Limutet is a conical hill 350 ft. high, slightly elongated in a WNW-ESE direction showing no outcrops but having basalt boulders on its surface (plate 18). A line of rugged ground with basalt boulders for $\frac{2}{3}$ mile from Limutet WNW as far as the hill 799881 is probably the site of an eruptive fissure.

$2\frac{1}{2}$ miles north of Londiani town is the hill Lessotet. This consists of basanite with olivine, augite and a few feldspar phenocrysts together with basic scoria and gritty yellow basic tuff containing some lumps of trachyte. It is 250 ft. high and $\frac{1}{2}$ mile long elongated north east - south west with a small subsidiary hill at its south west end. At 884867 on its north east side there is a crag of columnar jointed basanite. A mile east



plate 18: Limutet from the north west. Fissure zone in the foreground.



plate 19: Pumice of the Lower Menengai Tuff overlying a soil horizon on the north west slope of Menengai.

of Lessotet there is a similar basanite hill. Their limited extent and great height would not have been formed by fluid basic lava and they must consist mostly of basaltic cinder and spatter.

A date of 5.4 ± 0.2 m.y. was obtained from a specimen from Limutet, 14/903. This date, although consistent with the stratigraphy, the underlying Mau Tuff being about 6 m.y., is probably too old. The basanite hills are too well preserved to be more than 1 or 2 m.y. old.

Menengai Assemblage

The Menengai Assemblage consists predominantly of rocks derived from the volcano Menengai which lies just outside the area to the south east, including the Menengai Trachyte, the Lower Menengai Tuff and the Upper Menengai Tuff, of which the most important in this area is the Lower Menengai Tuff. Also included are the Esageri Beds, which lie along the foot of the high ground at the edge of the floor of the rift valley, and two small tuff units of only local significance.

Menengai Trachyte (McCall 1957)

Sparsely porphyritic microvesicular trachyte from Menengai is exposed around McCall's Sidings. The hill by the station is the beginning of a ridge which runs to the east, the southern side of which is probably a fault scarp. Trachyte outcrops occasionally over the low ground for two miles to the WNW of the station as far as an east facing ridge in which it is exposed.

A piece of Menengai Trachyte taken from a fallen block at the foot of the wall on the south side of the caldera gave a date of $0.33 \pm .01$ m.y. However K/Ar dates this young are not accurate and this date can only be taken to show that the Menengai Trachyte is less than 1 m.y. old.

Lower Menengai Tuff

Tuffs from Menengai cover much of the south east part of this area. They can be divided into two separate sequences, the Lower and Upper, divided by a considerable time gap.

The Lower Menengai Tuff begins with a great thickness of pumice near the Menengai caldera which passes laterally into waterlain reworked tuff farther away. This is followed by a massive unwelded ash flow tuff. Finally there is bedded pumice tuff found in Kilombe caldera, probably in Londiani caldera and on the low ground between them. On going south east towards the caldera progressively younger parts of the sequence are exposed. The distribution of the Lower Menengai Tuff is shown in fig. 9.

West side of Menengai Caldera

Pumice is exposed on the western wall of Menengai caldera. Usually it overlies trachyte but in the north west corner the whole height of the wall is pumice. A track running down into the caldera at 685755 exposes near the bottom a highly vesicular inhomogeneous trachyte flow which is the uppermost member of the precaldera trachyte sequence (McCall 1957). The adjacent part of the caldera floor is made of pumice the same as in the walls. This shows that the pumice eruption predates at least part of the movement on the fault, the vertical movement since its eruption being about 300 ft. The maximum thickness of pumice seen, in the north west corner of the caldera wall is 400 ft.

The pumice consists of round pumice lumps up to 3 ins. long with subordinate finer grained material. It is usually yellow with the coarser material grading to black. Bedding is poorly developed but poorly graded beds about 4 ft. thick occur. There are occasional agglomeratic horizons.

The pumice also occurs on the west facing slope running north from the caldera where it is about ten feet thick overlying trachyte (plate 19).

The sides of the road which runs by the western side of the caldera expose yellow pumice horizons in the soil. This shows that intermittent

Figure 9. Distribution map of Lower Menengai Tuff

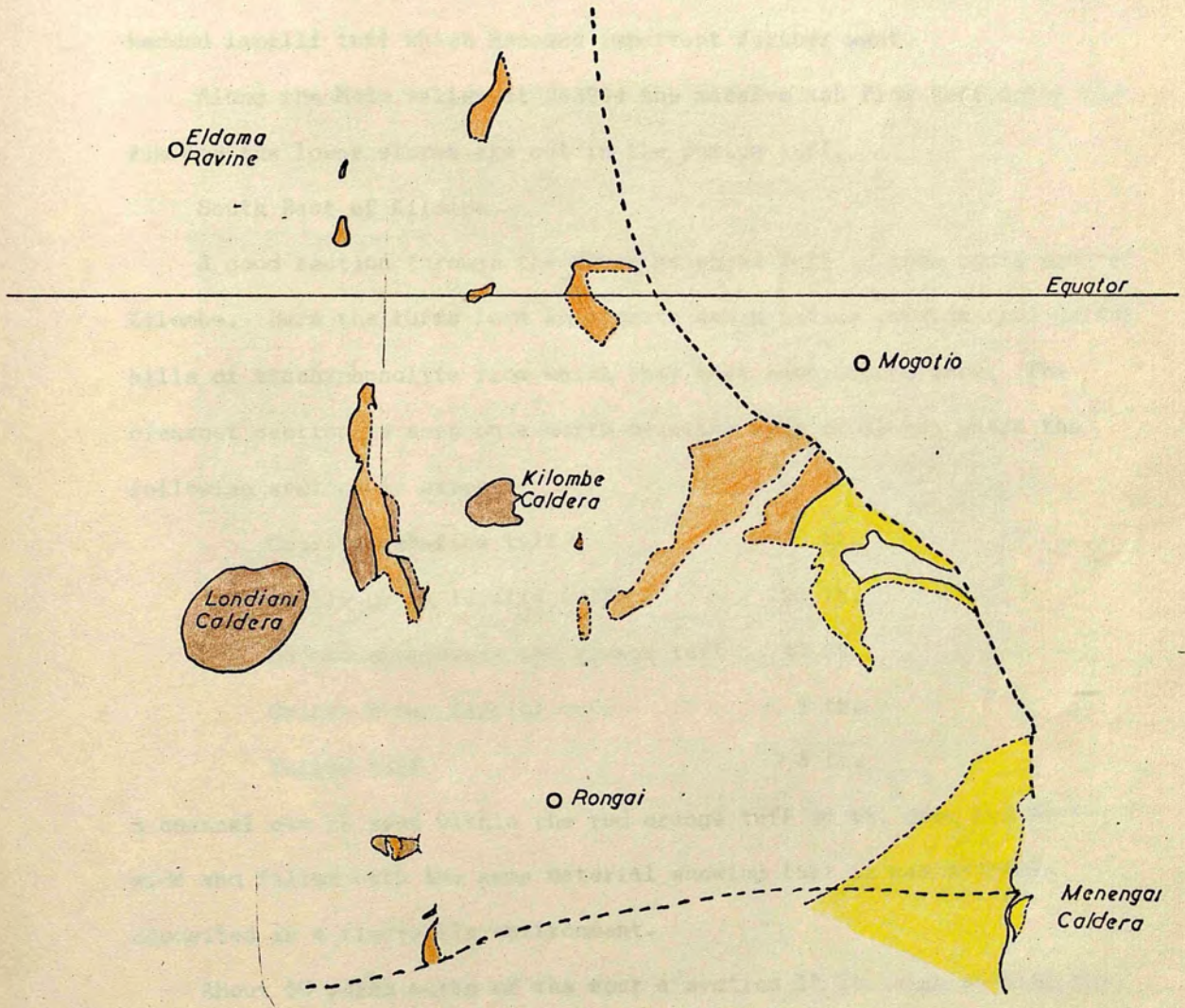
limit of area mapped

edge of outcrop of Lower Menengai Tuff

overlain by younger rocks
underlain by older rocks

5 Km.

5 Miles



bedded tuff

ash flow tuff

pumice

Nakuru

pumice eruptions have continued until very recently.

North East of Kampi ya Moto

Pumice tuff forms a line of low hills to the east of Kampi ya Moto. These hills form a part of an east facing scarp in the form of an arc of a circle of 5 miles radius (plate 20). In the northern part of the hills the pumice tuff overlies trachyte but near Kampi ya Moto the inward facing slope is all pumice tuff, with a facing of Upper Menengai Tuff in places.

At 310930 by the sisal factory a hillock shows gritty brown closely bedded lapilli tuff which becomes important further west.

Along the Molo valley at 283944 the massive ash flow tuff forms the rim and the lower slopes are cut in the pumice tuff.

South East of Kilombe

A good section through the Lower Menengai Tuff is seen south east of Kilombe. Here the tuffs form an arcuate scarp facing inwards towards low hills of trachyphonolite from which they have been eroded back. The clearest section is seen on a north pointing spur at 210895 where the following section is exposed:

Massive ash-flow tuff	10 ft.
Gritty brown lapilli tuff	25 ft.
Bedded apumiceous red orange tuff	40 ft.
Gritty brown lapilli tuff	3 ft.
Yellow tuff	> 3 ft.

A channel can be seen within the red orange tuff 20 ft. deep and 40 ft. wide and filled with the same material showing that it was probably deposited in a fluvial environment.

About 50 yards north of the spur a section 15 ft. high showing the succession from the underlying trachyphonolite up to the lower gritty brown lapilli tuff seen in the spur, contains a horizon from which Acheulean artifacts, including both handaxes and flakes, are eroding (fig. 10 plates 21 & 22). As a result of the author's discovery of this artifact



plate 20: The southern end of the arcuate fault scarp north west of Menengai, seen from McCall's Sidings. The edge of Menengai is on the left.

Figure 10. Sections at Artifact Site near Rongai

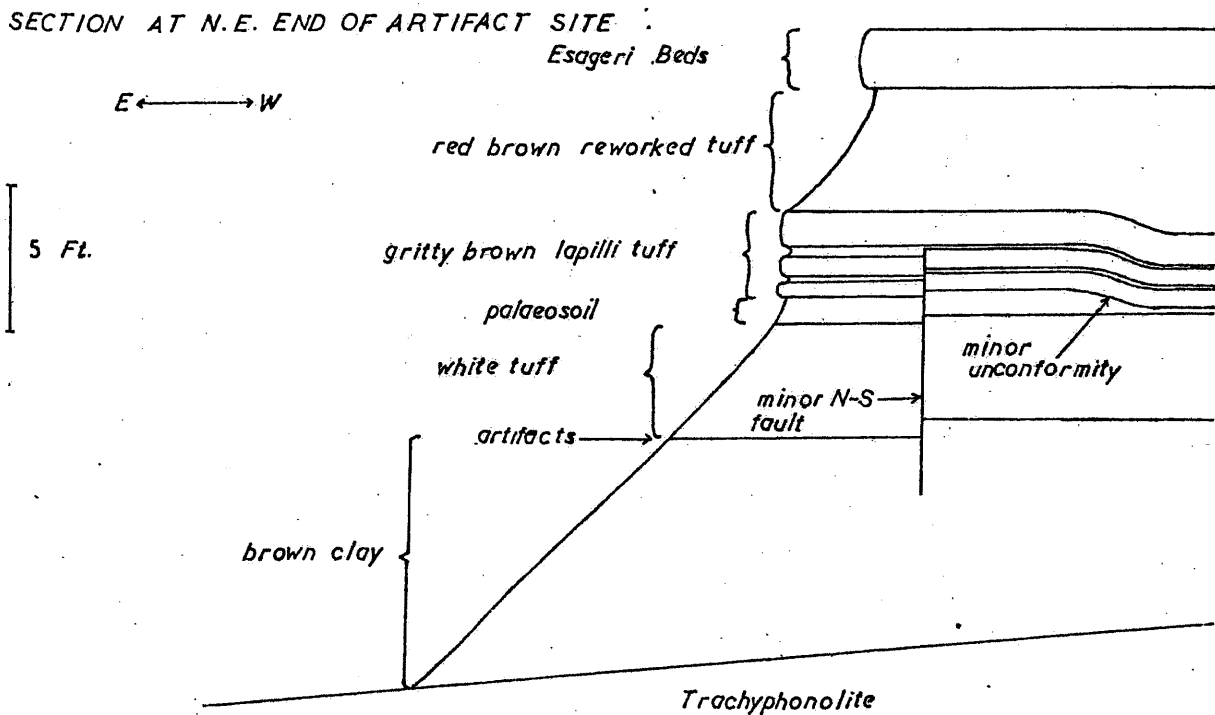
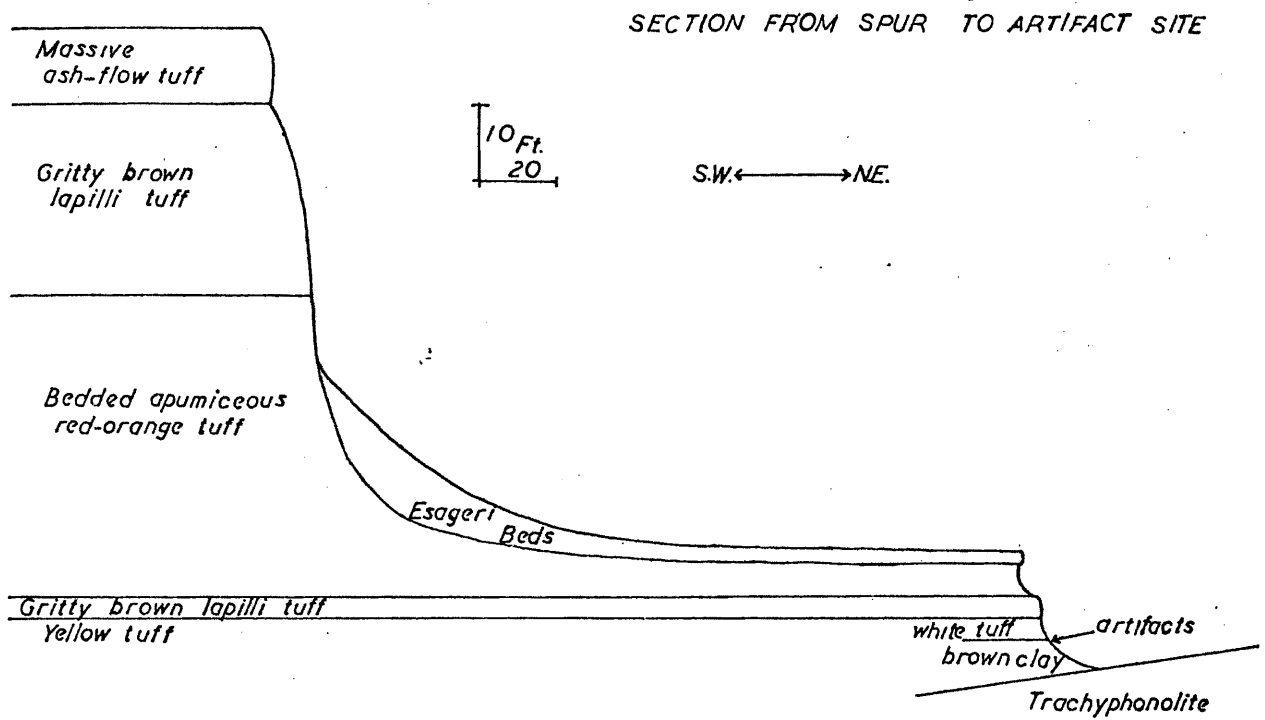




plate 21: The artifact site at Rongai, showing artifacts weathering out from the top of the brown clay (see fig.).



plate 22: Some of the artifacts at the Rongai artifact site.

site archaeological excavation was carried out during 1973 and 1974. This showed that the artifacts form a single horizon at the junction of the white tuff and the brown clay with a lesser horizon of flakes only in the palaeosol at the top of the white tuff, that the white tuff is a very weathered form of the yellow tuff at the base of the spur section, and that the brown clay is probably a wash of weathered trachyphonolite (W.W. Bishop and J. Gowlett, pers. comm.).

The ash flow tuff outcrops continuously from here to the edge of the area in the direction of Mogotio. It is a massive yellow brown tuff, sometimes grey brown. It contains black pumice lumps which become larger in the east, reaching 2 ft. long in the streambed which passes under the Kampi yo Moto - Esageri road at 234928. This increase in size of the pumice bombs to the east is strong evidence that the ash flow tuff is derived from the east and not from Kilombe which is closer. However it is not seen closer to the Menengai caldera than about ten miles and it becomes coarser to the east rather than to the south east, so that it cannot unequivocally be assigned to Menengai. Mapping of this horizon across a larger area around Menengai would be required to resolve this problem.

The ash flow tuff can be tentatively identified on the lower slopes of the Mau but it is very difficult to distinguish it from the Mau Tuff.

Kilombe and Londiani

The succession within Kilombe caldera cannot be correlated with certainty with that outside but it seems probable that the higher part of the section in the waterfall corresponds with the red orange tuff in the spur section to the south east described above. Boulders of massive tuff at the foot of the waterfall suggest that the ash flow tuff forms the top of the section here. The overlying pumice tuffs in the caldera do not have any equivalents to the south east.

Between Kilombe and Londiani the ash flow tuff is exposed by the side of the stream at 111945. In the stream here are waterlain tuffs containing blocks of the massive horizon showing that tuff deposition continued after the formation of the ash flow tuff. Bedded pumice tuffs occur away from the stream on the lower slopes of the volcanoes and these are assumed to overlie the welded tuff and correspond to the pumice tuffs inside Kilombe.

Much of the infill of Londiani caldera may be Lower Menengai Tuff, by analogy with Kilombe, but there is no direct evidence for this.

North of Kilombe

The Lower Menengai Tuff has a few outliers north of Kilombe. East of Esageri at 183085 it forms a west facing scarp where 20 ft. of yellow brown tuff overlies mugearite and trachyphonolite and is capped by the ash flow tuff which is 10 ft. thick. The yellow brown tuff outcrops along a stream valley east of there in which it shows graded and cross bedding and is clearly waterlain.

On the south east side of Kiborit a dry valley exposes the ash flow tuff, here 6 ft. thick, overlying orange tuff. Other small outcrops of the ash flow tuff are at the north end of the Kilombe graben, at Kabimoi and possibly 2 miles north east of Eldama Ravine. In its outcrops north of Eldama Ravine the ash flow contains black pumice enclaves with yellow rims which are not more than 1 cm long. These are very different from the large pumice boulders south east of Kilombe and show that the source of the ash flow is in the south east.

At 046987 near Sabatia in an area $\frac{1}{2}$ mile long by the stream has outcrops of graded bedded shale grading up to pumice tuff away from the stream. This probably belongs to the Lower Menengai Tuff.

Rosoga Tuff

A distinctive tuff outcrops over an area about a mile across west of Matebei. Ten feet of bedded pale grey green tuff are unconformably overlain by pale blue welded tuff with light coloured glassy fiamme and abundant feldspar phenocrysts which varies from two to seven feet thick. The Rosoga Tuff, which is very distinctive in its pale glassy appearance, overlies the Saos Mugearite and underlies the Esageri Beds.

Esageri Beds

These are red sediments occurring on the low ground in the east. They vary from clay to conglomerate, sand being the usual grainsize. They are bedded and sometimes show graded bedding and minor unconformities. Sections often have boulder beds at their base. A few thin discontinuous pale blue ash horizons occur within the red beds south of Matebei. These beds are named after Esageri, near to which they are exposed in stream sections.

In the north east the red beds infill basins, the largest being about five miles long. Around Kilombe and on the south east side of Londiani there is an almost continuous outcrop, the south east limit of which is buried under the Upper Menengai Tuff. Form lines on the surface of the Esageri Beds are correlatable from one basin to another (fig. 11) and this is strong evidence for their being the same age.

Steep sided canyons have been eroded in these beds, especially around the edge of the Rongai Plain, the deepest section so produced being 60 ft. (plates 23 & 24). These conspicuous canyons make the Esageri Beds visible from afar and by this means it can be seen that they continue southwards along the Mau Escarpment.

In the higher parts of their outcrop, and especially between Londiani and Kilombe the red beds contain horizons between a few inches and a few feet thick with the appearance of very weathered vesicular lava, known in Kenya as 'murram'. These more resistant horizons were probably formed by

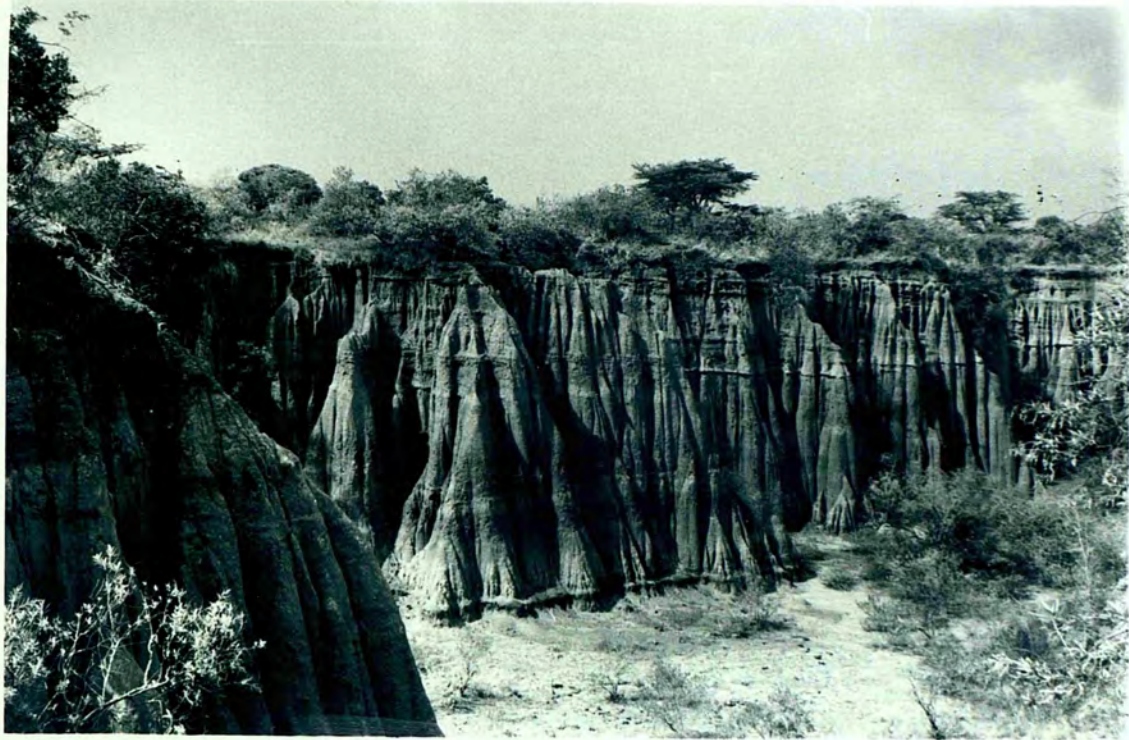
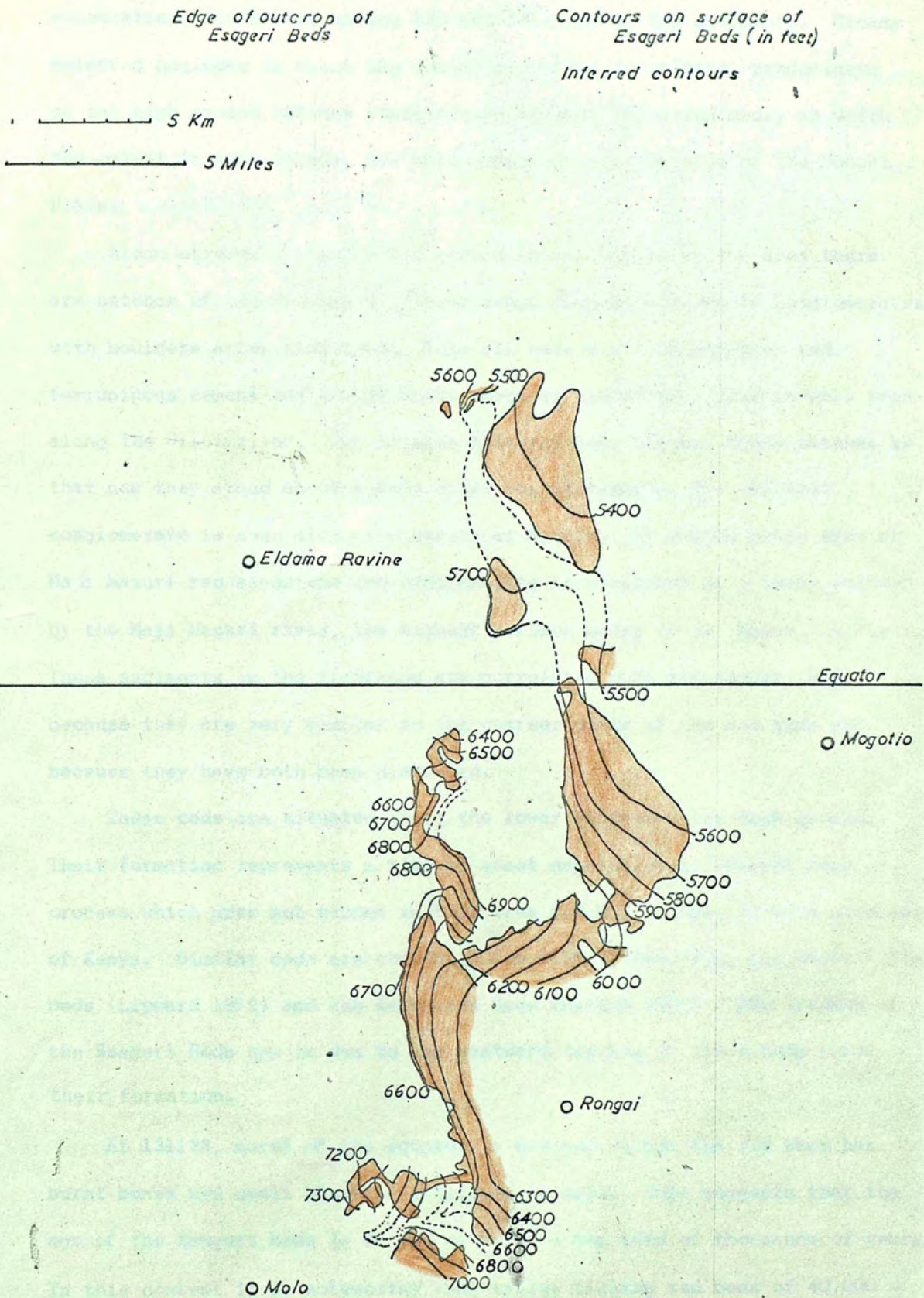


plate 23: Erosion of the Esageri Beds on the north side of the Rongai Plain.



plate 24: The Esageri Beds between Kilombe and Londiani.

Figure 11. Distribution Map of Esageri Beds



deposition of dissolved material in the surface of the sediments by evaporating groundwater during the accumulation of the sediments. Creamy coloured horizons in which the cement is silica or calcite, predominate on the high ground between Londiani and Kilombe while red beds, in which the cement is iron oxides, are more common around the edge of the Rongai Plain.

Along streams on the higher ground in the centre of the area there are patches of red sediments. These range from sandstones to conglomerates with boulders a few feet long. They all have a strong black or red ferruginous cement containing black specular haematite. This is well seen along the Siloi river. The streams have cut down through these patches so that now they stand about a foot above the streambed. The coarsest conglomerate is seen along the stream at Sigoro. At OO2006 north east of Maji Mazuri red sandstone and conglomerate is preserved in a small valley by the Maji Mazuri river, the highest horizon being 70 ft. above the river. These sediments in the highlands are correlated with the Esageri Beds because they are very similar to the coarser parts of the red beds and because they have both been dissected.

These beds are situated along the lower slopes of the high ground. Their formation represents a time of sheet deposition by torrent wash, a process which does not happen in this area now but is seen in more arid parts of Kenya. Similar beds are common in the Rift Valley, e.g. the Kerio Valley Beds (Lippard 1972) and the Kapthurin Beds (Martyn 1969). The erosion of the Esageri Beds now is due to the eastward tilting of these beds since their formation.

At 131128, north of the equator, a horizon within the red beds has burnt bones and small obsidian artifacts in situ. This suggests that the age of the Esageri Beds is of the order of a few tens of thousands of years. In this context it is noteworthy that valley filling red beds of 40,000 -

10,000 years B.C. are widespread over the Mediterranean and Middle East (C. Vita - Finsey, pers. comm.).

The source material was probably largely the readily weathered tuffs on Londiani and Kilombe, derived originally from these two volcanoes and from Menengai, and the soil formed on the high ground. By the main road at the south east end of Londiani Mountain there are dissected soils with concretionary horizons. It is not clear whether these are transported and so belong to the Esageri Beds or are an in situ soil profile.

Upper Menengai Tuff (fig. 12)

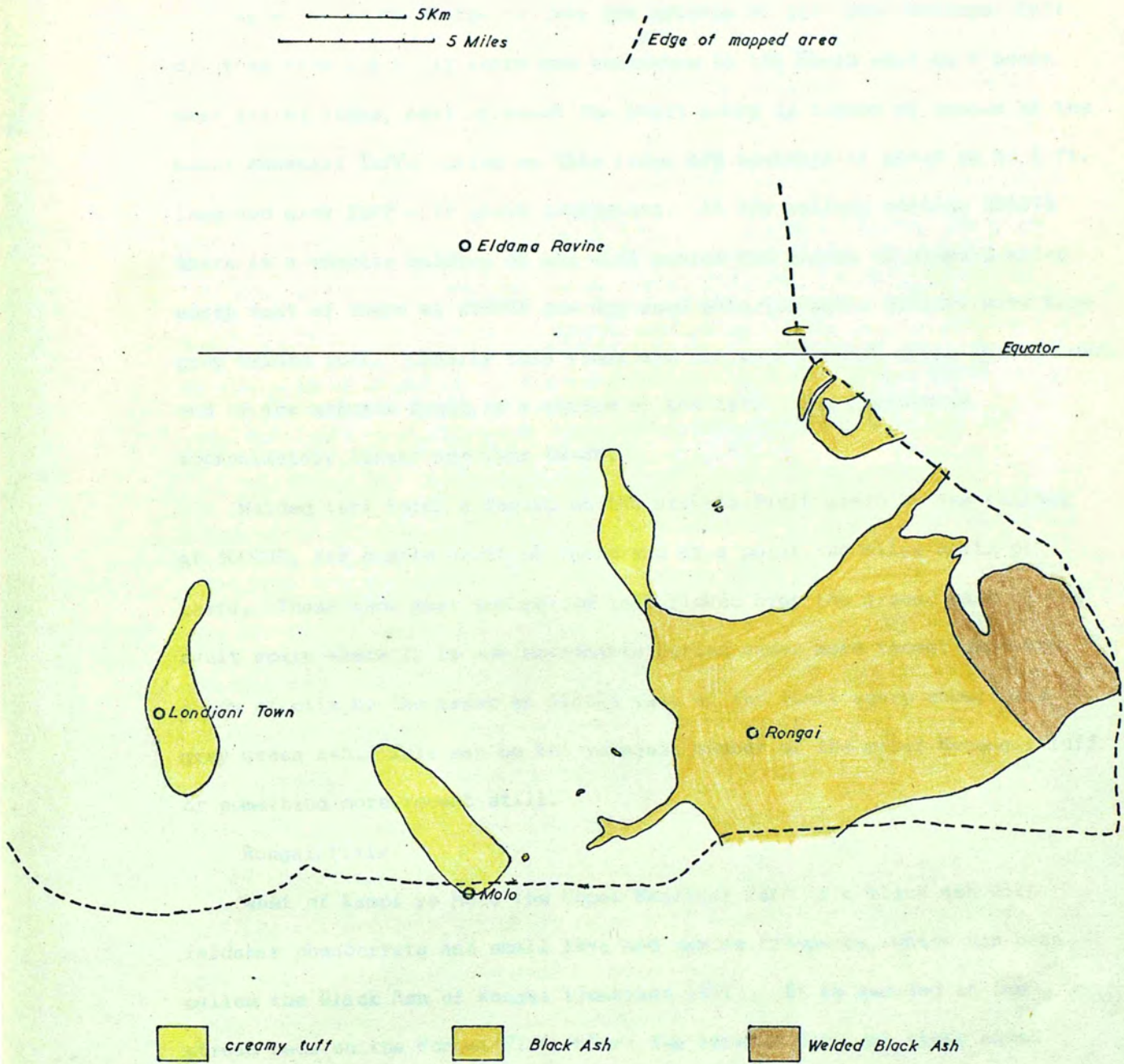
North of Menengai

On the west facing hillside which runs northwards from the north west corner of Menengai caldera a thin blue green massive tuff with flattened green pumice enclaves occurs overlying the pumice of the Lower Menengai Tuff and approximately mantling the present ground surface. On the spur 680832 this massive tuff is seen to be only 1 ft. thick. The massive tuff also outcrops along the top of the ridge. Further north on the lower slopes of this hillside it is much thicker and has a hummocky upper surface which is sometimes very vesicular. Here it is grey, slightly welded and contains black glass fragments $\frac{1}{2}$ cm. long. It seems that this tuff was erupted along the top of the ridge, flowed down the western side and thickened at the bottom where it became slightly welded. North west of this hillside it is not exposed until the arcuate fault scarp is reached.

East of Kampi ya Moto

The southern end of the arcuate fault scarp east of Kampi ya Moto is made of Upper Menengai Tuff. On the scarp it is blue grey welded tuff with large lumps of black glass and pumice while the top surface is very frothy. This seems to be a source area of the tuff, the magma coming up along the fault plane.

Figure 12. Distribution map of Upper Menengai Tuff



2½ miles south of the railway the outcrop of the Upper Menengai Tuff diverges from the fault scarp and continues to the north west as a north east facing ridge, east of which the fault scarp is formed by pumice of the Lower Menengai Tuff. Lying on this ridge are boulders of glass up to 1 ft. long and grey tuff with glass inclusions. At the railway cutting 286874 there is a chaotic outcrop of ash with pumice and blocks of glass. 2 miles north west of there at 270894 the new road cuts through a hillock with blue grey welded tuff. Clearly this ridge and its continuation along the southern end of the arcuate fault is a source of the tuff. The fissure is approximately linear and runs NW-SE.

Welded tuff forms a facing on the arcuate fault scarp by the railway at 300887, for a mile south of there and at a point two miles north of there. These show that the welded tuff flowed over the ground east of the fault scarp where it is now presumably buried under more recent deposits. A row of pits by the track at 315904 east of the fault scarp shows pale grey green ash. This may be the youngest member of the upper Menengai Tuff or something more recent still.

Rongai Plain

West of Kampi yo Moto the Upper Menengai Tuff is a black ash with feldspar phenocrysts and small lava and pumice fragments, which has been called the Black Ash of Rongai (Jennings 1971). It is exposed in the stream beds on the Rongai Plain where the streams have cut steep sided gorges in it up to 15 ft. deep. Along stream beds the ash always has a shiny black hard crust which does not form away from the streams. This is due to deposition of silica in the surface of the ash brought about somehow by the presence of running water. At 245907 an excavation for road metal shows that the fresh blue grey ash is completely unconsolidated and, in this case, grades up into 2 ft. of soil. In the east the Black Ash contains

large pumice bombs up to 1 ft. long whose interiors are largely empty. These are particularly common by the Molo river near the Kampi yo Moto - Eldama Ravine road. In boreholes on the Rongai Plain the Black Ash is about 30 ft. thick (McCall 1967).

At 283944, 4 miles south east of Kilelwa Hill, the Upper Menengai Tuff forms a crag below the rim of the valley on the south side of the river. The crag is 5 ft. of massive yellow pumice tuff grading down into grey unconsolidated ash with black pumice inclusions. This yellow massive form of the tuff is found by the Molo river south east of Kilombe where it is very difficult to distinguish from the underlying Lower Menengai Tuff.

The Black Ash outcrops along the valley of the Molo river for three miles north east of the point at which it ceases to outcrop on the ground away from the river. Similarly it outcrops along the Molo river up onto the Mau for 3-4 miles beyond the edge of its outcrop on the Rongai Plain. It is also found in a few outliers in the Molo river valleys and its tributaries of which the most westerly is at 069748 where it is 8 ft. thick.

A few patches of Upper Menengai Tuff were found in Kilombe caldera. Blue grey ash forms a crag 6 ft. high, 100 yards from the waterfall while in an adjacent valley at 167920 a small waterfall shows the blue grey ash infilling a previous valley to a depth of 20 ft. At 165924 the blue grey ash passes laterally into yellow brown massive tuff, the junction being sharp enough to be seen in hand specimen.

The outcrops of black ash on the Mau are up to 1300 ft. higher than its outcrop on the Rongai Plain. The height difference may be partly due to more recent tilting of the rift margin but the ground must have sloped downwards to the east at the time of the emplacement of the Upper Menengai Tuff because the Molo river valley already existed. The black ash may have been deposited uniformly over the Mau as an air fall tuff and subsequently concentrated in the stream valleys by surface runoff.

However the black ash along the valleys shows columnar jointing and so must have cooled initially where it is found now. A possible explanation is as follows: the tuff came from the vicinity of Menengai as an ash flow tuff and in the eastern part of its outcrop it is welded. When it reached the foot of the Mau Escarpment the ash flow had sufficient momentum to continue on upwards although confined to the Molo valley and its tributaries. An analogous situation might be a tidal bore.

Peripheral Areas

The Black Ash can be traced northwards where it becomes paler coloured and finer grained. Around Kilelwa Hill blue grey ash forms the surface, overlying Esageri Beds, and is two or three feet thick. The most northerly outcrop of the Upper Menengai Tuff is on the north side of the stream valley at 197014 four miles east of Esageri.

There is a cream coloured fine grained ash horizon 6 ins. to 1 ft. thick which caps the soil profile between Londiani and Kilombe, around Molo town and near Londiani town. This may be the distal end of the Upper Menengai Tuff sheet. It is not shown on the map.

Stratigraphic Relationships

The relationship of the Upper Menengai Tuff to the Esageri Beds is not clear. Although the pale blue grey ash in the north overlies the Esageri Beds there is no contact exposed on the Rongai Plain. The ash does not appear in the canyons in the Esageri Beds, which are sometimes floored by Lower Menengai Tuff. The Black Ash begins near the downhill ends of the canyons. It may be that the Black Ash postdates the formation of the Esageri Beds but predates the cutting of the canyons and formed a more resistant base level to which the erosion was downcutting. The youthfulness of the Upper Menengai Tuff is shown by the fact that it sometimes has no soil cover.

Gogar Tuff

The Gogar Tuff, named after a large farm on the Rongai Plain, is a lapilli tuff consisting of pumice lapilli about 3 mm long. The thickest development of this lapilli tuff is at 113797 at the south east end of Mt. Londiani (plate 25). Here a vertical section 50 ft. high in young tuffs has been preserved inside a west facing fault scarp in the Londiani Trachyte. 10 ft. of the Gogar Tuff overlies 25 ft. of Esageri Beds which unconformably overlies Lower Menengai Tuff. West of there the Gogar Tuff is exposed on the flank of Londiani at 061823 where it is four feet thick and caps the soil profile. Gogar Tuff up to 3 ft. thick caps many of the sections seen in the Esageri Beds on the west and north of the Rongai Plain.

Since the greatest thickness of Gogar Tuff is on the south east flank of Londiani its source is probably there also. This suggestion is supported by the fact that a vertical dyke of lapilli tuff $1\frac{1}{2}$ inches wide cutting the Lower Menengai Tuff was seen close to the large vertical section mentioned above.

Thin lapilli tuffs occasionally occur on the Rongai Plain overlying the Black Ash, as at 181854. At 196834 by the river Molo a dyke 15 ft. long and 3 ins. wide containing yellow lapilli tuff, cuts through the Black Ash. This suggests that the Gogar Tuff is younger than the Upper Menengai Tuff. Since it is thin and discontinuous the Gogar Tuff is not shown on the map.



plate 25: Section at S.E. end of Londiani Mountain showing Lower Menengai Tuff, Esageri Beds and Gogar Tuff.

Chapter IV

STRUCTURE

Introduction

The dominant structure in the Londiani area is the north south trending Equator Monocline which forms the western margin of the Kenya Rift Valley at the equator and runs through Londiani Mountain. It continues northward into the Kamasia Hills where it is antithetically faulted. To the south it ends against the Mau Monocline which trends north west - south east and forms the south western margin of the Kenya Rift Valley between Menengai and Lake Naivasha. The north western end of the Mau Highlands south of Londiani Town is also a monocline with a north east - south west strike.

Faulting is relatively unimportant. Large faults such as form the margins of the rift valleys elsewhere in Kenya do not occur within the area the author mapped although two, the Elgeyo and Nyando faults, begin close to its boundary. As well as faults there are linear valleys which look as though they were formed by erosion along the lines of faults although no displacement of one side relative to the other can be demonstrated. These features are here called lineations.

Faulting

Faulting of the Timboroa Assemblage

In the outcrop of the Timboroa Assemblage, especially around Londiani Town, there are faults showing three distinct trends. These are here considered separately.

North-South Faults

Three miles NNW of Kedowa at 825795 a notch in the hillside has Kericho Phonolite on its western side and Makutano Tuff on its eastern side. This notch seems to be the site of a fault downthrowing the phonolite to the east by about 400 ft. A similar notch half a mile north of there is probably the emergence of the fault on the other side of the

hill, although this latter locality was not visited in the present survey. Tuffs do not outcrop on the flat top of the phonolite on this hill except near the line of the fault so it would seem that the 500 ft. of tuffs east of the fault were banked up against the phonolite and not downfaulted against it. This dates the fault as between the Timboroa Phonolite and the Makutano Tuff, i.e. about 8 m.y. old.

The southerly extension of this fault runs for two miles along the Kedowa River valley west of Kedowa where it cuts through the Timboroa Phonolite. This stretch of the river course has been excavated along the line of the fault. Phonolite outcrops up to comparable heights on either side of the river but a downthrow of up to 100 ft. to the east is possible. Minor later movements on this fault are suggested by the straight western edge of the trachyte outcrop east of the railway at 829782.

West of this fault three north south trending valleys mark the sites of lineaments the clearest of which is the most westerly, running from 792772 in the south to 790830 in the north. They do not perceptibly offset the base of the pyroxenephyric phonolite flow so that if they are faults their throws are very small. These lineaments are probably the result of erosion excavating along joints where there has been little or no relative movement between the two sides. Other north-south lineaments are seen at 820830 where a valley in the Londiani Plain Basanite is a continuation of the line of the main north-south fault and at 814829 where a small valley cuts through Mau Tuff. Finally the fairly straight course of the Masaita River for three miles north of Londiani Town may represent a north-south lineament.

North West - South East Faults

South of Londiani Town the northern end of the Mau Highlands has been deeply dissected along the lines of three north west - south east trending faults. The two eastern faults both have throws of about 250 ft.

to the south west (fig. 4). They cut the Kericho Phonolite, the Lumbwa Phonolitic Nephelinite and the Makutano Tuff while at the foot of the Mau Highlands Mau Tuff lies across them unaffected. This brackets these two faults between the Makutano and the Mau Tuffs, i.e. between about 7.5 and 6 m.y.

The westernmost fault downthrows the base of the phonolitic nephelinite to the south west by about 150 ft. on the Mau slope. Unlike the other two faults this one can be followed north of the Mau. A mile north east of Kedowa its fault scarp in the Makutano Tuff is 300 ft. high and has the Mau Tuff M4 draped over it showing that this fault is also bracketed between the Makutano Tuff and the Mau Tuff. The fault continues to the north west, curving slightly more westward. Outcrops of Kericho Phonolite and the basanite of the Lumbwa Phonolitic Nephelinite by the railway and on the hilltops to the north just inside the western margin of the mapped area, show that they were downthrown by about 500 ft. to the south west. The fault clearly must continue beyond the edge of the area but it is difficult to see where it goes. $2\frac{1}{2}$ miles north of Kedowa the Kedowa Pillar Trachyte flow can be seen above and below the fault scarp and at 842793 the outcrop is continuous from top to bottom. This shows that the fault scarp was in existence at the time of the emplacement of the Kedowa Pillar Trachyte and that the trachyte flowed over it from the north. The fault can therefore be placed between the Makutano Tuff and the Kedowa Pillar Trachyte.

North East - South West Faults

West of Londiani Town there are a number of faults trending approximately north east - south west forming a graben (fig 4)

On the hillside 844795 trachyte is exposed dipping from the top to the bottom as explained above. On the south eastern side the trachyte is cut by a fault and reappears, still dipping south eastward, on the hilltop

847791. The throw of the fault is here 200 ft. One mile further north east trachyte can again be seen on both sides of the fault and the throw has become much smaller. Further north east the fault fades out completely while its south western extension is probably shown by a north east - south west valley south of the railway.

The Mau Tuff just west of Kedowa has been downthrown about 50 ft. to the north west by a north east - south west fault. To the south this fault controls the course of the Kedowa River for about half a mile and is continued south of the river as a straight valley. North eastwards it becomes a lineament which controls the course of the Masaita River as far as just beyond Londiani Town. A section across the lineament can be seen at the waterfall at 862806. Here there is no displacement of the Kedowa Pillar Trachyte. However the lava is strongly jointed in a north east - south west direction and a powerful spring issues from joints at the base of the flow just above the impermeable Makutano Tuff. Downstream from there the river has excavated a gorge 200 ft. deep along the lineament.

At 841796 the trachyte at the top of the escarpment is downthrown to the north west by a few tens of feet by a fault which rapidly dies out north eastwards and can be traced for a mile south westwards.

A fault of this trend downthrows the Timboroa Phonolite by 300 ft. to the north west at 820810. Its extension south of the river is not marked by any topographic feature. To the north east a stream crossing the Londiani Plain Basanite marks a lineation along the continuation of this fault. The outcrop of trachyte along the top of the fault scarp shows that the trachyte was also cut by the fault.

Two thirds of a mile north west of this fault another north east - south west fault has controlled the erosion of a prominent valley cut in the phonolitic nephelinite. It downthrows the phonolite by about 50 ft. to the north west.

The five faults mentioned so far all downthrow to the north west. However, north west of them there are three faults which downthrow to the south east, so that altogether this set of faults forms a graben. The most south easterly of the three faults has a small throw of perhaps 50 ft. The central and north eastern faults form prominent scarps in the Timboroa Phonolite 300 and 200 ft. high respectively. The Londiani Plain Basanite seems to flow over these last two fault scarps.

The age of this set of faults around Londiani Town is not clearly defined. They cut the Kedowa Pillar Trachyte but their relationship to the Mau Tuff is equivocal. At Kedowa the faults offset the Mau Tuff by a small amount but north of the Kipchoriet Mau Tuff seems to be unaffected by faults in the underlying Timboroa Phonolite. The Londiani Plain Basanite is not affected by this set of faults although it does show a lineament along the line of one of them. The north east - south west faults around Londiani Town were probably active about the time the Mau Tuff ash flows were being deposited, i.e. 6 m.y. ago, so that some of the faults affect the ash flows and others do not.

Lineaments on this trend are shown by streams on the Londiani Plain, and also by the north east - south west elongation of Lessotet.

Londiani Plain Fault

Around its northern margin the Londiani Plain is enclosed by an inward facing escarpment about 500 ft. high. This escarpment is curved and forms one third of a circle whose diameter is approximately twelve miles and whose centre is about $2\frac{1}{2}$ miles ENE of Limutet. It can be readily interpreted as a curved fault which let down the Londiani Plain to the south. Although it is an area of very poor exposure Timboroa Phonolite appears to form the whole height of the escarpment in two places in the north east (880985 and 905965) showing that the faulting postdated the phonolite. Most of the escarpment face is probably Makutano Tuff but it is not possible to decide whether the tuff mantles the fault scarp or

is cut by it. At 905974 an outcrop of welded tuff belonging to the Eldama Ravine Tuff dips down the slope towards the Londiani Plain, indicating that the escarpment already existed 4 m.y. ago. At its south eastern end the escarpment becomes less pronounced and Londiani Trachyte has overflowed it from the east. Its western end passes into a lineament of the north east - south west trend which can be followed as a linear valley to the south west as far as the railway 2 miles east of Ft. Ternan.

This semicircular fault can be considered as a partly developed ring fracture letting down the Londiani Plain like a caldera subsidence and was probably formed at the end of the eruption of the Timboroa Assemblage, at around 7 m.y. ago. A similar semicircular fault downthrows the higher part of the Tinderet Basanite to the south (fig. 2).

Faulting of the Kapkut Assemblage

The river Perkerra runs through a gorge cut in the Eldama Ravine Tuff and in the Kapkut Trachyte in a north east - south west direction. On the south east side of the Kapkut Highlands the gorge cut in the Kapkut Trachyte is up to 1000 ft. deep and yet the formation exposed south east of the gorge and forming much of its south eastern rim is the more readily erodable Eldama Ravine Tuff. That the river flows straight across the flank of the Kapkut Trachyte volcano rather than taking the apparently easier course around its edge raises a considerable problem.

A possible explanation is that there is a fault running along the line of the gorge and that the river has excavated its valley along the foot of a north west facing fault scarp. At first sight this appears to be the case. In general the top of the trachyte is at about the same height on either side of the gorge but since the lavas are dipping to the south east they must have been upfaulted on the south east side with respect to the north west side. The Kapkut Trachyte hill at O66116 on the south east side of the river is in fact higher than the ground on the north west side opposite it as far as half a mile from the river. However, the Perkerra Valley Hawaiiite which underlies the trachyte at Sigoro and

by the Perkerra River below does not outcrop in the valley side south east of the river as it would if it has been upfaulted. This precludes the possibility of any substantial fault along the Perkerra.

From the hawaiite outcrop in the river at its foot to the top of the hill O66116 the trachyte is 1000 ft. thick. North west of the river the maximum thickness of trachyte overlying the hawaiite is 500 ft. and the maximum dissection of the hawaiite is about 200 ft. so that erosion has removed between 500 ft. and 1200 ft. of lavas from the north west side of the river. It is this much greater erosion of the north west side of the gorge relative to the south east side, due to the south easterly regional dip, which gives rise to the illusion of a major fault scarp along the Perkerra.

Although it can be proved that there is no substantial fault along the Perkerra the straight course of the river downstream of Eldama Ravine, where it changes from north north east to north east, is probably controlled by a fault. This fault must be small, as explained above, but the gorge on the Masaita River below Londiani town shows how a deep gorge may form along the line of a fault of little, if any, throw. The line of the Perkerra Gorge is continued south west of Eldama Ravine by a north east - south west valley which passes two miles north west of Maji Mazuri. This may be traced to the south west as far as the railway.

At Sigoro a fault downthrowing to the north can be seen in the east side of the valley at O50140 where trachyte is juxtaposed against hawaiite over a vertical distance of 250 ft. indicating a throw of at least that amount. This fault continues east, curving round to the north east and dying out after two miles. Its westerly extension is hidden under the Eldama Ravine Tuff. The shape of the outcrop of this fault is mirrored by the Perkerra Gorge downstream from O70130 suggesting that this stretch of the gorge may be controlled by a similar fault, though not necessarily with any large throw.

The Eldama Ravine Tuff is unfaulted across the Perkerra Gorge and also across the fault at Sigoro. This means that this set of faults is more than 4.3 m.y. old. If it is assumed that these faults are the same age as the faults which cut the Kaparaina Basalt in the Kamasia Hills, then they are younger than 5.3 m.y. (see Chapter II). The youngest known flow of Kapkut flowed into an already existing Perkerra Gorge so the faulting occurred before the ending of volcanic activity at Kapkut. The faulting may therefore be placed at about 5 m.y. ago.

Faulting of the Londiani Assemblage

Faulting in the Eldama Ravine Tuff (fig. 5)

The Eldama Ravine Tuff is cut by numerous small faults while on adjacent areas of the overlying lavas such small faults are less common. This difference might be due to the different lithologies of the tuffs and the lavas but there are a few faults which can be seen to cut one and not the other. Two such faults have been mapped which affect the Eldama Ravine Tuff but not the Saos Mugearite, both trending slightly east of north. One is along a stream valley $2\frac{1}{2}$ miles WSW of Saos. Here at O99104 the Eldama Ravine welded tuff E7 is cut by a fault and reappears further down the streambed having been downfaulted to the west by 30 ft. Erosion has picked out this fault line so that the western side of the valley follows the surface of the eastward dipping welded tuff and the eastern side exposes 200 ft. of overlying tuff. Saos Mugearite and E9, the last of the Eldama Ravine welded tuffs, mantle the eastern side of the valley showing that the faulting and consequent erosion occurred within the time of eruption of the Eldama Ravine Tuff.

The other fault is $1\frac{1}{2}$ miles west of the last. Here a stream valley up to 150 ft. deep has the Eldama Ravine Tuff flow E6 along the top of its eastern side. Saos Mugearite laps against the scarp. Subsequent erosion has cut down through the mugearite so that in some places, e.g. O72094 the

eastern side of the valley still has a mantle of mugearite and elsewhere the mugearite has been removed, exposing tuff. Erosion by a stream along the foot of the scarp before the emplacement of the mugearite has probably increased the height of the eastern side beyond its original faulted height, as happened along the other fault, so that an estimate of its displacement cannot be made. At O75106 at the northern end of the scarp there appears to be no displacement of E7 so the fault has died out by here.

The Eldama Ravine Tuff is affected by numerous small faults and joints trending in several directions but chiefly north-south with throws to both east and west. Some can be discerned on aerial photographs as lines of vegetation and these are shown on the map. In the field they are sometimes well seen in stream sections, especially between O90105 and O98113 forming erosional notches. They dip generally at 70° and throws vary from nothing for the joints to 2-3 ft. for the small faults. A few larger faults can be seen but their displacements are not directly measurable. The strikes of 21 faults and joints measured in the field are shown in the rose diagram fig. 7. The dominant direction is about 015° with a lesser trend at 140° . In fig. 8 is shown the rose diagram for the 19 tuff dyke trends measured in the field. This shows the same two principal directions, though with the approximately 130° trend more pronounced than the 010° .

The Chemususu River runs in a meandering gorge whose overall course is uniformly east - west. Ash flows on both sides of the valley can be seen dipping in towards the river, e.g. at O45108, which shows that the gorge existed during the time of eruption of the tuffs. There is no evidence for a fault along the gorge so it is best regarded as an east - west lineament.

North of Eldama Ravine two north - south faults cross the Perkerra River, causing the river to be offset southwards by about half a mile, enclosing the Poror Spur. From the offset of the feeder dyke of the Theloi

Basalt, the throw of the western fault is about 20 ft. to the west and that of the eastern about 100 ft. to the west. These are two more examples of a deep gorge being excavated along the line of a small fault. A small outcrop of Londiani Trachyte on the Poror Spur has been downfaulted from the more extensive outcrop above the eastern fault showing that these faults postdate the Londiani Trachyte.

Faulting of Londiani Mountain

Londiani's caldera is elongated ENE-WSW and is about 4 miles long and $2\frac{1}{2}$ miles wide. At its western end aerial photographs show an inner fault scarp about a mile inside the outer fault. Since the floor of the caldera seems to be entirely buried by tuffs it is not possible to measure the throw of the caldera fault. A minimum estimate, taken from the maximum height of the inward facing wall of the caldera above the Visoi river is 1000 ft. From this a minimum volume of the caldera below the rim can be estimated to be 5 km^3 .

South east of the caldera a graben about a mile wide occurs on the slopes of the mountain, bounded by faults with throws of about 100 ft. The fault scarp on the north eastern side of this caldera can be followed up to the rim of the caldera. On the north side of the caldera the topography suggests a set of faults trending slightly east of north, some of which continue into the caldera.

Faulting of Kilombe (fig. 8)

Kilombe has a near circular caldera with a graben stretching away from it to the north. In the north and west of the caldera there is one fault scarp visible. This fault has a throw of at least 700 ft, the downthrown side being covered by later tuffs. It continues eastward onto the flanks of the volcano, the throw being 600 ft. where trachyte first appears on the downthrown side and dying out to near nothing at the foot of the mountain a mile further east. In the south the outer fault scarp

is 100-200 ft. high. However inside this fault the ground is the post caldera flow K12 and the thin overlying K13 so that this small height represents only the late movement of the fault, the movement associated with the main faulting phase being unobservable. Only in the east is the throw of the outer fault directly measurable. Here the precaldera trachyte flows outcrop inside the fault and the throw can be seen to be 300 ft.

Much of the floor of Kilombe caldera is covered with tuffs so that the faulting pattern in the underlying lavas is hidden. However in the south and east there is evidence that within the outer ring fault there are other faults downthrowing the lavas towards the centre of the caldera. This is best seen in the gorge where horizontal precaldera trachyte flows outcrop on the inside of the outer fault and are cut out at an inner fault which has a throw of at least 150 ft. (fig. 8). In the south the small straight cliff marking the north eastern limit of the post caldera flow K12 shows the line of a late fault. Another late fault is suggested by the topography between this one and the outer fault.

On the north side four faults run into the caldera from the graben. The two outer ones can be considered as curving outwards and joining the main caldera fault. However the two inner faults probably continue across the floor underneath the tuffs. Thus it seems that there is a complex pattern of faulting within the outer caldera fault and that the caldera was formed by movement along a number of fault planes, all downthrowing towards the centre of the structure.

A ridge on the north side of the caldera extends as far as the Eldama Ravine - Kampi ya Moto road, a distance of five miles. The crest of this ridge is downfaulted to form a graben. In the northern part three faults can be made out with throws of up to 100 ft, the graben being a third of a mile wide. Towards the south the number of faults and their individual throws increase while the width of the graben increases and the fault planes become more curved so that the caldera appears as the climax of the graben faulting.

Faulting of the Menengai Assemblage

The Menengai Assemblage is affected by faulting which produced the Menengai caldera and a similar arcuate structure north west of the caldera.

The Menengai caldera covers an area of 35 square miles and was formed by piecemeal foundering of the early trachyte lava pile (McCall 1957A). At the western end of the caldera two arcuate faults, one in the north and one in the south, have downthrown the floor of the caldera so as to leave a tongue of high ground projecting into the caldera in the centre. The greatest height of the caldera wall is about 900 ft. at the Lion's Head on the south east side. On the western side it is usually about 300 ft. high. In the northwest corner the tuffs forming the original caldera wall have been eroded back so that now there is no fault scarp.

Two miles north west of the north west corner of the caldera is the beginning of an eastward facing fault scarp which can be traced to the north west curving to pass two miles east of Kampi ya Moto and ending four miles south of Mogotio. This scarp forms a third of the circumference of a circle of radius 4 miles. If complete it would enclose a caldera of area about 50 square miles, an area a little larger than the Menengai caldera. The fault scarp rises abruptly to 300 ft. at its south eastern end. Northwards its height falls slowly to 100 ft. east of Kampiya Moto, which height it maintains, except for a gap through which the railway passes, to near its northern end. In the south the fault is cut in the Upper Menengai Tuff while east of Kampi ya Moto it is cut in the Lower Menengai Tuff and has a facing structure of Upper Menengai Tuff. This shows that the fault moved twice, once between the two tuff eruptions and once after the Upper Menengai Tuff. At its southern end there is a minor fault in front of the main fault scarp.

The fissure from which the Upper Menengai Tuff was erupted separates from the arcuate fault about two miles south east of Kampi ya Moto and continues in a straight line to the north west. The edge of the outcrop of the Upper Menengai Tuff is a small north east facing ridge so it seems that the fissure developed into a small fault.

The only other fault found in the present area which affects the Menengai Assemblage runs north - south across the Molo four miles north west of Kampiya Moto at 226893. This downthrows the Black Ash to the east by 50 ft.

Age of the Faulting

The oldest fault around Londiani town seems to be the north - south fault west of Kedowa which occurred between the Timboroa Phonolite and the Makutano Tuff, i.e. about 8 m.y. ago. However north - south lineaments affect the Mau Tuff and even the Londiani Plain Basanite while the main north south fault also cuts the Kedowa Pillar Trachyte. It seems that the main movement on the north - south fault was 8 m.y. ago although there were minor later movements and lineaments of this trend affect rocks of all ages.

The north west - south east faults are bracketed between the Makutano Tuff and the Kedowa Pillar Trachyte, so they are about 7.5 - 6.5 m.y. old. The north east - south west faults, being contemporary with the Mau Tuff are about 6 m.y. old.

It can be tentatively concluded from the above that faulting around Londiani Town began about 8 m.y. ago and continued, probably intermittently, until 6 m.y. ago, the predominant strike of the faults varying during that time from north - south to north west - south east and finally to north east - south west.

The faulting of the Kapkut Trachyte which ultimately gave rise to the Perkerra Gorge is about 5 m.y. old and may be contemporary with some of the younger north east - south west faulting around Londiani Town.

Three periods of faulting affect the Londiani Assemblage, the earliest and least important of which occurred between the Eldama Ravine Tuff flows E7 and E9, probably between 4 and 3.5 m.y. ago. Faulting affected Londiani at a late stage in its history to produce the caldera and rift zones. The same happened to Kilombe but since the two volcanoes have been dated at a million years apart, there must be two distinct faulting episodes. The faulting of Kilombe was not one single event since post faulting flows such as K12 are themselves cut by later faulting. The same may be true of Londiani although this has not been demonstrated.

Faulting affected the Menengai Assemblage after the extrusion of the Lower Menengai Tuff at some time less than 1 m.y. ago, producing the Menengai caldera. A later period of faulting after the extrusion of the Upper Menengai Tuff is probably only a few thousand years old. The arcuate fault east of Kampi ya Moto moved on both occasions.

In conclusion faulting has occurred intermittently since 8 m.y. ago and it is not possible to group it into a few major episodes. What is clear, though, is that the faulting has migrated eastwards during that time. Apart from the two calderas no fault has a throw of more than a few hundred feet.

Correlation of the Faulting with Adjacent Areas

Correlation of the faulting in this area with the faulting in adjacent areas is difficult. No faulting is apparent which correlates with the 12 m.y. movement on the Elgeyo Fault. However rocks older than 12 m.y., the Kericho Phonolite, are only found in a small area on the Mau and if faulting of this age does occur it is buried beneath younger rocks. There probably is no such faulting since the Elgeyo Fault dies out just north of the present area.

The faulting at 7 m.y. associated with the change from phonolitic to trachytic eruption, which is so important over much of the Kenya Rift Valley (see chapter II), is represented here by the faulting around Londiani Town and in particular by the north west - south east faulting at 7.5 - 6.5 m.y.

In the region between Kedowa and Ft. Ternan the drainage is predominantly along north east - south west valleys with a subsidiary north south trend. This pattern of lineaments is probably controlled by faults in these directions. The faults need not be large for, as shown above, very small faults can give rise to deep valleys. The north east - south west trend controls the course of several rivers around Kericho (Binge 1962). These lineaments affect the basanites of Tinderet so that faulting on these trends was still active after 5.5 m.y. ago. The part of the mapped area south west of Londiani Town is the eastern end of this region of lineaments.

The faulting of the Londiani Assemblage, being mostly associated with the two trachyte volcanoes, does not correlate with any regional faulting elsewhere. Likewise the faulting of the Menengai Assemblage is a peripheral part of the faulting of the Menengai volcano. The closely spaced young block faulting characteristic of the Lake Hannington Trachyphonolite in the centre of the Kenya Rift Valley (McCall 1967) is unrepresented in this area.

Monoclines

The Equator Monocline

The main structural feature seen in the present area is the Equator Monocline (Lippard 1972), which forms the western margin of the Kenya Rift Valley at the equator. Much of its history can be deduced from consideration of the dips of the formations it affects. These dips can be accurately deduced from the map when the formations outcrop over a vertical distance of a few hundred feet or more.

The oldest exposed formation affected by the monocline is the Perkerra Valley Hawaiite which dips to the south east at $7\frac{1}{2}^{\circ}$. These lavas, since they form part of an extensive outcrop without any identifiable centre (Lippard 1972), were probably originally approximately horizontal, so that their dip is a measure of the extent of the monoclining. The dip of the overlying Kapkut Trachyte lavas is partly primary, being close to the centre of the volcano, and so cannot be used.

The Eldama Ravine ash flow tuffs flowed from the east and therefore their present easterly dip is entirely post depositional. The earliest extensively exposed Eldama Ravine Tuff flow E2 dips to the south east at 5° (fig. 13). E7 (fig. 14) dips eastward at $4\frac{1}{2}^{\circ}$ around Saos and at 3° between Eldama Ravine and Maji Mazuri. The greater dip of the older horizon shows that monoclining was going on between the emplacement of the two ash flows. This is illustrated by the fact that E7 rests directly on E2 near Sigoro while in the south side of the Perkerra Gorge they are separated by 500 ft of tuffs. E9, the last of the Eldama Ravine ash flow tuffs dips eastward at $2\frac{1}{2}^{\circ}$ (fig. 15). The base of the Londiani Trachyte dips eastward at 3° while the base of the Kilombe trachyte dips eastward at about $1\frac{1}{2}^{\circ}$ (fig. 16). The youngest usable marker horizon is the ash flow of the Lower Menengai Tuff which dips ENE at about $1\frac{1}{2}^{\circ}$.

A plot of the approximate age of all these horizons against their dip (fig. 17) shows a crudely linear relationship indicating that the formation of the monocline is a process which has continued at least since the formation of the Perkerra Valley Hawaiite and is presumably still going on. The rate of tilting is about 1° per million years.

The formations used above to define the evolution of the monocline show a steady rotation of their strike from north east - south west to north west - south east from the older to the younger rocks. This is

Figure 13. Distribution map of E2

5 Km
5 Miles

Strike lines for E2

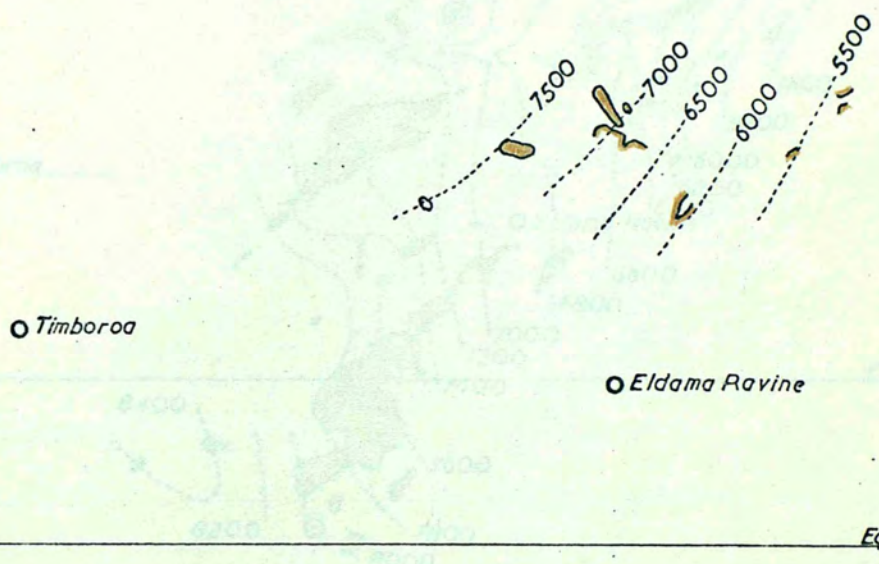


Figure 14. Distribution map of E7

5 Km
5 Miles

Strike lines for E7
heights in feet

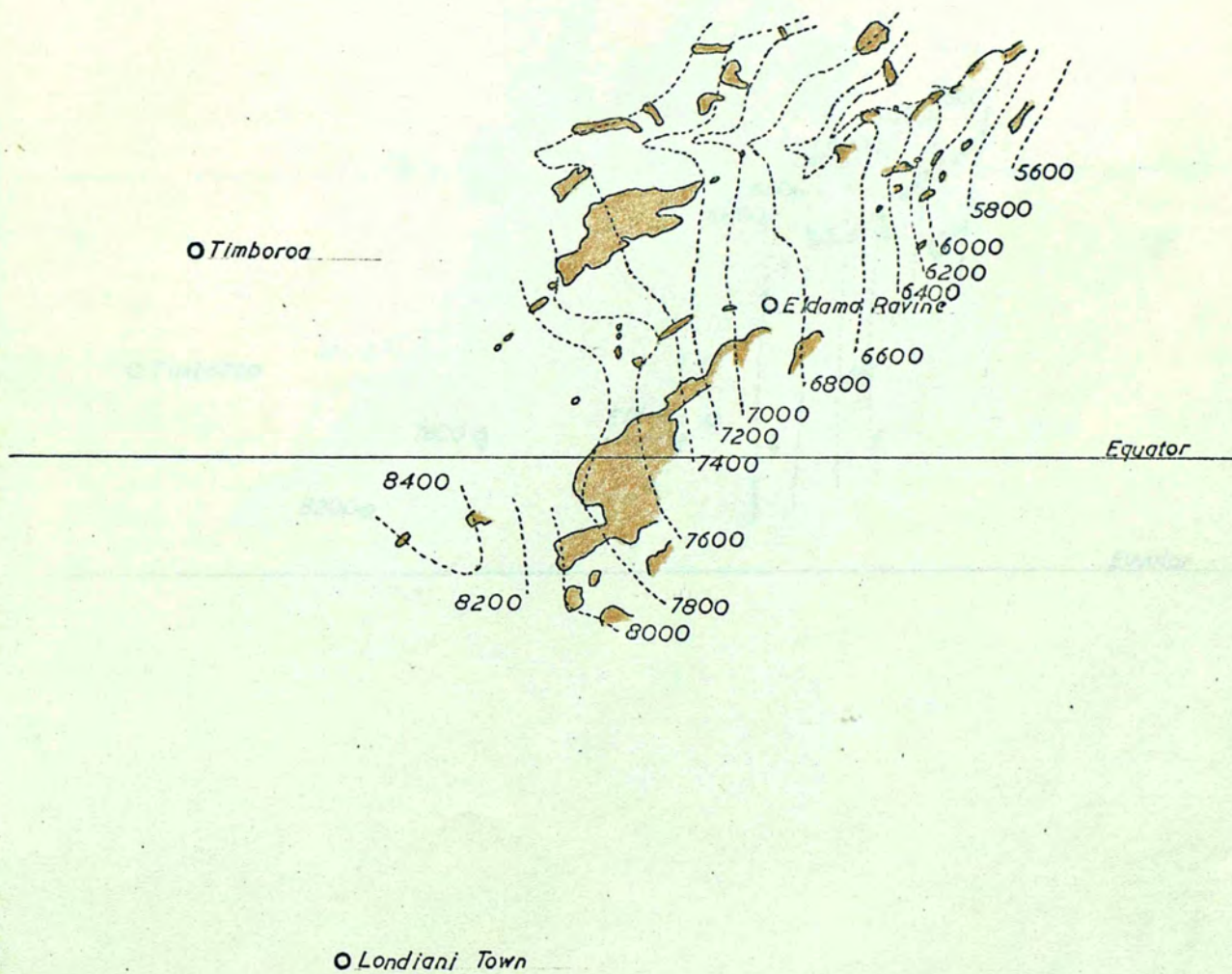
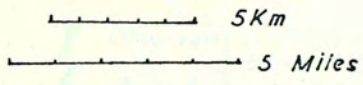


Figure 15. Distribution map of E9



strike lines for E9, heights in feet

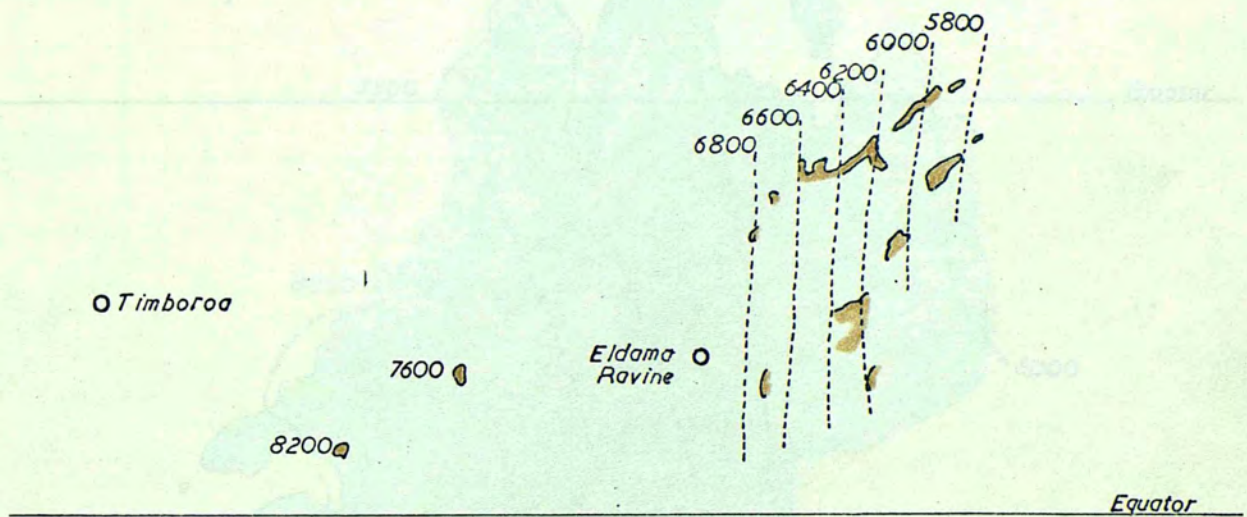
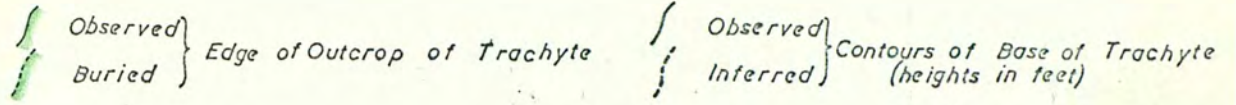
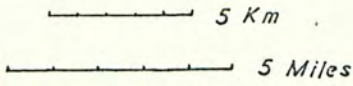


Figure 16. Distribution Map of Londiani and Kilombe Trachyte

 Observed } Edge of Outcrop of Trachyte
Buried }
Observed } Contours of Base of Trachyte
Inferred } (heights in feet)

 5 Km
5 Miles

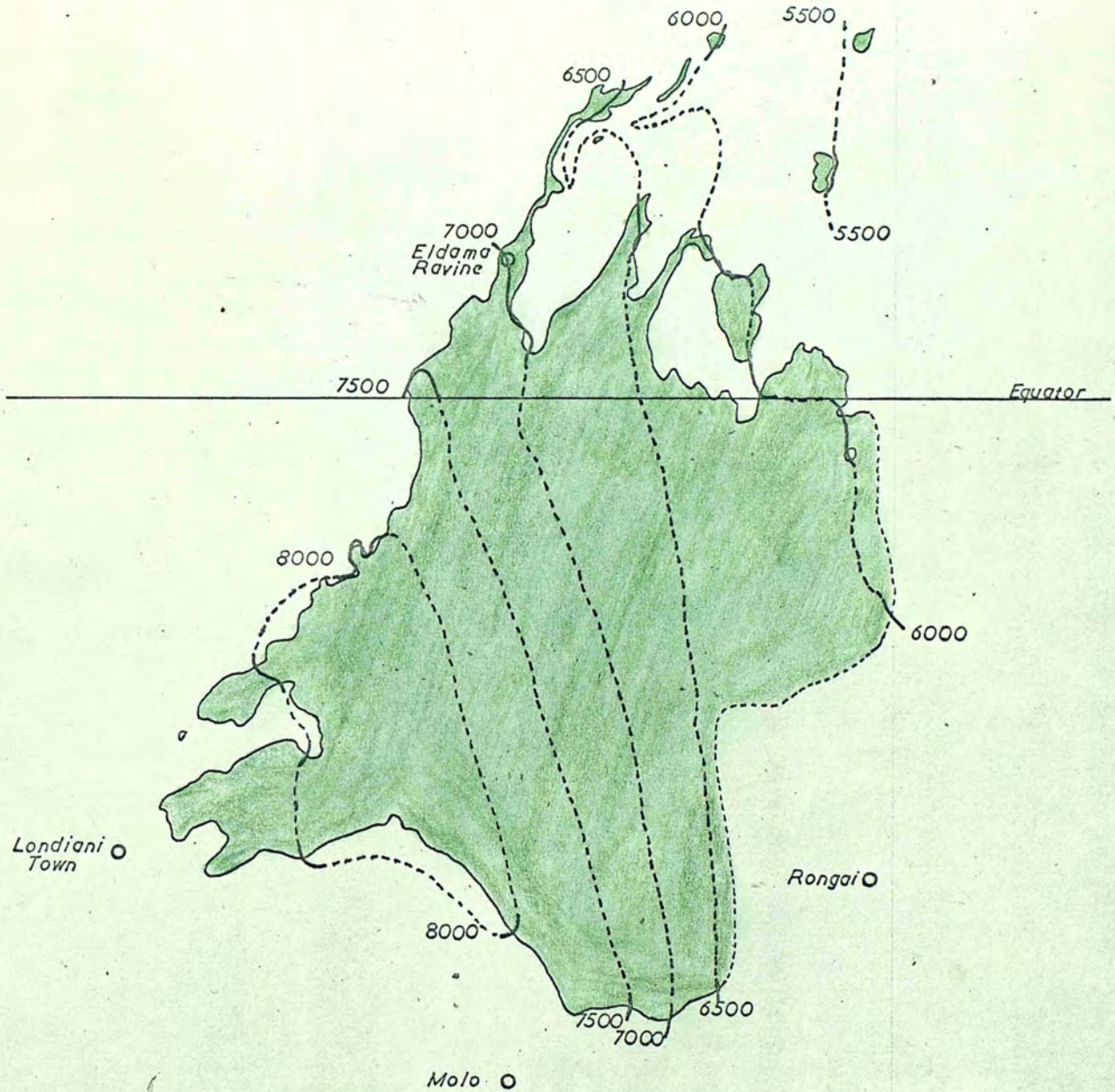
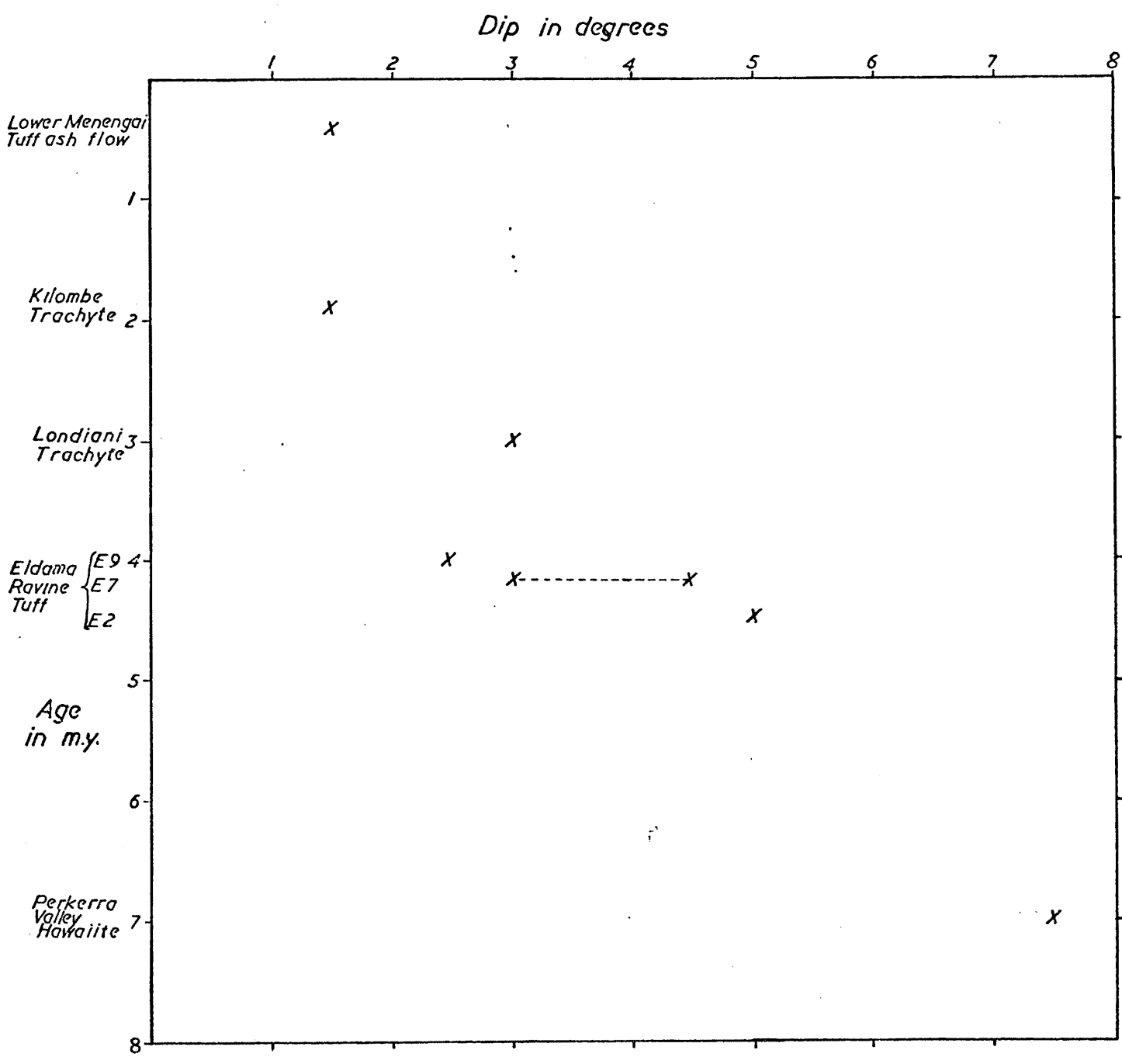


Figure 17. Plot of dip against age of formations on the Equator Monocline



probably largely due to the successive horizons being further south so that the variation is not so much a variation in time as a variation in space. For example the outcrops of E2 from which its south easterly dip can be deduced are all north of the Chemususu. E7 dips to the east south of the Chemususu and curves round to dip in the same direction as E2 north of the river. This shows that a particular direction of dip is characteristic of a particular area and one horizon may dip in different directions in different parts of its outcrop. It seems that the north south Equator Monocline curves round to the north east at its northern end and curves round to the south east to merge into the Mau Monocline at its southern end.

Even though the floor of the rift valley was subsiding throughout the time of eruption of the Eldama Ravine Tuff, it must have remained at least level with respect to the western shoulder as the ash flows continued to flow westward across it. This is readily explained by the assumption that the tuff succession grew more quickly on the rift floor than on the shoulders because a large part of the succession was only deposited close to the source which was probably on the floor of the rift valley. The Kapkut Highlands however remained as high ground and the ash flows banked up against it.

The Londiani Trachyte ends on the eastern side of the mountain at a north south escarpment close to the caldera while flows can be traced for a long way north and west. This shows that at the time of its eruption the ground dipped to the north and west while higher ground in the east prevented the lavas from spreading far from their sources in this direction. The same is true of Kilombe. Thus it is apparent that since the beginning of the eruption of the Eldama Ravine Tuff the general dip of the ground has been northwards and westwards around the upstanding block of Kapkut. Although the east has been continually subsiding with respect to the west the westward dip has been maintained by greater deposition in the east.

Much can be learned by consideration of the history of the Perkerra river. West of Eldama Ravine, where it is known as the Siloi river, it flows generally ENE across Makutano Tuff and Kapkut Trachyte while north of that town it flows along a very straight north easterly gorge. The river was probably initiated on a surface dipping ENE which may have been a dip slope of the Makutano Tuff. After the eruption of the Kapkut Trachyte the river seems to have been deflected to the north east by a north west facing fault scarp in the trachyte as discussed previously. An uprise of the margin of the rift valley with respect both to the rift valley floor in the east and to its source area in the west caused the river to excavate its gorge through the Kapkut Trachyte. This gorge is up to 1000 ft deep on the south east side of Kapkut and 300 ft deep on Murungwa. This uprise of the rift margin initiated the generally westerly dip of the area south of Kapkut which persisted throughout the time of the eruption of the Londiani Assemblage. The gorge was infilled by the Eldama Ravine Tuff although continued erosion by the river partly kept pace with it. This is well illustrated by the occurrence of small patches of Theloi Basalt on the sides of the Perkerra Gorge well below the outcrops of ash flows which it overlies in its main outcrop and of outcrops of Saos Mugearite in a side valley of the gorge near Sigoro. The presence of the Londiani Trachyte flow L18 on its south east rim shows that the gorge was entirely filled in at the time of extrusion of that flow. Since then the river has reexcavated its gorge so that in places, as just west of Eldama Ravine, there is a patchy facing of tuff on the trachyte valley sides.

That the river continued to flow down to the rift valley floor at the time that the Eldama Ravine ash flows were flowing onto the rift margin restricts the range of directions from which the ash flows could have come. The early Eldama Ravine Tuff flow E2 outcrops near

the bottom of the gorge at three places O59116, O98138 and 115156 so the bottom of the gorge is near parallel to the plane of the ash flow. Since the downstream direction of the river is necessarily downhill, and assuming that the gorge had already acquired its present form, then the ash flow had an original component of dip along the river, i.e. N.E. This, with the fact that the ash flow flowed from the floor of the rift valley, shows that it probably came from a direction somewhat south of south east, i.e. from somewhere in the approximate direction of Kilombe. However there is no evidence for how far away the source was.

The present eastward dip of the surface around Londiani Mountain is a recent feature since much of this surface consists of backtilted Lower Menengai Tuff. Erosion of this new escarpment probably gave rise to the Esageri Beds, in which case its age is measured in tens of thousands of years.

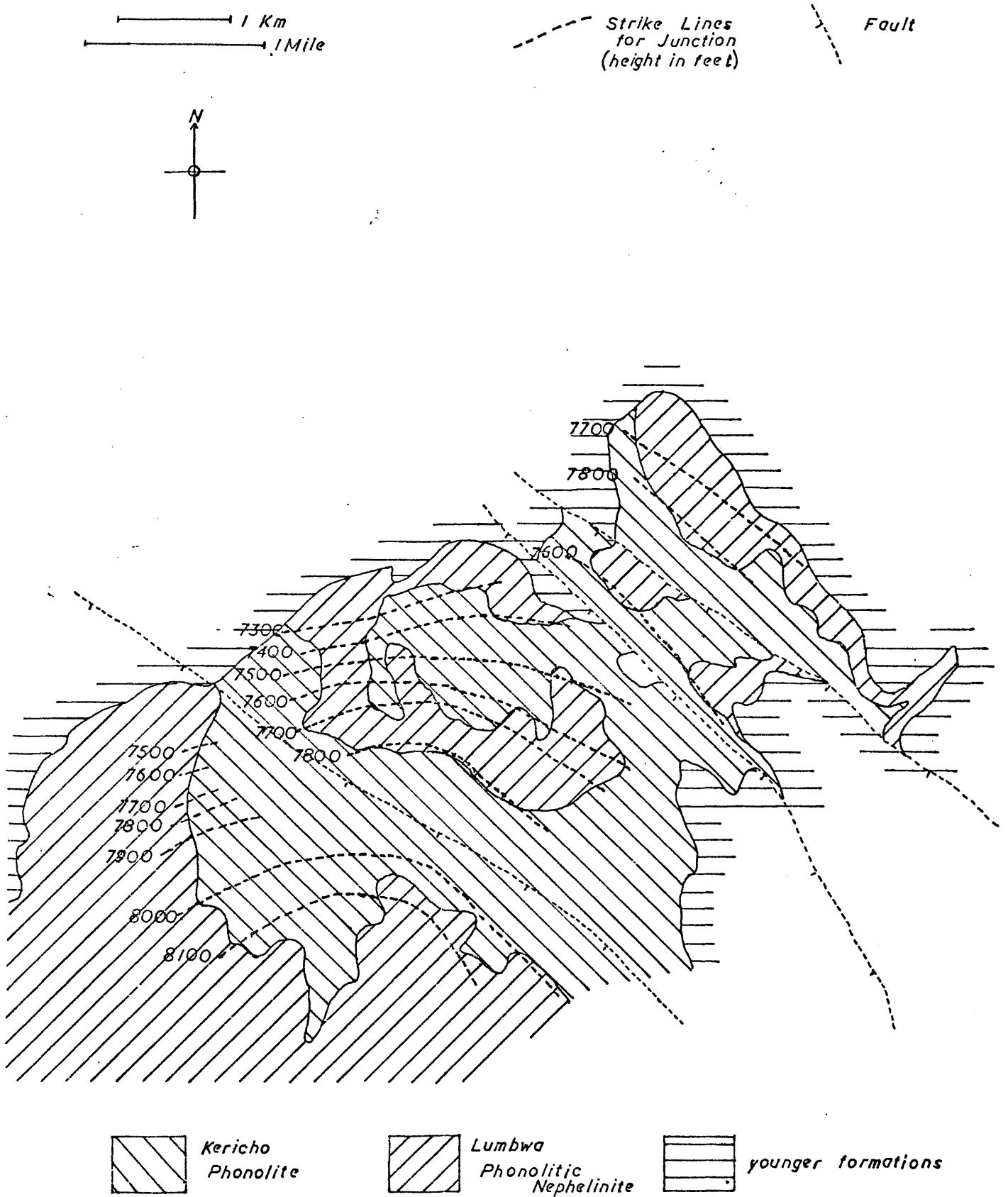
Monoclining of the Mau Highlands

At the northern end of the Mau Highlands the Phonolitic Nephelinite and the Mau Tuff both show a change in their direction of strike. In the east they both dip to the north east forming the northern end of the Mau Monocline. In the west they dip north westwards towards the Londiani Plain along what may be called the Kedowa Monocline as it is most strongly developed near Kedowa.

South of Londiani town the Kericho Phonolite - Phonolitic Nephelinite junction is sufficiently exposed to show it curving round from dipping north east to dipping north west (fig. 18). South west of there the junction is not seen but as the Phonolitic Nephelinite is only about 100 ft thick and forms the ground surface, the dip of the hillside approximates to the dip of the flow. Thus south of Kedowa the Phonolitic Nephelinite dips north westward at about 20° along the Kedowa Monocline. The Makutano Tuff flow P1 can be seen in the field to dip approximately north east. It

Figure 18. Map of Kericho Phonolite - Lumbwa

Phonolitic Nephelinite Junction



outcrops at 7200 ft at 856785 south west of Londiani town and at 7700 ft at 919751 on the Mau, giving a component of dip of $1\frac{1}{2}^{\circ}$ to the north west. This shallow dip is probably close to its direction of strike confirming the outcrop evidence that P1 is dipping approximately north east conformably with the underlying Phonolitic Nephelinite in this area.

The hinge line for the change of strike in the Phonolitic Nephelinite is at the longitude of Londiani town while that for the Mau Tuff runs through Mau Summit as can be seen from the outcrop pattern of M4 (fig. 19). These two are about six miles apart. This shows that there has been an eastward migration of the hinge line with time. This is consistent with the similar eastward migration of eruptive activity and faulting with time.

The Mau Tuff M3 (fig. 20) is affected by the Kedowa Monocline. An outcrop by the river east of Kedowa at 856760 is at 7100 ft while another at 890725 3 miles to the south east is at 8800 ft giving a dip of $6\frac{1}{2}^{\circ}$. Outcrops of M3 around the north west to north east edge of the Londiani Plain all dip inwards (fig. 20). This strongly suggests that the centre of the Londiani Plain has been continually subsiding since the emplacement of M3 and probably since the Londiani Plain was originally formed. Initially the Plain subsided by collapse along the arcuate Londiani Plain Fault but since then the floor has continued to sag in the centre producing inward dips around the edge.

Discussion of the Structures

Curved Faults

The faults may usefully be divided into straight and curved faults. The extreme form of curved faults are the completely circular faults

Figure 19. Distribution map of M4

5 Miles
5 Km

strike lines, heights in feet

Equator

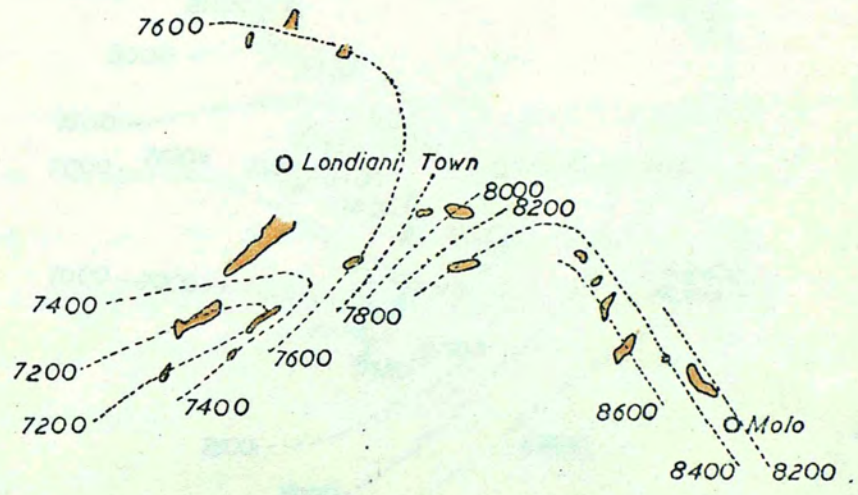


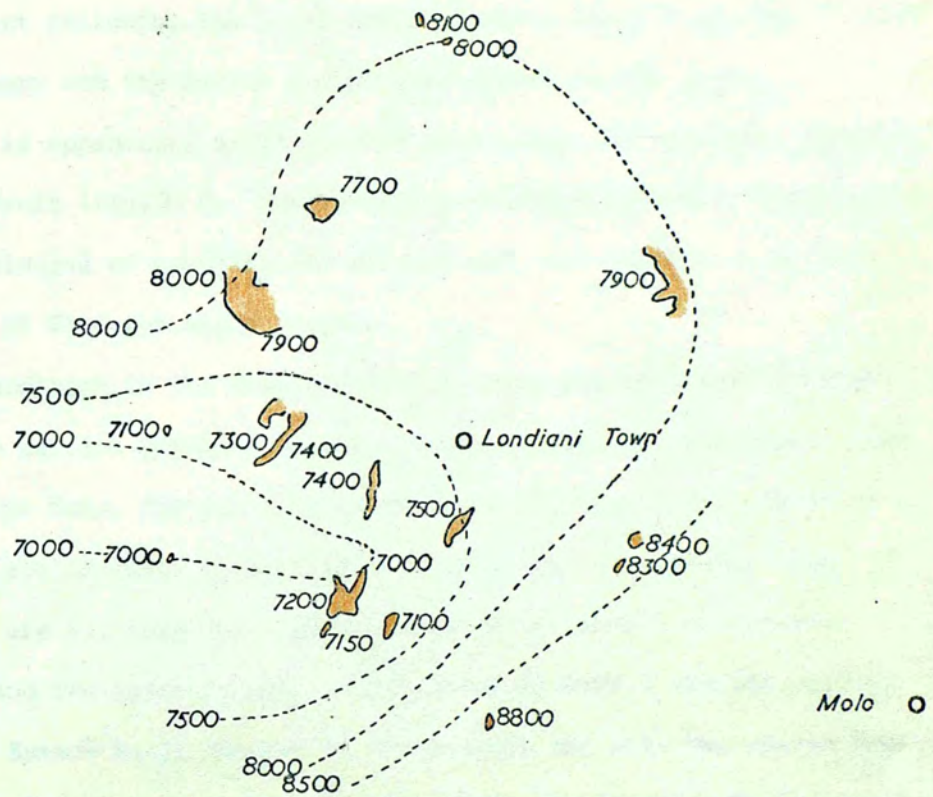
Figure 20 Distribution map of M3

showing heights of outcrops in feet

5 Km
5 Miles

strike lines for M3

Equator

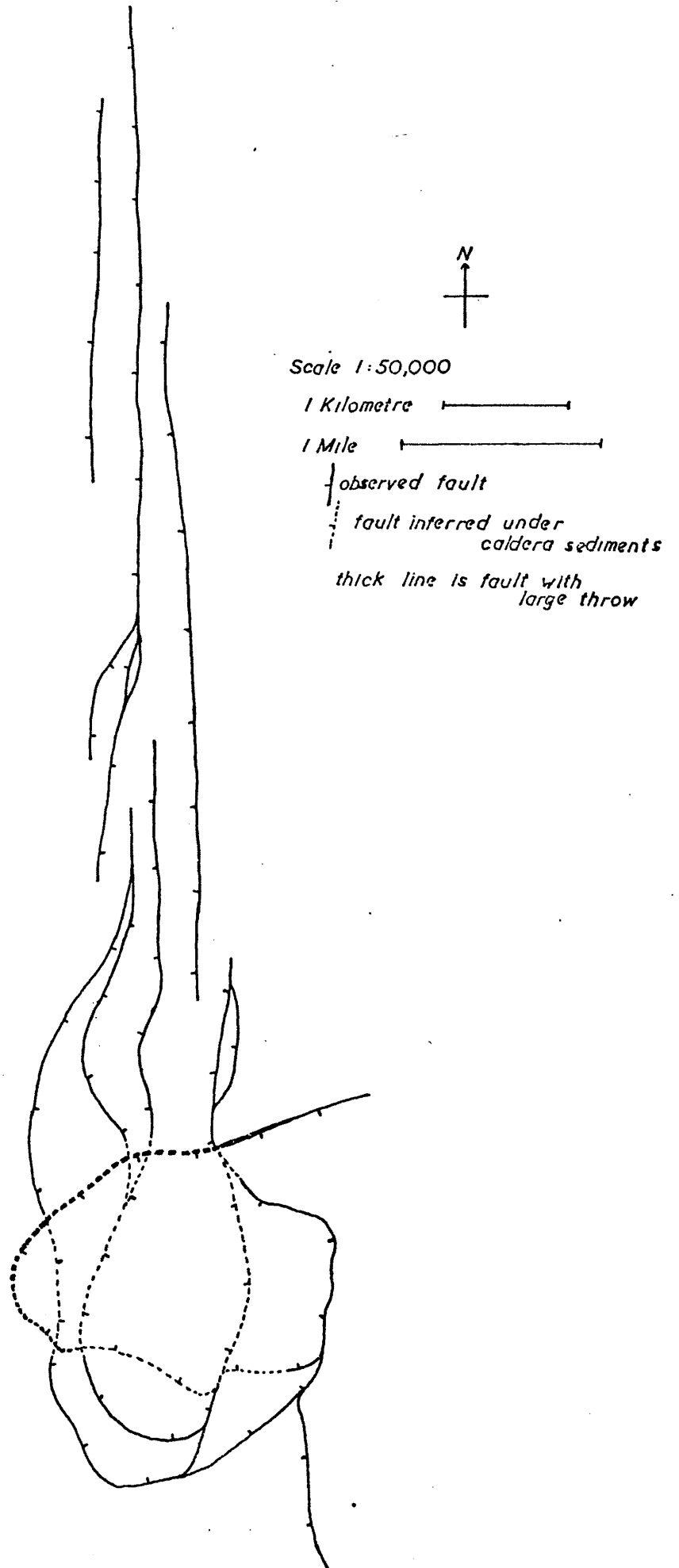


which form calderas. These are only found around centres of eruption sufficiently pronounced to have built up shield volcanoes. This shows that they are caused by local stress fields, possibly associated with high level magma chambers. On the other hand straight faults often follow the same trend over large areas which shows that they are controlled by regional stress fields. This difference is well illustrated by the Kilombe rift zone. At its northern end the faults are straight following the local regional north south trend but towards its southern end the faults become more curved as the centre of eruption is approached until finally they merge into the near circular caldera fault (fig.21). Near circular faults are shown in this area by the calderas of Londiani and Kilombe and just outside it by the calderas of Tinderet and Menengai.

In addition to the circular faults there are developed in this area some partial circular faults. These are the arcuate faults east of Kampi ya Moto, the Londiani Plain Fault and the arcuate fault on Tinderet all of which constitute about a third of a circle. The calderas are all caused by the collapse of the summit of a shield volcano and the large arcuate faults probably have a similar origin.

The Nyando Fault divides at its eastern end into two curved faults along the Mtetei and Kipkurere rivers, both downthrowing to the south. This, on a larger scale, is similar to the straight faults of the Kilombe rift zone which diverge and become curved as the caldera is approached. The Tinderet Basanite is cut by a semicircular fault on its northern side which lets down the higher part of the mountain to the south but there is no corresponding feature on the southern side. This fault thus produces a one sided caldera. The higher part of Tinderet has been let down by these three faults on its northern side, not including the small inner caldera, but is not downfaulted at all on

Figure 21. Fault Pattern of Kilombe



its southern side. This reflects the structure of the Kavirondo Rift just west of Tinderet where the northern side is bounded by the Nyando Fault Scarp but the southern side is just a gentle monocline (Binge 1962).

The Londiani Plain Fault is a partial caldera fault down-throwing the Londiani Plain to the south. It is very similar to the onesided caldera fault of Tinderet and was probably caused by subsidence of the Londiani Plain at the end of the eruption of the rocks of the Timboroa Assemblage. The fault east of Kampi ya Moto is another partial caldera. It was probably initially formed at the same time as the Menengai caldera and is part of the foundering of the volcano.

Fault Trends

Three distinct fault trends are apparent in this area; north-south, north east - south west and north west - south east. South west of Londiani town all three can be seen affecting the Timboroa Assemblage. Here each trend seems to have predominated at a certain time though the evidence for this is not conclusive. In the Londiani Assemblage the north-south and north west - south east trends are represented, apparently active at the same time. North-south faulting occurs in the rift zones north of Londiani and Kilombe calderas while north west - south east faulting forms the rift zone on the south east side of Londiani Mountain. Both trends are shown by the tuff dykes and small faults in the Eldama Ravine Tuffs (fig. 7).

The north-south faulting, occurring throughout the area but especially in the north east, is characteristic of the Kamasia Hills (Lippard 1972). The north west - south east trend of the south and east is the trend of faulting in the Mau Highlands (Jennings 1971) and follows the direction of the floor of the rift valley between Menengai and Longonot. Finally the north east - south west trend, whose most northerly representative is the Perkerra Gorge, is the

principal structural feature of the area on the south side of the Kavirondo Rift and is followed by the Sondu Flexure (Binge 1962). This area is thus the meeting point of three structural provinces; the north-south faulting of the Kamasia Hills, the north west - south east faulting of the central section of the Kenya Rift Valley and the north east - south west trend of the south side of the Kavirondo Rift.

Whether these fault trends apparent in the Tertiary rocks are related to structures in the basement has long been a controversial issue (Shackleton 1951, Binge 1962). In this area it seems that they are. In the Elgeyo escarpment between $0^{\circ} 32'N$ and $1^{\circ} 00'N$ the trend of the Basement System rocks is uniformly slightly east of north (Lippard 1972). This is the same as the faulting in the Kamasia Hills, so clearly the north-south faulting is controlled by the basement. Between $0^{\circ} 32'N$ and $0^{\circ} 22'N$ in the Elgeyo escarpment the Basement System rocks trend NW-SE while from $0^{\circ} 22'N$ to their disappearance at $0^{\circ} 20'N$ they swing round to being north-south again. The Elgeyo Fault follows this curve in the basement. West of the outcrop of the Uasin Gishu Phonolite, between $0^{\circ} 20'$ and $0^{\circ} 05'$ the Basement System rocks trend NW-SE while north of $0^{\circ} 20'$ they strike north-south (Jennings 1964). Thus the NW-SE trend of the Mau Highlands can be seen in the Basement System north of the equator and it may be that the basement follows this trend under the Mau Highlands where it is not exposed.

In the Songhor area the strike of the foliation is north-south but around Koru the foliation is NE-SW (Binge 1962). This NE-SW trend is also shown in the Nyanzian rocks south west of Kericho. The NE-SW foliation of the basement at Koru shows that the Basement System rocks close to the Nyanzian outcrop have taken on the structural trend of the Nyanzian System and this explains how the Nyanzian trend shows up in the Tertiary rocks although they are

underlain by the Basement System. In this area there is a decline in the influence of the Nyanzian NE-SW trend and a rise in the influence of the NW-SE and north-south trends characteristic of the Basement System from west to east. It is known that the Nyanzian is older than the Basement (Cahen & Snelling 1966) and it is likely that the trend of the Nyanzian System has been inherited in the part of the Basement System adjacent to it.

Whereas the three fault trends can all be shown to have their counterparts in the underlying basement it is noteworthy that the east-west strike of the Nyando Fault does not seem to be related to any basement structure.

Relationship of Vulcanicity to Faulting

In some places it is clear that the sites of eruption are controlled by faults and lineaments in the underlying rocks. This is particularly clear for the Londiani Plain Basanite as first noted by Binge (Binge 1962). Lessotet and the hill $1\frac{1}{2}$ miles east of it are both elongated in a north east - south west direction parallel to the lineaments on the Londiani Plain and to much of the faulting south west of Londiani town. This strongly suggests that they were erupted from north east - south west fissures. Limutet is elongated north west - south east and lies on a possible northerly extension of the prominent north-south fault west of Kedowa. It may therefore have formed by eruption of basanite at the junction of a north-south and a north west - south east line of weakness.

Faulting and eruption are often concentrated in the same areas, as in the rift zones of Kilombe and Londiani. Sometimes an eruption can be shown to have occurred along the line of a particular fault and a good example of this is K21 which first appears on the top of the hill 155949 as a very thin and narrow flow and spreads out and thickens

on the lower ground to the west. This flow was almost certainly erupted along the line of the fault which cuts the eastern side of the hill. The Upper Menengai Tuff was partly erupted along the southern part of the fault east of Kampi ya Moto and this fault moved both before and after the eruption. Kilombe caldera, to be described below, shows a wealth of this kind of relationship.

A hypothesis to explain this clear relationship is presented here. Regional tension produces near vertical cracks. These cracks may then act as fissures for magma ascending to the surface. Alternately the two sides may move vertically with respect to each other to produce a fault. Evidence for this is shown by the Eldama Ravine Tuff in which tuff dykes and small faults and joints show the same strikes and steep dips (fig. 7). A third possibility is that these cracks may be picked out by erosion to form linear valleys. Individual cracks may undergo a combination of these things at the same time or at different times.

Evolution of Kilombe Caldera

Evidence was presented in Chapter III which suggests that Kilombe was built up by eruption not from a central vent but from fissures around the edge of the future caldera. The evidence is summarised here:

- (1) The apparently inward dip of flows exposed in the north west face of the caldera wall;
- (2) The early tuffs exposed in the gorge showing their maximum dip just where they are cut out by the outer caldera fault;
- (3) The dyke zone in the gorge passing up into the overlying lavas;

(4) The change in the lavas exposed in the gorge from an outward dip to horizontal at the inner end of their outcrop where they are in contact with the dykes;

(5) The horizontal precaldera lavas exposed between the inner and outer faults along the gorge;

Other points which are important in reconstructing the history of Kilombe are:

(6) The trend towards increasing phenocryst content in the younger lavas;

(7) The extrusion of two postcaldera flows, K12 and K13, along the caldera fault;

(8) The occurrence of syenite as xenoliths only in the post-caldera flows and as large blocks on the flanks of the volcano.

A possible model for the growth of Kilombe is presented here and illustrated in fig.22 .

A) A magma chamber is created at a high level in the crust and is filled with aphyric trachyte magma. The more volatile rich upper part of the magma is erupted from a vent to form a tuff ring.

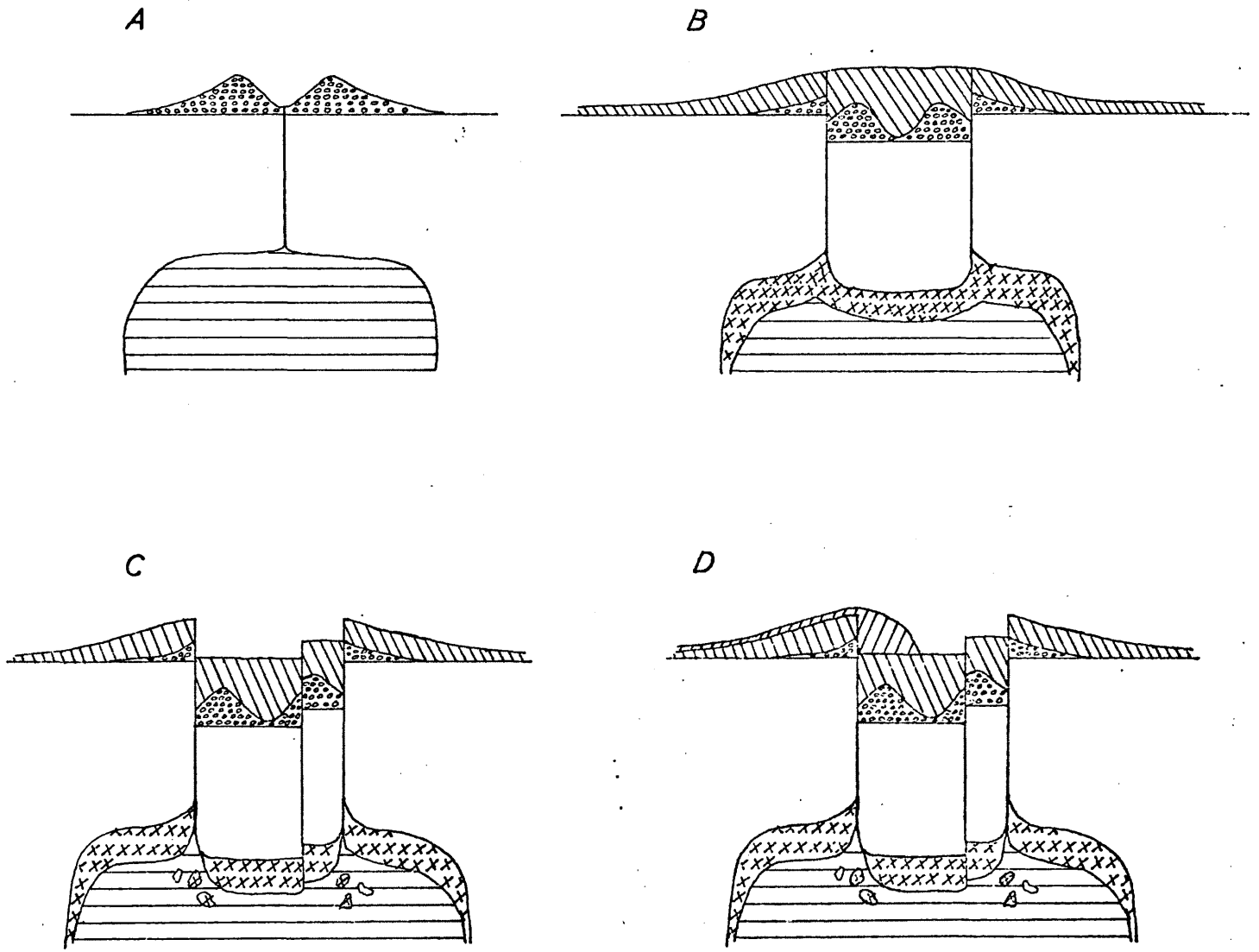
B) This causes a reduction in pressure in the magma chamber so that its roof falls in along a circular fault. Less volatile rich magma then makes its way up the circular fault and is erupted as lavas flowing inwards and outwards to produce a flat topped mountain. Crystallisation begins in the magma chamber so that later lavas are progressively more porphyritic and syenite grows around the edge.

C) Collapse of the roof of the magma chamber along the circular fault, probably consequent upon the withdrawal of magma towards its source, formed the caldera at the surface.


D) Resurgence of magma from depth caused the extrusion of post caldera flows containing pieces of the syenite which was disrupted by collapse of the roof of the magma chamber. Finally violent eruption of gases threw out large blocks of syenite.

Figure 22. Model of the Evolution of Kilombe

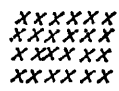
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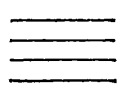


 Tuff

 Precaldera Flows

 Postcaldera Flows

 Syenite

 Magma

Tuff cones similar to that envisaged for Kilombe are common at the south end of Lake Elmenteita. Honeymoon Hill near Nakuru is a possible analogue of the next stage. It is an incomplete tuff ring with walls rising to about 100 ft in which the tuff dips consistently outwards at about 30° . The steep inner face encloses a space half a mile across floored by later ash. This may be a tuff ring whose central part has been downfaulted along a ring fault. Kapkut, which shows a series of hills in a semicircle (see Chapter III), may be a volcano in which lava has been erupted along a circular fissure but without the formation of a later fissure.

In the gorge of Kilombe the dyke zone and the outer fault are close to each other but not in the same place. This is probably because the dykes, once solidified, would be stronger than the tuffs they cut so that the fault plane, following the same general zone of weakness, would form beside rather than in the dyke zone.

Volcanoes of this kind in which eruption has occurred from a circular fissure rather than from a central vent have not, to the author's knowledge, been reported before and may represent a new type characteristic of trachyte vulcanism.

Rift Valley Tectonics

In the early days of geological work in Kenya there were two rival theories for the origin of the Rift Valley; the compressional theory (Bullard 1936) in which the floor of the rift valley was supposed to have been pushed down by the flanks riding up over it along reverse faults, and the tensional theory (Gregory 1921) in which the floor sank along normal faults due to movement apart of the two flanks. It is now generally agreed that the Kenya Rift Valley is a tensional feature.

Widening of the Kenya Rift Valley

It may be suggested that the rift faulting is the result of the collapse of the top of a domal uplift to accommodate the extension of the crust over the dome. A simple calculation demonstrates the inadequacy of this hypothesis. The surface of the basement rocks along the Elgeyo Escarpment is at 5000-8000 ft (Lippard 1972) while west of the outcrop of the Uasin Gishu Phonolite it is at similar heights so that there is no rise in the basement surface towards the rift on the western side. The height of the surface of the basement rocks at Maralal, close to the edge of the rift valley on the eastern side is 6000 ft while at Kom 100 miles further east it is at 2000 ft. The tilting of this block 100 miles long so as to raise its western end by 4000 ft would produce a horizontal gap of about 35 ft at its western end which could be accommodated by a normal fault of 60° dip with a throw of about 60 ft. This clearly has no bearing on the origin of faults of throws of several thousand feet.

To account then for the faulting the two sides of the rift valley must have separated by an amount much greater than that purely attributable to updoming. A minimum estimate of the extension can be found from the faulting. At $\frac{1}{2}^{\circ}N$ the displacement of the basement by the Elgeyo fault is 8000 ft (Lippard 1972) while at the same latitude in the Kamasia Hills the Saimo fault has a throw of 13,000 ft (Martyn 1969). Assuming that the faulting of the eastern side of the rift at this latitude has a total displacement of about 10,000 ft then the horizontal displacement associated with the faulting, with a dip of the fault plane of 60° , is 0.4 miles. Adding to this the effect of the small scale faulting of the rift floor and the extension across the rift due to faulting may not be more than 0.5 miles.

Any great extension across the rift valley would involve separation of the older rocks so that the existence basement rocks in the centre of the rift would be strong evidence against separation. However along the whole of its length in Kenya the central strip of the Rift Valley shows only very young volcanic rocks and no basement xenoliths have, to the author's knowledge, been found in them. Only in northern Tanzania can basement rocks be seen across the width of the rift system.

The minimum distance between corresponding outcrops of old rocks on either side of the rift valley can be used as a maximum measure of the separation of the two sides. The basement rocks outcrop in the Saimo scarp in the Kamasia Hills but not on the opposite side of the rift valley so they do not help. However the Plateau Phonolites of 13.5 - 11.5 m.y. can be used. These outcrops in the southern Kamasia Hills and, as the Kukuruti Phonolite, on the eastern side of Lake Hannington on the other side of the rift valley, which are 25 miles apart. 25 miles then is the maximum distance by which the rift valley has widened since the eruption of the Plateau Phonolite. Separations of the sides of the Kenya Rift Valley of anything from .5 to 25 miles are thus compatible with the geological evidence.

A Model for Rift Valley Structures

Experiments show that rocks under tension fracture along planes perpendicular to the greatest tension while rocks being compressed under a low confining pressure break along conjugate faults and rocks being compressed under a high confining pressure flow plastically. Transferring these results to the Kenya Rift Valley one would expect rocks close to the surface where there is little lithostatic pressure to fracture along vertical faults perpendicular to the main regional tension. This is what is seen in the swarms of young parallel very steep faults along parts of the floor of the Kenya Rift Valley. At depth one might expect the faults to change to dips of about 60° while

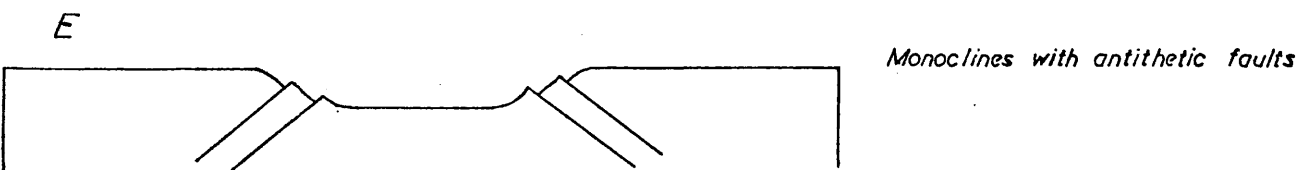
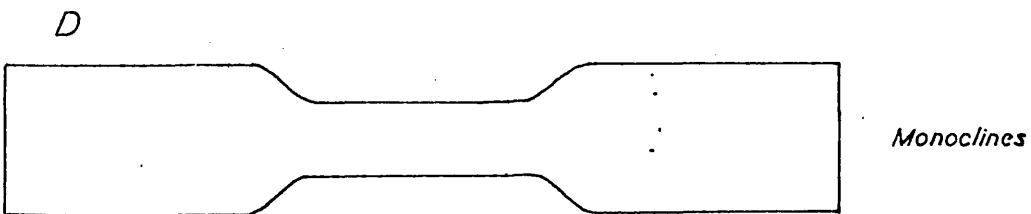
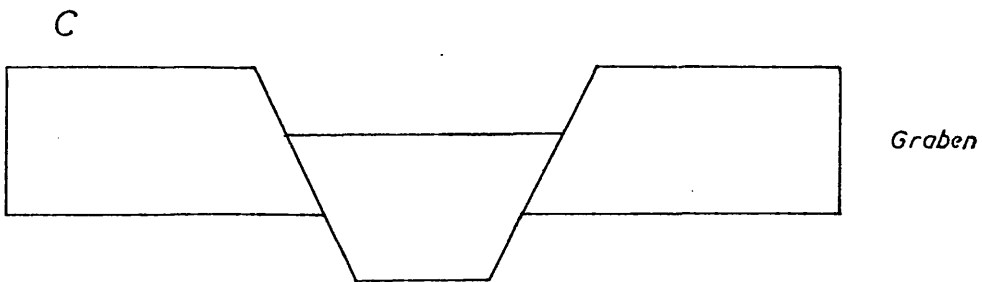
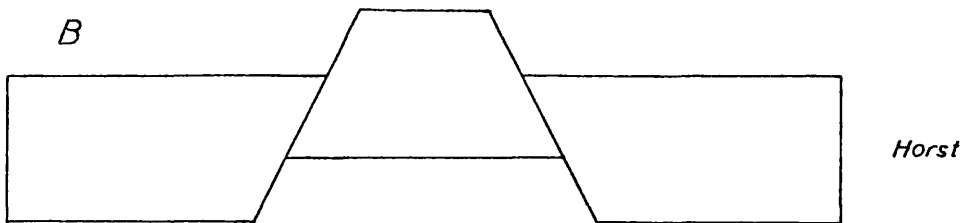
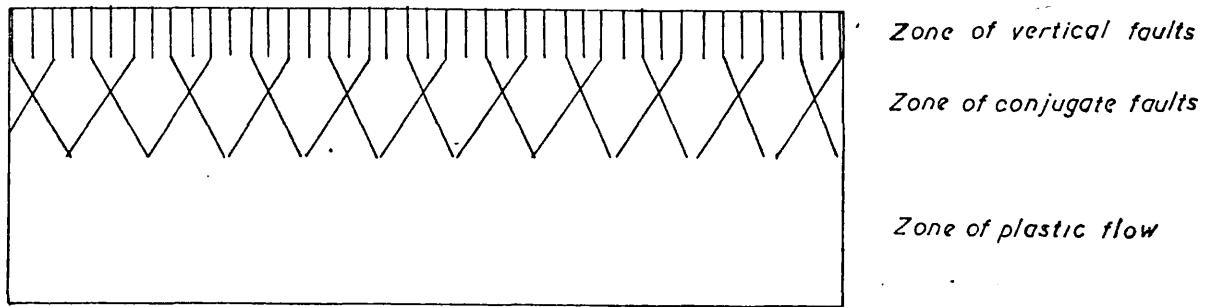
at greater depth faults would disappear and all movement would be by plastic flow (fig. 23A).

A slab of crust under tension may deform by faulting or by necking. Faulting occurs along conjugate faults for which σ_3 , the least compressive stress, corresponds to the direction of maximum tension, σ_2 follows the direction of minimum tension and σ_1 acts vertically to produce either a horst with the centre rising along outward dipping faults (fig. 23B) or a graben with the centre falling along inward dipping faults (fig. 23C). Whether a horst or graben is produced probably depends on whether the supporting pressure under the centre is greater or less than under the flanks. Faults along the edge of the Kenya Rift Valley usually downthrow inwards and outward downthrowing faults seem only to occur near the junction of the Kenya and Kavirondo Rifts. This may be because there is a greater upward pressure of magma under the topographically higher part of the floor of the rift valley.

Necking forms a rift valley bounded on both sides by monoclines (fig. 23D). Necking and faulting may happen together in which case outward dipping faults would tend to occur rather than inward dipping ones since they would give a larger extension for the same throw (fig. 23E). This would produce a monocline with antithetic faults of which the Mau Highlands south east of Londiani Town is a good example. The downtilting and antithetic faulting of the south east side of Kapkut may be explained in the same way.

Often the structure of one side of the rift valley is different from the structure of the other. For example, opposite the antithetically faulted Mau Monocline the margin of the rift is a set of thirteen faults all downthrowing into the rift valley (McCall 1967), while the south side of the Kavirondo Rift opposite the Nyando fault is a monocline (Binge 1962).

Figure 23. Diagrammatic Rift Valley Structures



Chapter V

THE LAVAS AND SYENITE BOMBS

Form and Structure of the Lava Flows

In this section the form and structure of lava flows of different compositions is compared and it is shown that the thickness of flows varies with the composition.

The only place where a good section through a basic flow can be seen is in the Perkerra Valley Hawaiite at O65125. Here a flow 20 ft thick has a vesicular top and is separated from the underlying flow by 4 ft of rubble, which should probably be regarded as its basal part. The Theloi Basalt, which thickens from its source to 200 ft thick on Murungwa, has ponded in a depression behind the barrier of Kapkut Trachyte and therefore its thickness cannot be taken as typical of the basalt flows. It is massive throughout having vesicles only near its top surface. Where the base is exposed near Eldama Ravine at O25068 and O21066 there is no sign of a basal rubbly horizon. The other basalt flows in the Eldama Ravine Tuff are usually represented by nonvesicular round boulders which are the final products of spheroidal weathering and the original form of the flows is lost.

Good sections through flows are seen in the Saos Mugarite where good pahoehoe structures are seen, though the presence in some places of rubbly bases to the flows shows a transition towards aa flows (see Chapter III). These flows seem to be about 40 ft. thick.

The trachyte flows are usually massive and nonvesicular for most of their thickness often with a strongly vesicular upper part in which the vesicles are spherical. Uneroded flow tops are very rare but one such can be seen north of Kabimoi at 107068 where a Londiani Trachyte flow is preserved in the valley down which it flowed. The surface is

smooth with occasional ridges about a foot high perpendicular to the direction of flow. The Kilombe Trachyte flows exposed in the gorge coming out of the caldera are all about 40 ft thick while the Kapkut Trachyte flows on the south east side of the Pekerra Gorge are uniformly about 50 ft thick. Probably the majority of trachyte flows are 40-50 ft thick but many are thicker. Some flows thicken away from their source such as K21 which may be a few tens of feet thick on the steep slope close to its source at 155949 but is about 100 ft thick at 135946 and reaches 200 ft at 109990 near its distal end. Thickening of flows away from their source is also shown by the two flows L16 and L17 which flowed onto the Londiani Plain. The former is 300 ft thick at its front north east of Londiani Town, the greatest known thickness attained by a trachyte flow in this area. Great thickness of trachyte is also shown by the domes Matebei and Kiborit both of which are about 200 ft thick. The thinnest trachyte flow seen was K13 which is about 15 ft thick along the caldera rim.

The Phonolitic Nephelinite on the Mau seems to be a single flow which is 100 ft thick. North west of Kedowa two flows of Timboroa Phonolite are 100 and 150 ft thick respectively. In the phonolites and phonolitic nephelinites vesicular tops and rubbly bottoms of flows are not seen, the outcrops always being massive. This may in part be the result of poor exposure in which only the massive centres of flows outcrop.

Flows of different composition thus resemble each other in being mostly massive with vesicular tops and occasional rubbly bases but there is a steady increase in the thickness of flows from 20 ft for the basic rocks to 40-50 ft for most trachytes to 100-150 ft for phonolites. The thickness of a flow is only dependant upon its viscosity (G.P.L. Walker pers. comm.), so this shows that there is an increase in the viscosity of the magma from basalt to trachyte to

phonolite. The increase in thickness of some trachyte flows away from their source is probably caused by the increase in viscosity of the magma as it cools away from the vent. The abnormal thinness of K13 implies that it had an abnormally low viscosity. This was probably due to it having a very high volatile content since it just preceded the ejection of large syenite blocks by a very powerful gas discharge.

Classification of the Lava Flows

Some specimens representative of all the lava types found were analysed and classified on the basis of their normative mineralogy as explained below and illustrated in fig. 24. The normative feldspars of these specimens are plotted in fig. 25 which also shows the normative feldspars of average rocks of the alkalic suite in Hawaii (Macdonald 1968) for comparison. Other lavas were then classified on the basis of their petrography by analogy with the petrography of the analysed specimens.

The lavas seem to belong to two distinct trends, one mildly and the other strongly undersaturated, which may be distinguished by whether they contain more or less than 10% normative nepheline.

The mildly undersaturated trend is divided according to the percentage of normative An in the total of $An + Ab$. Basalt has $An > 50\%$ ($An + Ab$), hawaiiite has 30-50%, mugearite 10-30% and trachyte $< 10\%$. The hawaiiites and mugearites are further divided at the centres of their ranges into calcic and sodic parts while trachytes containing normative An are termed calcic and those without An are called sodic. For the rocks with $Ne > 10\%$, basanite has $An > 50\%$ ($An + Ab$), nepheline hawaiiite has 30-50%, nepheline mugearite has 10-30% and phonolite has $< 10\%$.

Figure 24. Normative Classification of the Lavas

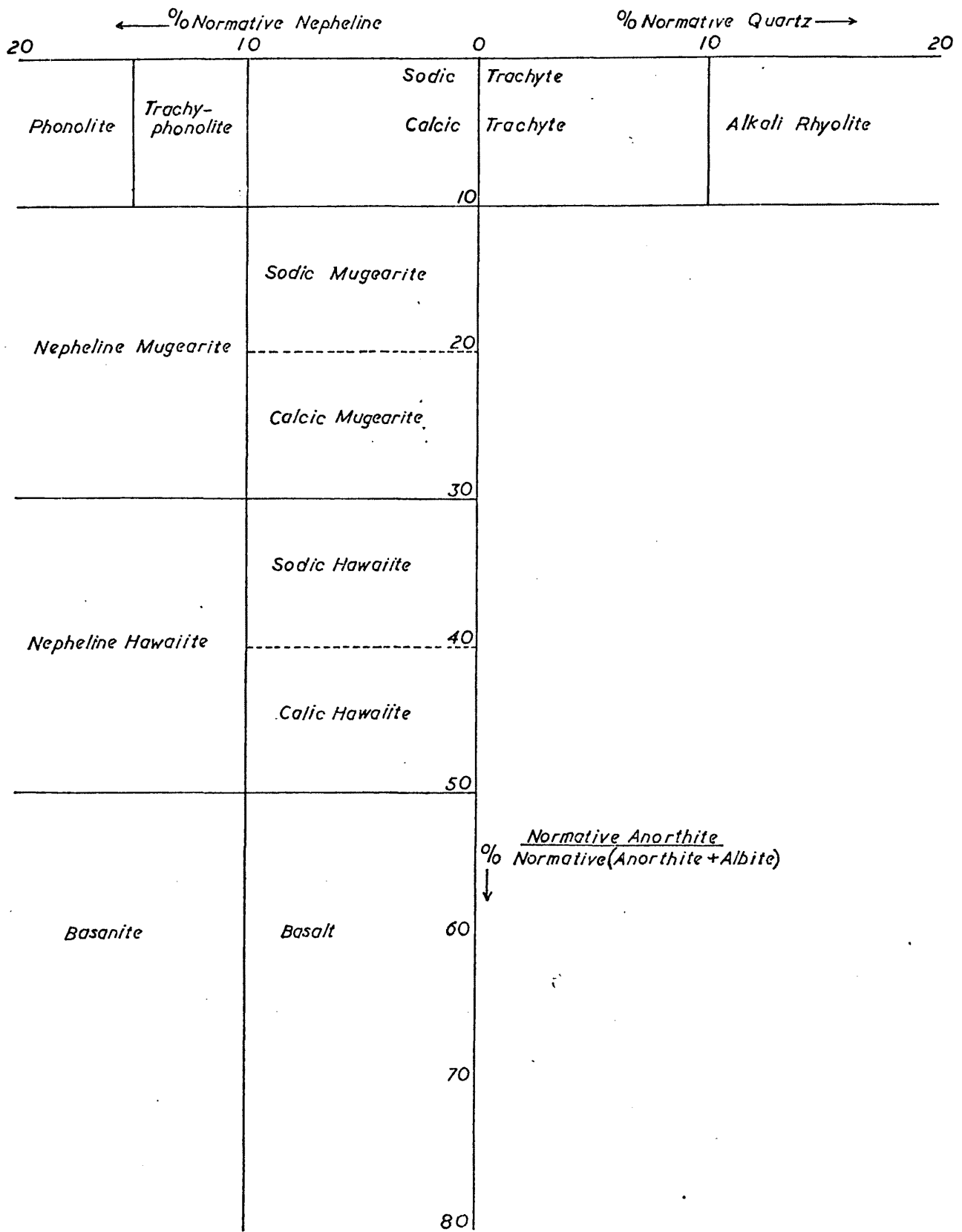
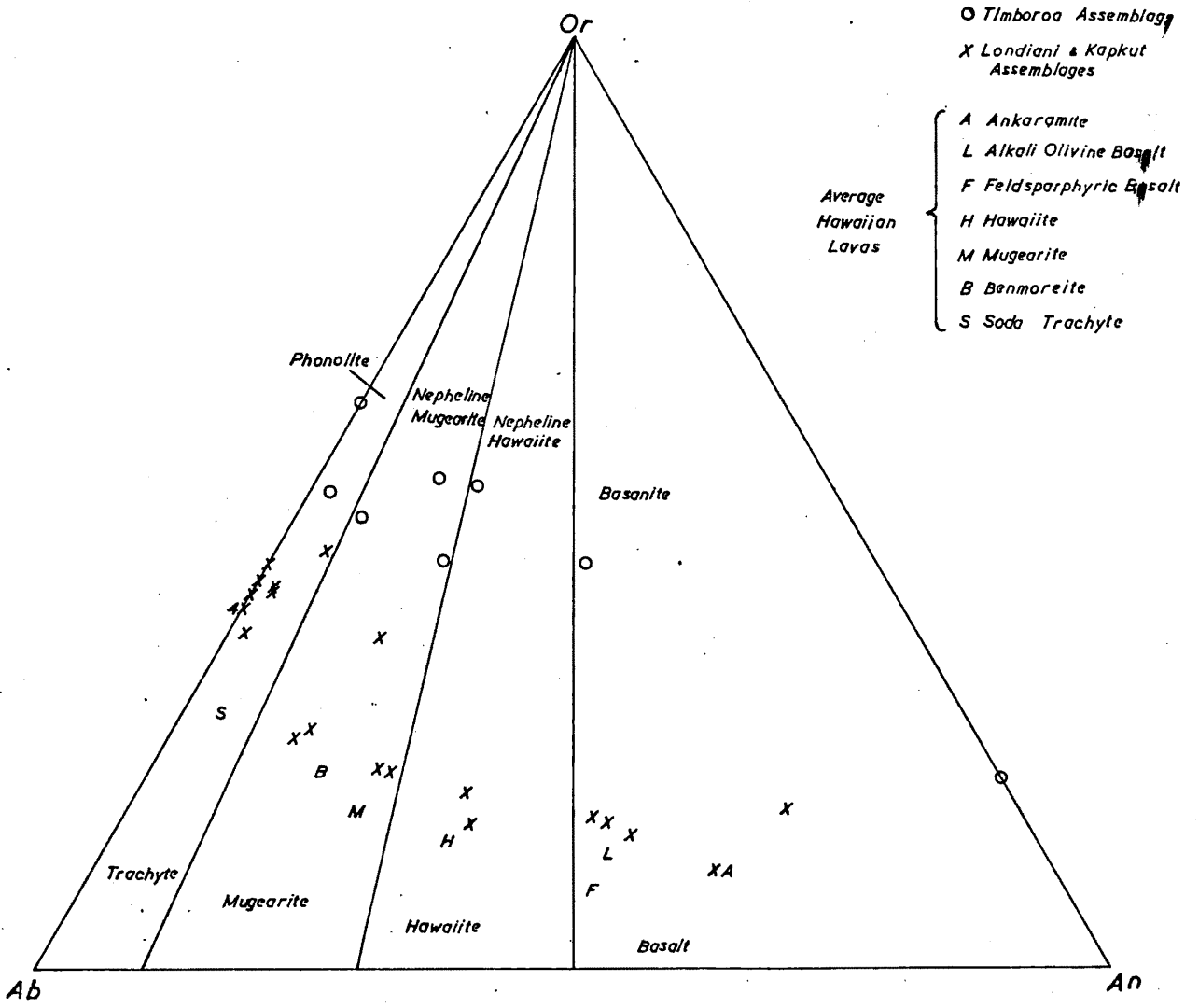


Figure 25. Normative Feldspar Diagram for the Lavas



This classification is similar to that used by previous E.A.G.R.U. workers (Lippard 1972, Weaver 1973) except that it is based on normative rather than modal compositions. Modal compositions were not used because of the difficulty of identifying fine grained groundmass constituents, especially in the more under-saturated rocks. Another weakness of the modal classification is that the assumption it makes that there are two distinct coexisting feldspars in the intermediate rocks is mistaken. In fact there is one feldspar which shows a continuous gradation from oligoclase to anorthoclase (Muir and Tilley 1961). Furthermore the terms 'Benmoreite' and 'Trachymugearite' are not used here since they seem to represent only a small range of composition that is adequately covered by sodic mugearite; for example see the position of the Hawaiian benmoreites in fig. 25.

Petrography of the Lavas

Basalts

Basalts are found in this area only in the Eldama Ravine Tuff and only the Theloi Basalt forms more than just isolated outcrops. In the Theloi Basalt olivine forms colourless microphenocrysts and phenocrysts up to 2 mm long forming 5 to 10% of the rock. Augite occurs as colourless phenocrysts up to 2 mm and exceptionally up to 5 mm long forming 5 to 15% of thin sections. The augite phenocrysts sometimes form clusters with subordinate olivine and occasionally plagioclase and both the isolated phenocrysts and the clusters show a pale green rim. Augite also forms pale green groundmass grains, the total of groundmass and phenocryst augite being about 30%. Plagioclase is sometimes present as phenocrysts forming 0-15%. These have centres of composition An 70% with more sodic margins and are sometimes

marginally corroded. Plagioclase forms laths in the groundmass generally up to 1 mm long, the total of groundmass and phenocryst plagioclase being 40-50% of the rock. Euhedral ore grains in the groundmass make up 10% and a green brown interstitial cryptocrystalline material, probably representing original glass, forms up to 10% of the lava. A small amount of calcite is always present interstitially.

In the feeder dyke olivine, pyroxene and feldspar phenocrysts are set in a groundmass with 25% of a pale grey slightly anisotropic base, probably glass caused by rapid cooling of the magma in the 10 ft thick dyke. There is very little groundmass augite and 15% of ore grains, rather more than in the lava. This suggests that the magma cooled under conditions of higher oxygen fugacity in the dyke than in the lava.

In the Theloi Basalt there is a continuous gradation in size from phenocrysts to groundmass grains in both the augite and plagioclase and furthermore the total percentage of phenocrysts and groundmass grains in the rock is approximately constant for both minerals, however porphyritic the rock. This may be due to differential cooling of different parts of the magma, prior to eruption, in a situation in which crystal setting did not occur, perhaps during a period when the magma was static in the feeder dyke. There is no clear pattern of variation in phenocryst content in different parts of the flow.

The two outcrops of Theloi Basalt exposed on the side of the Perkerra Gorge both show xenoliths of sanidine, strongly corroded and largely altered to a fine mesh of dark minerals but with strongly zoned fresh plagioclase rims. This shows that there has been some admixture of trachyte or phonolite liquid in the basalt. One specimen of Theloi Basalt, 14/108A, contains a xenolith of quartzite with a reaction rim of clinopyroxene, the only non-igneous xenolith found in the Londiani area.

The other basalts in the Eldama Ravine Tuff are petrographically similar to the Theloi Basalt. Specimens from Maji Mazuri (14/145) and Makutano (14/147) both show xenoliths of oligoclase with strongly zoned more calcic rims, with implications the same as for the sanidines in the Theloi Basalt.

Basanites

Basanites are volumetrically unimportant in this area forming only the Londiani Plain Basanite, the flow in the Lumbwa Phonolitic Nephelinite, the flow in the Makutano Tuff and the small dome at 948076. To the west they are extensively developed on the higher part of Tinderet.

The basanites of the Londiani Plain contain up to 40% of phenocrysts which are olivine or olivine and colourless augite. Perovskite microphenocrysts are sometimes present. The groundmass consists of plagioclase laths, colourless pyroxene prisms, ore grains and 10-25% of near isotropic base in which the feldspathoidal minerals are presumably occluded.

The basanite flow in the Lumbwa Phonolitic Nephelinite contains olivine or olivine and augite phenocrysts in a groundmass of pyroxene, ore and sometimes feldspar in a large amount of cryptocrystalline base containing fine disseminated ore. For example where it outcrops by the railway at 801796 it consists of 15% olivine phenocrysts in a groundmass of 25% pyroxene, 10% ore and 50% base with amygdales of natrolite.

Although feldspar phenocrysts were occasionally seen in the field in the basanites, they were only found in thin sections in the flow in the Makutano Tuff. This flow then, with augite, olivine and plagioclase phenocrysts is probably transitional to the basalts. It is also notable in containing strongly resorbed alkali feldspar phenocrysts.

The basanites of Tinderet have abundant phenocrysts of augite and ore forming up to 40% of the rock. The augites have pale green cores, showing a gradation towards ferroaugite, and pale lilac rims, tending towards titaniferous augite, with sharp boundaries between them. Olivine phenocrysts are rare. The groundmass has ore, lilac augite, plagioclase and a cryptocrystalline base. Some specimens contain a small amount of interstitial carbonate. One specimen, 14/1053, contained rounded patches rich in tiny ore grains which are probably pseudomorphs after kaersutite (see below). 14/1053 also showed a coarse grained xenolith of pale green augite with subordinate ore and apatite in which the pyroxene had a pale lilac rim where in contact with the groundmass. The later basanites of Tinderet have plagioclase phenocrysts of composition An 60% as well as the ore and augite. In these later basanites the augite phenocrysts reach 1 cm long.

The Tinderet basanites, because of their pale green pyroxene and relatively sodic plagioclase are at the end of the range of basanites and probably overlap into nepheline hawaiites.

Hawaiites

Hawaiites occur in three small areas of the Kapkut Assemblage as the Perkerra Valley, the Chemususu and the Murungwa Hawaiites and constitute about half of the Saos Mugearite.

Plagioclase phenocrysts are usually present, forming up to 35% of the rock. The lavas with the large platy plagioclase phenocrysts, such as the Perkerra Valley Hawaiite and the Chemususu Hawaiite form a distinctive easily recognised lava type in the field. An evolutionary trend can be seen from lavas in which the centres of the phenocrysts are about An 70% to more sodic lavas in which the centres are An 55%. These

phenocrysts are zoned to more sodic compositions marginally, with a zone of inclusions near the margin and with the calcic core often strongly corroded. These features are more marked in the calcic rocks. The groundmass plagioclase ranges from An 40% in the calcic rocks to more sodic compositions.

Olivine forms small phenocrysts grading to large groundmass grains. The proportion of olivine in the rock drops from 10% at the calcic end of the series to 2% at the sodic end. The olivines are almost entirely converted to iddingsite except at the centres of the larger phenocrysts. Sometimes a thin rim of fresh olivine mantles the iddingsite, showing that the iddingsitisation process ceased before crystallisation was complete. One specimen 14/589, contains 20% of olivine, largely as phenocrysts up to 3 mm long, probably representing a liquid in which excess olivine has accumulated.

Pyroxene occurs only in the groundmass as small grains, colourless or occasionally pale lilac, forming 10% of the rock. Ore forms small euhedra, occasionally up to microphenocryst size, constituting 10% and rarely up to 20% of thin sections. One also occurs sometimes as tiny needles, presumably of a different composition to the euhedra. The hawaiites are usually holocrystalline but vesicular specimens have up to 30% cryptocrystalline glass, in which case pyroxene is absent.

14/522 contains a few xenoliths of sanidine. These are strongly embayed and have a fresh core with a rim clouded with ore grains and finally a thin marginal zone of sodic plagioclase in optical continuity with the core.

Mugearites

Mugearites form the Lembus Mugearite and about half the Saos Mugearite but fairly fresh specimens can only be obtained from the Saos Mugearite.

They do not contain large feldspar phenocrysts. The plagioclases form microphenocrysts up to 2 mm long in which the centres are An 60% at the calcic end and An 40% at the sodic end, zoned outwards to more sodic compositions. The groundmass feldspar forms laths of oligoclase. Olivine is usually present as occasional microphenocrysts sometimes largely altered to bowlingite. Colourless pyroxene grains, sometimes reaching microphenocryst size, form 10-20% and ore grains form about 10% of the rock.

Two amphiboles appear in the mugearites. Occasional phenocrysts of kaersutite are strongly altered to ore and pyroxene and often completely pseudomorphed by them, while katophorite appears in the groundmass in some sections. Interstitial cryptocrystalline brown or green material is usually present and can constitute up to 20% of the rock.

An unusual mugearite is 14/533. This contains 2% of strongly corroded sanidine phenocrysts and the groundmass is one third oligoclase laths and two thirds subpoikilitic alkali feldspar. This rock was probably formed by the mixing of one part of aphyric mugearite liquid and two parts of porphyritic trachyte liquid.

Nepheline Mugearites and Nepheline Hawaiites

Rocks of this range of composition are found only in the extreme south west of the area, as the Lumbwa Phonolitic Nephelinite and the basal flow of the overlying Timboroa Phonolite. The name 'phonolitic nephelinite', like the similar 'nephelinitoid phololite' (Holmes 1920) and 'nephelinite phonolite' (Johannsen 1938) implies a rock with more nepheline than feldspar. However the analysis of 14/957, which can be taken as representative of the great majority of these lavas, shows that they contain more feldspar than nepheline. It is therefore incorrect to call them phonolitic nephelinites and 14/957 is a nepheline mugearite. Nevertheless the Lumbwa Phonolitic Nephelinite is a useful stratigraphic term and is retained since it is in keeping with the usage of the Kenya Geological Survey (Binge 1962, Jennings 1964 & 1971).

The nepheline mugearites have up to 30% of phenocrysts, chiefly euhedral nepheline and pyroxene with minor sphene and ore and sometimes apatite and anorthoclase. The pyroxene is pleochroic with α pale green, β pale yellow and γ golden yellow and has $\gamma:z \sim 50^\circ$ which indicates that it is ferroaugite. The pyroxene phenocrysts sometimes have lilac titanite rims and in other sections have darker green aegirine-augite rims. The groundmass is fine grained with aegirine, ore, alkali feldspar laths and a cryptocrystalline base which can be up to 40% of the rock.

Of the glassy rocks that outcrop north of the railway at 790803 has nepheline, melilite and a few perovskite phenocrysts in a black glassy base with occasional vesicles filled with three distinct zeolites. Around the phenocrysts and vesicles the base has devitrified to brown and green cryptocrystalline minerals. The melilites are length slow and are zoned, the maximum birefringence increasing from .007 in the centre to .016 at the margin. This shows that the melilite is close to the akermanite end-member and is zoned outwards probably to near pure akermanite (Deer et al 1966). It would be tempting to call this a melilite nephelinite but this would be incorrect as the chemical analysis of this rock, 14/1034, shows that it has more normative feldspar than nepheline and is a nepheline hawaiite according to the classification used here. The glassy rock on the south side of the railway at 793765, 14/1046, is similar. It has sparse nepheline and ferroaugite microphenocrysts and tiny nepheline euhedra and melilite microlites in an isotropic base which is coloured in bands of brown and green. In this rock the melilite is also length slow but is less akermanite-rich, having a birefringence of only about .005.

A section of the pyroxenephric flow at the base of the Timboroa Phonolite, 14/1037, shows sparse ferroaugite, nepheline and sanidine phenocrysts with microphenocrysts or ore and biotite. The nephelines

show exsolution lamellae, presumably of kalsilite. The biotites, have a reaction rim of tiny ore grains but one unaltered crystal was seen enclosed in a nepheline phenocryst. The groundmass consists of small sanidine laths, aegirine, aenigmatite and a near isotropic base. Petrographically then this rock resembles the plateau-type phonolites (see below) except for its ferroaugite phenocrysts and is clearly transitional between the nepheline mugearite and phonolite.

Trachytes

Trachytes are abundant, forming the volcanoes Kilombe, Londiani and Kapkut. Fresh rocks were not found on Kapkut so this description concentrates on the lavas of Kilombe and Londiani. Generally there is nothing in the petrography which distinguishes between these two volcanoes.

In the trachytes feldspar phenocrysts may be absent or may form up to 35% of the rock. In the calcic trachytes these phenocrysts are anorthoclases with rhombic outlines and well developed cross-hatched twinning. In the soda trachytes they are simply twinned laths with their OAP perpendicular to (010) in which ghost albite twinning can sometimes be seen. These phenocrysts, especially the more calcic ones, have a zone of inclusion of groundmass minerals near their margins followed outwards by a zone of clear feldspar of slightly different optical orientation. In extreme cases this outer zone follows a strongly embayed outline of the inner zone. The groundmass alkali feldspar has a pronounced fluidal texture and often has a bimodal grainsize distribution, the larger grains being up to 1 mm long and sometimes just visible to the naked eye, as in the flow L4. With their phenocrysts, such rocks show three phases of feldspar crystallisation.

Olivine occasionally appears as pale yellow microphenocrysts with reaction rims of aenigmatite. Pyroxene forms tiny green prisms of aegirine in the groundmass and sometimes pleochroic green to yellow green ferroaugite microphenocrysts which are rimmed by aegirine. The

ferroaugite is often altered to a phyllosilicate mineral. In the less altered microphenocrysts a ferroaugite core is surrounded by a yellow highly birefringent mantle resembling the interstitial base, in turn enclosed by a rim of green aegirine. In the most advanced state of alteration the microphenocryst is entirely pseudomorphed by a red brown mineral which previous E.A.G.R.U. workers have called 'hydrobiotite' (Weaver 1973), the (0001) cleavage of the hydrobiotite being parallel to the (100) faces of the original pyroxene. The presence of ferroaugite cores in the less altered pyroxenes and of aegirine rims around all but the most altered ones indicates that the alteration postdates the growth of the pyroxene microphenocrysts and predates the crystallisation of the groundmass, a process clearly analogous to the iddingsitisation of olivine.

Aenigmatite is invariably present while ore is only occasionally seen as small microphenocrysts mantled by aenigmatite. An amphibole in the groundmass has α , near colourless, close to X and β , green, close to Z while γ , lilacish brown is along Y. This often grades outward to a mantle in which α , near colourless, and β , blue, have rotated to be both about halfway between X and Z, while γ , now brownish lilac, remains along Y. The birefringence is in the lower part of the first order, α and β being very close, and, particularly in the mantles, there is pronounced anomalous extinction. This optical scheme suggests that the cores are katophorite and the mantles are transitional to arfvedsonite (Deer et al. 1966).

Aenigmatite, aegirine and katophorite all form subpoikilitic or mossy patches in the groundmass. The sum of the percentages of the aegirine and katophorite is about the same as the aenigmatite which is 10-15%. Usually there is about twice as much pyroxene as amphibole but in the more evolved rocks there may be more amphibole than pyroxene. An interstitial pale yellow brown cryptocrystalline highly birefringent

material forms 5-20% of the trachytes. It is probably an aggregate of clay minerals formed by alteration of an original glass. In sections with little interstitial material the small feldspar grains form allotriomorphic interpenetrating masses.

Although the major element analyses show the trachytes to be slightly quartz normative, quartz has only been seen in a few sections. It forms pools of equidimensional grains in the groundmass. A few rocks, such as 14/692, have fine grained patches of what seems to be a myrmekitic intergrowth of quartz and feldspar. The only rock in which substantial amounts of quartz was seen is 14/382 from L13 which contains about 25% modal quartz and so is a pantellerite. Such quartz rich rocks were not seen on Kilombe.

The dome Kiborit consists of a slightly undersaturated aphyric trachyte containing sparse small euhedral isotropic crystals mantled by aegirine. The 0.13% of Chlorine detected in the rock, 14/581, shows that this mineral is sodalite.

In the flow K17 there are xenoliths of a purple vesicular porphyritic rock. They range in size from a few mm to 30 cm and have irregular rounded outlines, the smaller ones sometimes being amoeboid. They have about 20% of anorthoclase phenocrysts which can be up to 5 cm long. There are also small ferroaugite phenocrysts partly altered to hydrobiotite. The groundmass is dark and cryptocrystalline in the smaller xenoliths and fine grained with 10% pyroxene prisms and 20% ore, partly as small euhedra but mostly as ragged needles, set in a base of equidimensional alkali feldspar in the larger xenoliths. This fine grained groundmass looks as if it was rapidly chilled. One very corroded plagioclase phenocryst was seen of composition An 50% showing that the xenolithic material has incorporated some more basic liquid. The xenoliths seem to be intermediate in composition between the trachytes and the mugearites

of the Saos Mugearite, representing a rock type which is nowhere seen to outcrop. The smaller xenoliths are finer grained than the larger and this together with their rounded irregular shapes strongly suggests that they were liquid when incorporated in the trachyte. The mugearitic liquid, having presumably a higher melting point than the trachyte liquid, would have been rapidly chilled, the smaller blebs of liquid becoming finer grained than the larger. Blebs of the same material up to 5 cm across were also seen in the field in the flows K6, K8 and K13, in the last of which they can be seen to grade to large isolated anorthoclase phenocrysts with no mugearitic matrix about them. This implies that during the eruption of the Kilombe Trachyte a body of porphyritic mugearite was available at depth which never erupted to form a flow of its own but blebs of which were incorporated in some of the trachyte flows. A similar situation has been reported from Iceland where basalt blebs were incorporated in a rhyolite flow (Blake et al. 1965).

The Kapkut Trachyte lavas, including the Kedowa Pillar Trachyte, are similar to the trachytes of Londiani and Kilombe but are generally more porphyritic while the ferroaugite phenocrysts are invariably altered to hydrobiotite and katophorite predominates over aegirine. Small porphyritic mugearite xenoliths, a few cm across, similar to those in the Kilombe Trachyte, are fairly common in the Kapkut Trachyte flows exposed on the south side of the Perkerra gorge and on the north west side of the Sigoro Plateau and, as at Kilombe, there is no known outcrop of this rock type around Kapkut. The post Sigoro Tuff flow which flowed down the valley to the Perkerra gorge has about 15% of very fresh alkali feldspar phenocrysts in a very fine grained ground-mass of alkali feldspar, aegirine, katophorite-arfvedsonite and a near isotropic base which forms about half the rock.

Some boulders which seem to have weathered out of the Makutano Tuff at the northern end of the Mau Highlands, such as 14/900, are trachytes similar to those described above and have alkali feldspar phenocrysts in which the OAP is perpendicular to (010). However one specimen, 14/874, is an alkali rhyolite with 25% quartz in groundmass pools. This rock contains alkali feldspar phenocrysts in which the OAP is parallel to (010) which indicates that these phenocrysts are more potassium rich than those seen in any of the lavas (Deer et al. 1966). This alkali rhyolite then represents a lava type which has not been found outcropping in this area.

The petrography of the analysed specimens of Kilombe and Londiani trachytes is tabulated in Table 3.

Phonolites

Phonolites are represented by the Kericho Phonolite, the Timboroa Phonolite and the Mt. Blackett Phonolite.

The Kericho Phonolite has sparse phenocrysts of nepheline, sanidine and biotite in a fine grained groundmass of alkali feldspar laths, mossy patches of aegirine, aenigmatite, sometimes cored by ore grains, and less abundant, sometimes even absent, katophorite-arfvedsonite, in a very low birefringent base. The groundmass is sometimes spherulitic and sometimes segregated into mafic-rich and mafic-poor bands. In one specimen, 14/894, a biotite crystal is half embedded in a nepheline phenocryst and the end in the nepheline is fresh while the end in the groundmass has a reaction rim of ore grains, showing it to have been out of equilibrium at the time of crystallisation of the groundmass.

The Londiani Phonolite is more variable in its petrography. It also has sparse phenocrysts of nepheline, alkali feldspar and biotite; the biotite here however, not showing any sign of reaction with the groundmass. The groundmass minerals are the same as in the Kericho

Phonolite but the range of grain size is greater, the groundmass being sometimes completely cryptocrystalline. Some specimens, e.g. 14/100, contain microphenocrysts of ferroaugite rimmed by aegirine, showing a transition towards the nepheline mugearites. In one section with a cryptocrystalline groundmass, 14/88, a fresh kaersutite microphenocryst was found while in a crystalline specimen, 14/1031, two rounded patches were seen with remnants of kaersutite in the centre and soda amphibole around it, both minerals being peppered with tiny ore grains. Patches of ore grains in a few other sections may also be pseudomorphs of kaersutite. It seems that on extrusion the phonolites contain the hydrous minerals biotite and sometimes kaersutite. Kaersutite is rapidly destroyed in all but the mostly quickly cooled lavas while biotite only sometimes begins to react with the crystallising groundmass.

A section of the phonolite of Mt. Blackett, 14/955, has rare nepheline and alkali feldspar phenocrysts in a groundmass the same as in the other phonolites but much coarser, as would be expected in an intrusive rock.

Trachyphonolites

The trachyphonolites in this area are the Emining, Kilelwa Hill and Rongai Plain Trachyphonolites. These resemble the trachytes in having alkali feldspar phenocrysts and unaltered ferroaugite microphenocrysts in a coarse grained fluidal groundmass of alkali feldspar laths subpoikilitic aegirine, aenigmatite and soda amphibole and a yellow-brown cryptocrystalline base. They differ in also having small euhedra of nepheline up to microphenocryst size, small euhedra of sodalite and pools of analcite and zeolite. The difference between the trachyphonolites and the phonolites is that the former are coarser grained, have a yellow brown cryptocrystalline base, show a gradation

from phenocryst to groundmass feldspar, have a fluidal texture and contain small euhedra of sodalite. These differences, except for the presence of sodalite microphenocrysts in the trachyphonolites, are the same as those recorded by Lippard (1973) from consideration of the Elgeyo-Kamasia area. This last distinction is brought out by comparing the chlorine analyses of two trachyphonolites; 0.18% for 14/369 from the Rongai Plain and 0.26% for 14/609 from the Kilelwa Hill Trachyphonolites, as well as 0.13% for 14/581, the sodalite bearing undersaturated trachyte of Kiborit, with the 0.01% for 14/924 from the Kericho Phonolite. Similar sodalite microphenocrysts have been found to be common in the trachyphonolites of Mt. Suswa (Nash et al. 1969).

Petrographic Evidence for the Petrogenesis of the Lavas

It is clear from the petrography that there are two distinct series of lavas; the basanite to phonolite trend which includes the Kericho Phonolite, the Timboroa Assemblage and the Tinderet and Londiani Plain Basanites; and the basalt to trachyte trend which includes the Kapkut and Londiani Assemblages except for the Londiani Plain Basanite.

The petrographic continuity of the rocks within each trend shows that they are genetically related. All but a few of the lavas are porphyritic and many of the sections examined have cognate xenoliths formed of clusters of the phenocryst minerals, particularly the basalts and basanites, e.g. the Tinderet basanite 14/1053. Some rocks contain excess phenocrysts such as 14/589, a hawaiite from the Saos Mugearite, in which olivine phenocrysts seem to have accumulated. The Kilombe Trachyte flow K8 is in places aphyric and in others strongly porphyritic with up to 30% of large anorthoclase phenocrysts showing that there can be considerable variation in phenocryst content in a body of magma,

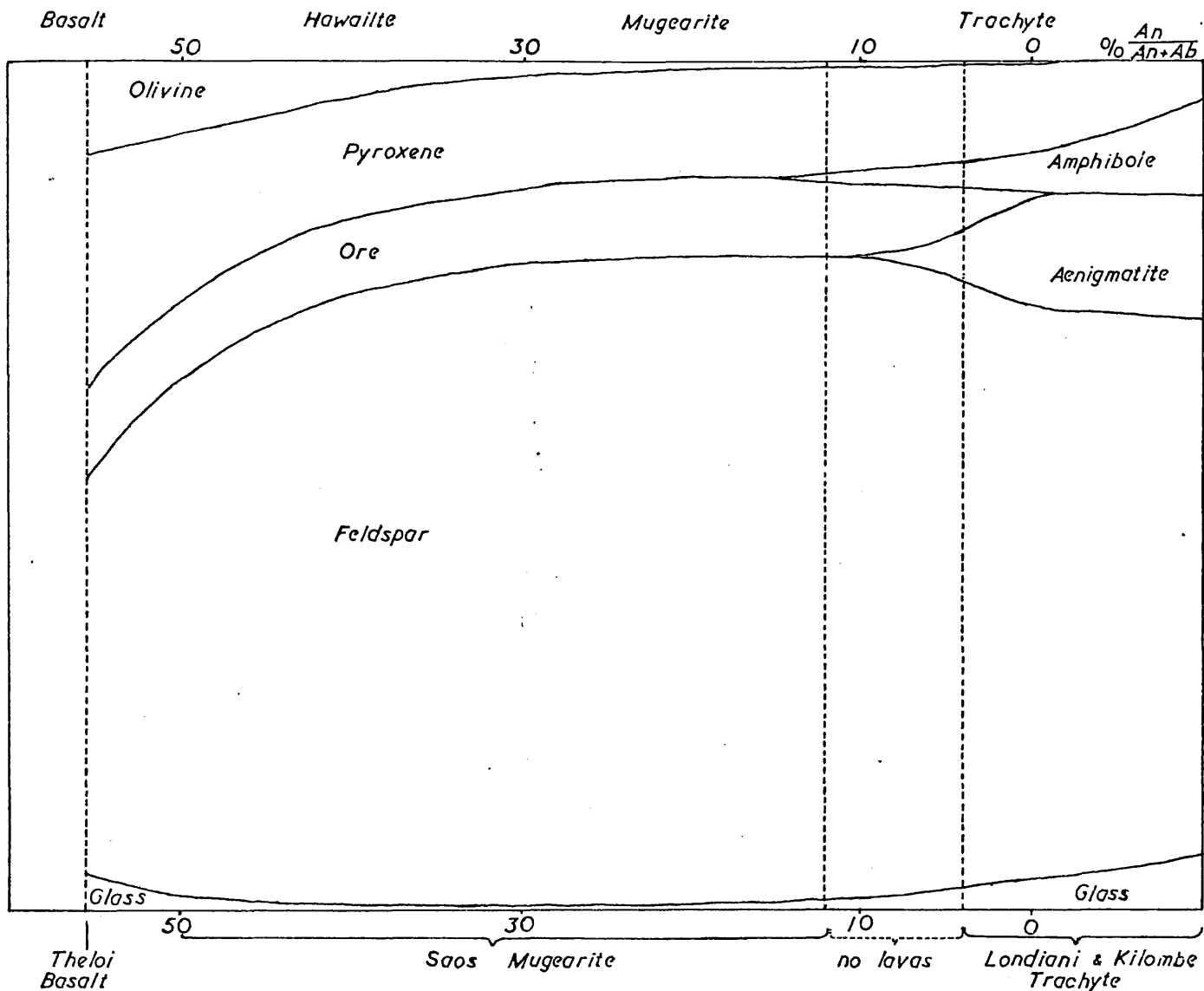
probably due to accumulation of phenocrysts by rising or settling. Thus the great majority of the lavas are porphyritic, sometimes strongly, and there is clear evidence that phenocrysts migrate within magmas. It therefore seems likely that within each of the two lava series the rocks are related by fractional crystallisation.

Fig. 26 shows the phenocryst minerals in the two trends. It also shows the petrography of the mildly undersaturated series but it is not possible to produce a similar diagram for the strongly undersaturated series because of the difficulty of identifying the groundmass constituents of these fine grained lavas.

The most primitive lavas of the strongly undersaturated trend are the Londiani Plain basanites which contain abundant olivine and pyroxene phenocrysts and sometimes, as in 14/859, only olivine phenocrysts. Clearly olivine is the first mineral to crystallise, followed by pyroxene, the lower Tinderet basanites show the next stage, having abundant pyroxene but only rare olivine phenocrysts. Ore first appears as a phenocryst mineral in the Tinderet basanites and declines in importance from there on. The series is continued by the nepheline hawaiites and nepheline mugearites of the Lumbwa Phonolitic Nephelinite in which nepheline phenocrysts appear, accompanying the pyroxene. The augitephyric phonolite flow shows the beginning of alkali feldspar and traces of biotite while in the true phonolites ore disappears, pyroxene declines into insignificance and biotite rises in importance. An evolutionary trend is also apparent in the pyroxene phenocrysts: they are colourless augite in the Londiani Plain Basanite, pale green augite with lilac rims in the Tinderet Basanite, green ferroaugite with either lilac or dark green rims in the Lumbwa Phonolitic Nephelinite and finally green ferroaugite with dark green aegirine rims in the phonolites. There seems to be a continuous range of lavas from olivine phyric basanites to phonolites governed principally

Figure 26. Petrography of the Two Trends

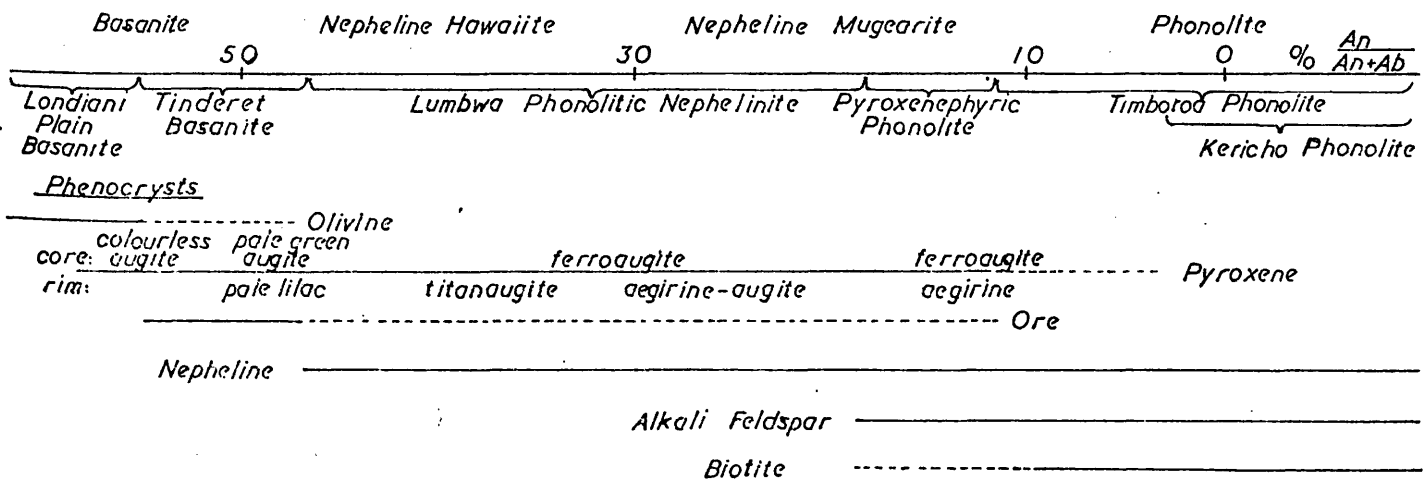
Basalt-Trachyte Trend



Phenocrysts

Olivine	-----			
Pyroxene	colourless	colourless	colourless	ferroaugite
Feldspar	-----			

Basanite - Phonolite Trend



Phenocrysts

Olivine	-----			
Pyroxene	ferroaugite	ferroaugite	Pyroxene	
Ferroaugite	titanaugite	aegirine-augite	aegirine	-----
Aegirine	-----			
Aegirine-augite	-----			
Ore	-----			
Nepheline	-----			
Alkali Feldspar	-----			
Biotite	-----			

by the fractionation of olivine and pyroxene in the basanites, pyroxene and nepheline in the nepheline hawaiites and nepheline mugearites and nepheline and alkali feldspar in the phonolites.

The youngest flows of the Tinderet Basanite have plagioclase as well as olivine and pyroxene phenocrysts and so do not truly belong in the strongly undersaturated trend as described above. They are probably transitional towards the mildly undersaturated trend. The two melilite bearing glassy rocks found in the Lumbwa Phonolitic Nephelinite also do not belong in the strongly undersaturated trend but they may be the only representatives seen of a yet more undersaturated trend.

Primitive lavas of the mildly undersaturated trend are not seen since the Theloi Basalt, its most basic representative, has olivine, augite and often plagioclase phenocrysts and therefore represents a liquid which is already crystallising two and is beginning to crystallise three minerals. There is no evidence as to whether olivine or augite would crystallise first in this trend. Olivine remains an important phenocryst mineral in the hawaiites but is unimportant in the mugearites and trachytes. Augite phenocrysts disappear in the hawaiites but small colourless augites reappear in the mugearites and ferroaugites become significant in the trachytes. From the hawaiites onwards feldspar is the dominant and sometimes only phenocryst mineral, varying from calcic labradorite to sanidine. Beyond trachyte this trend diverges to alkali rhyolite and trachyphonolite with the appearance in the groundmass of quartz and feldspathoids respectively. This series of lavas is probably related by the fractionation of olivine and augite in the basalts and of feldspar in the rest of the series.

The series of lavas is continuous from basalt to mugearite but there is a gap between mugearite and trachyte. This gap is shown by the groundmass minerals; there is nothing intermediate between the near colourless pyroxene prisms, rarity of soda amphibole and absence of

aenigmatite in the mugearites and the green micropoikilitic or mossy pyroxene and common soda amphibole and aenigmatite in the trachytes. The porphyritic xenoliths found in the trachytes, particularly in K17, probably belong in this gap but their chilled nature makes them difficult to compare with the crystalline rocks. Nevertheless there remains an absence of lavas intermediate between the mugearites and trachytes and this fact may be significant for the petrogenesis of the trachytes, suggesting that they do not simply follow on from the mugearites.

Strongly reacting kaersutite phenocrysts were seen in the mugearites and the phonolites while probable pseudomorphs after them were found in the Tinderet Basanite. Since they are rapidly destroyed on extrusion it may be that they are commoner as phenocrysts prior to eruption than is apparent in the solidified lavas. It is therefore possible that fractionation of kaersutite may contribute to the evolution of the lavas of both series.

There is considerable evidence that mixing of magmas has taken place. Strongly resorbed phenocrysts of feldspar of different composition from the phenocrysts in equilibrium with the groundmass are widespread though always uncommon in any one rock. Sanidines have been found in the Theloi Basalt, oligoclases in the other Eldama Ravine Tuff basalts and sanidines in the hawaiites and mugearites of the Saos Mugearite. This shows that these magmas have often incorporated a small amount of more evolved magma. The xenoliths in the Kilombe Trachyte flow K17 have occasional plagioclase phenocrysts of composition An 50% among the abundant anorthoclase phenocrysts showing the addition of some basic magma. It seems that in general only small amounts of one liquid are mixed into another. In fact it is possible that sometimes only alkali feldspar phenocrysts without any of their associated magma are picked up by a more basic magma. The only example found of large scale intimate mixing of magmas was 14/533 from the Saos

Mugearite which seems to have been formed by the mixing of two parts of trachyte and one part of mugearite. Resorbed xenolithic feldspars are not seen in the strongly undersaturated series except in the basanite flow in the Makutano Tuff but this flow is transitional to a basalt and does not truly belong with the strongly undersaturated trend. Small scale mixing of magmas then is characteristic of the mildly undersaturated trend but not of the strongly undersaturated trend.

In conclusion, the petrography shows that the lavas are related by fractional crystallisation along two distinct trends, one mildly and one strongly undersaturated, with mixing of magmas playing a minor role in the mildly undersaturated trend.

Chemistry of the Lavas

Introduction

A representative collection of all the rock types found in the Londiani area was analysed in order to see whether the basanite to phonolite series and the basalt to trachyte series showed clear evolutionary trends ascribable to fractional crystallisation within themselves and were distinct from each other. This turned out to be the case. It was also hoped to understand the relationships between the different basic rocks, which was partially successful. Finally particular attention was paid to the Londiani and Kilombe Trachytes as the chemistry of trachytes and related rocks from East Africa has been the subject of much attention recently. This led to very interesting and unexpected results.

Analytical Techniques

The major elements were analysed on a Phillips PW 1212 automatic XRF spectrometer using fused rock disks. Water, ferrous iron and, where appropriate, chlorine and carbon dioxide were measured by chemical methods. The XRF spectrometer had been calibrated by comparison with a set of rocks

analysed by wet chemical methods by Mr. H. Lloyd. As a test of the reliability of the XRF spectrometer for the rocks of the Londiani area 17 of the rocks analysed by it were also analysed by Mr. Lloyd by wet chemistry. The two sets of analyses are very similar, showing that the calibration of the XRF spectrometer is appropriate for these rocks. However the Al_2O_3 are consistently higher on the XRF spectrometer by up to 1%. This is because the wet chemical Al_2O_3 analyses used to calibrate the spectrometer were done by a gravimetric method which measures other trivalent ions such as the lanthanides with Al while the Al_2O_3 measured in the comparison were done on a flame photometer which measures Al alone. The XRF Al_2O_3 measurements quoted here are therefore slightly high.

13 trace elements were analysed on the same spectrometer and corrected for mass absorption effects. Rb, Sr, Y, Zr, Nb, Ba and the first four lanthanides La, Ce, Pr and Nd were analysed for all the rocks. In addition Co, Ni and Cr were analysed for the basic rocks and a very few specimens representative of the other rock types. 12 standard rocks were analysed in parallel with the rocks of the Londiani area and are quoted in Table 4.30 to facilitate comparison with analyses in other laboratories.

Comparison of the Two Series, 1: Major Elements

In fig.27-29 the major element analyses of the lavas are plotted against SiO_2 for the different assemblages. It is immediately apparent that the basanite to phonolite series, represented by the Timboroa Assemblage, is distinct from the basalt to trachyte series, represented by the Londiani and Kapkut Assemblages. The three analysed rocks of the Kapkut Assemblage are indistinguishable from the trend of the Londiani Assemblage. The difference between the two trends may be summarised as the mildly undersaturated trend having more SiO_2 than the strongly undersaturated trend for the same content of any other major element. This division of the lavas into an older strongly undersaturated and a younger mildly

Figure 27. TiO_2 , Na_2O and K_2O v SiO_2 for the lavas.

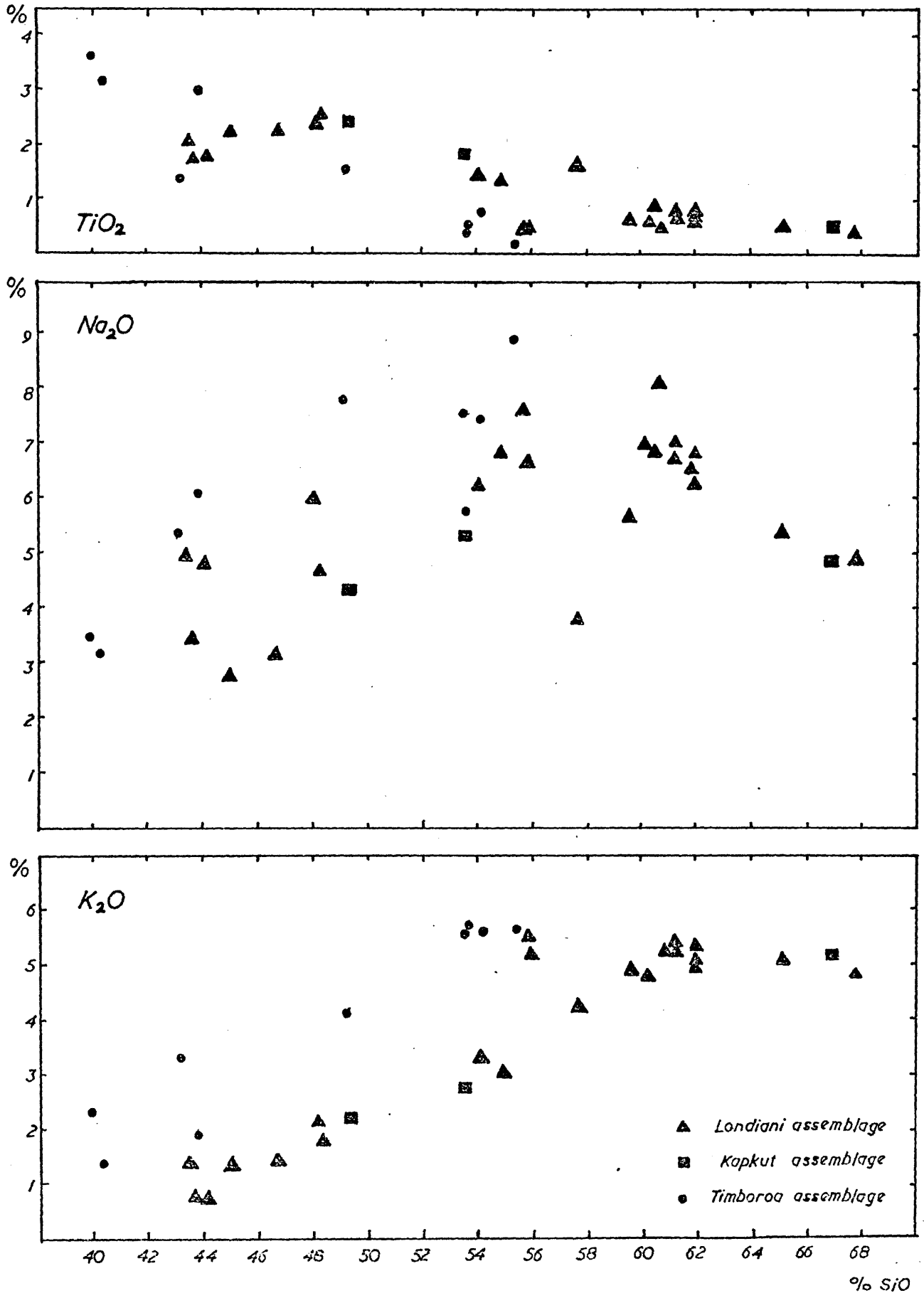


Figure 28. $\frac{Fe^{2+}}{Fe^{2+} + Fe^{3+}}$ total Fe as FeO and MgO v SiO₂ for the lavas.

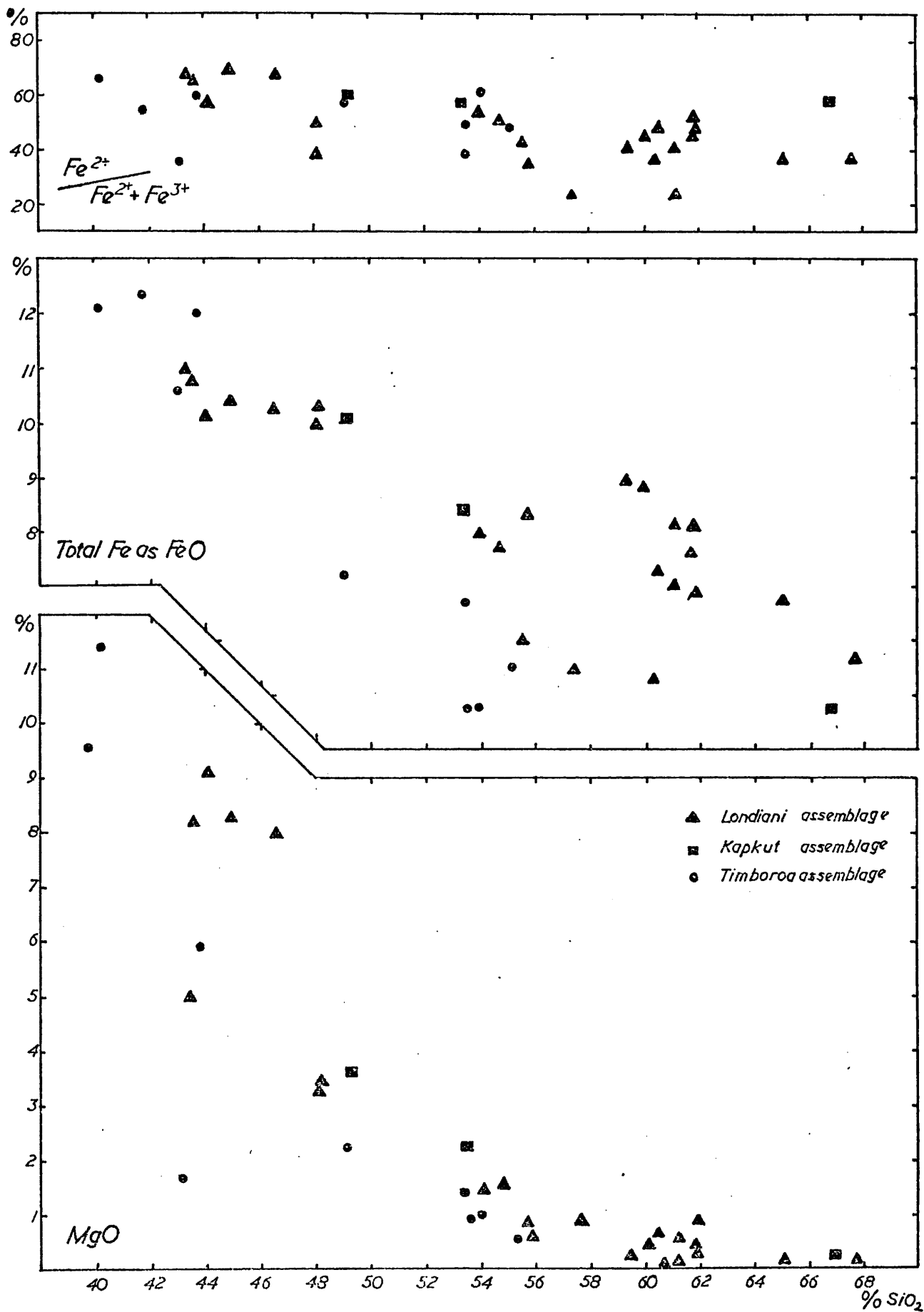
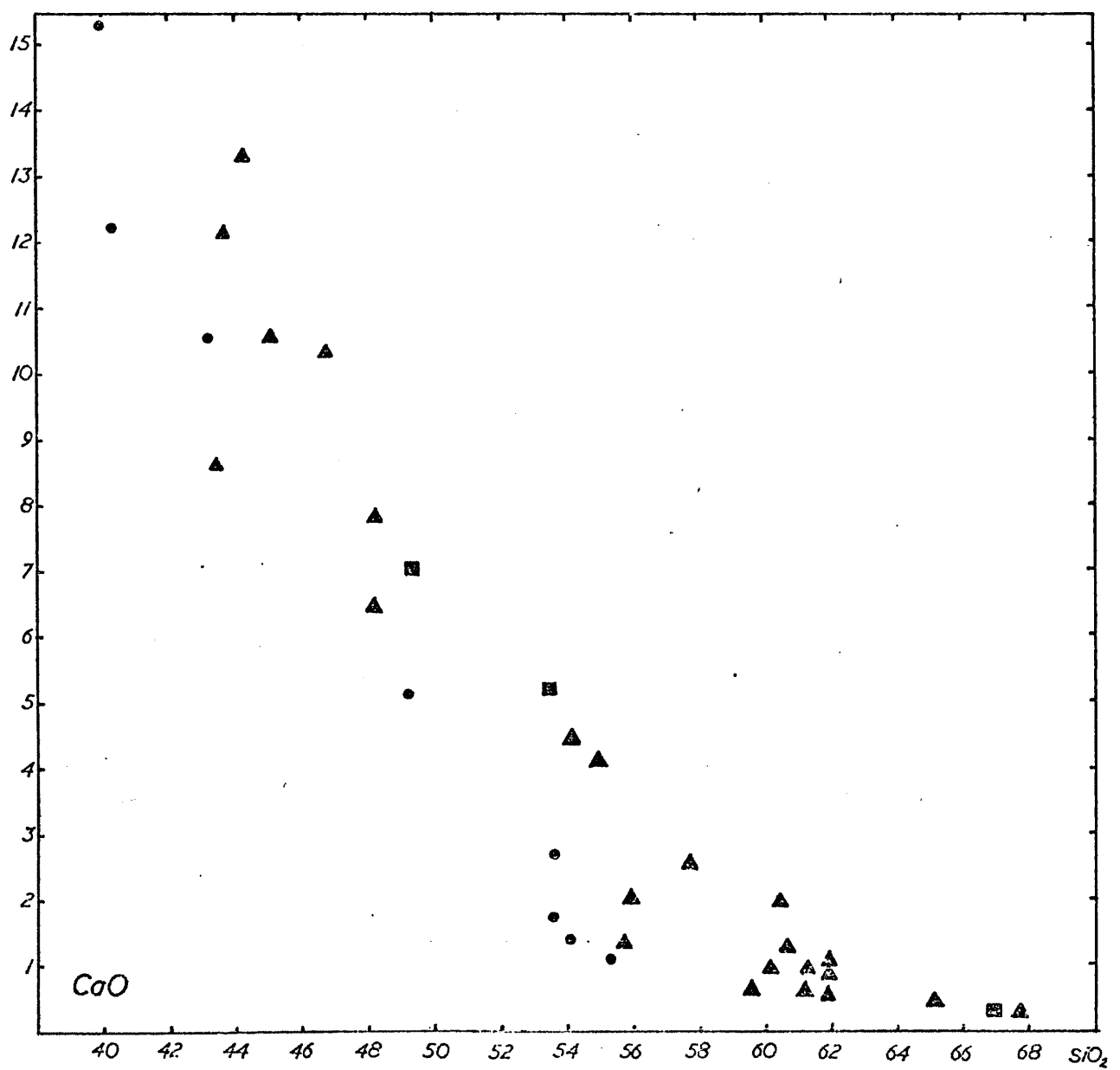
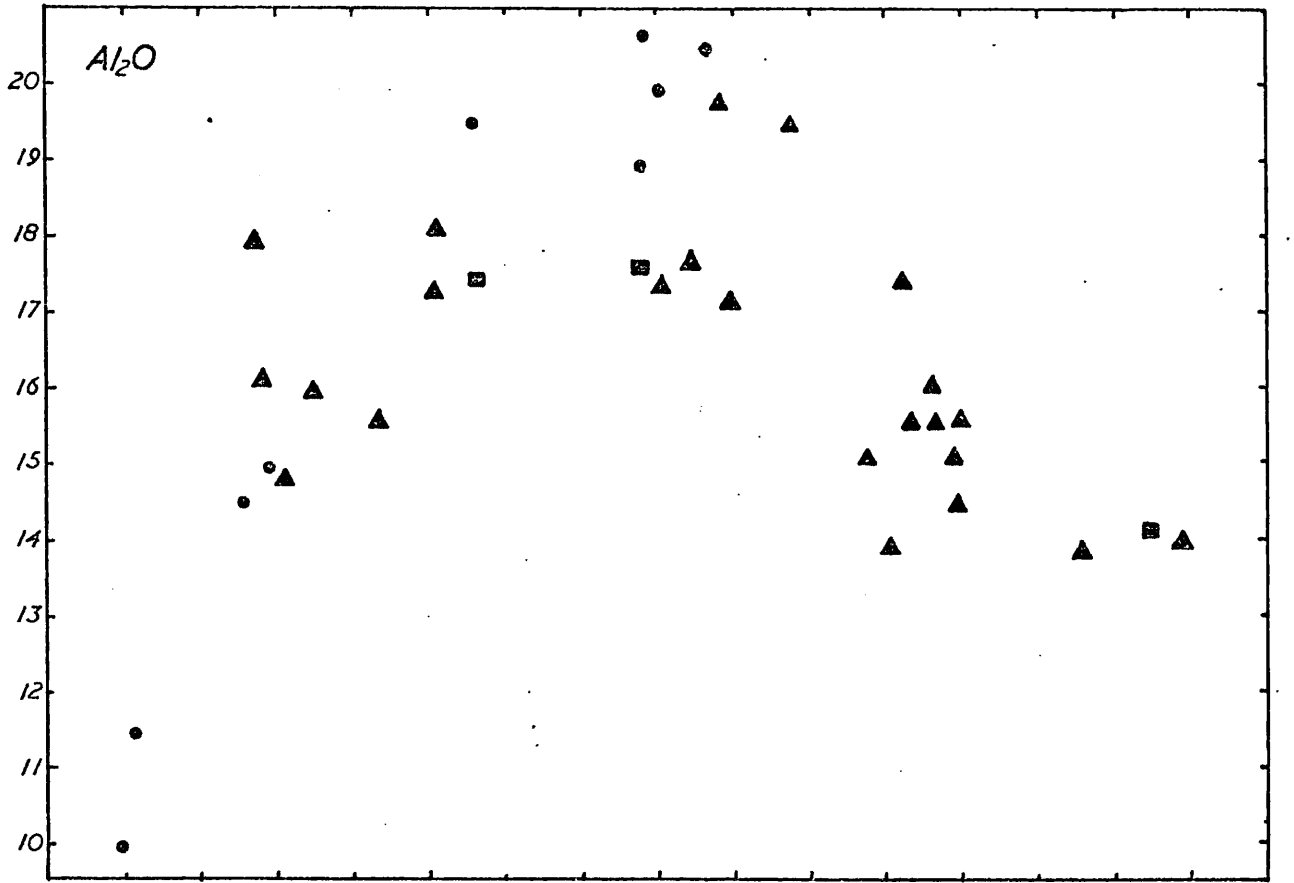


Figure 29. Al_2O and CaO v SiO_2 for the lavas.



undersaturated trend has been shown by Williams (1972) to be characteristic of the Rift Valley as a whole. In fact a comparison of fig.27 with the graphs in Williams's paper shows that the Londiani area has representatives of almost all the lava types found in the Rift Valley.

The K_2O v SiO_2 graph shows the two trends most clearly distinguished. In the mildly undersaturated trend there is a continuous straight line variation from basalts with $K_2O = 1\%$ and $SiO_2 = 43-47\%$ through hawaiites and mugearites to trachytes with $K_2O = 5\%$ and $SiO_2 = 60-62\%$. The xenolith in K17 plots, as expected, on this trend between the mugearites and trachytes at $K_2O = 4.3$ and $SiO_2 = 57.7\%$. The alkali rhyolites trend away from the trachytes as far as $SiO_2 = 68\%$ while the trachyphonolites at $K_2O = 5-6\%$ and $SiO_2 = 56\%$ look as if they branched off the main trend at the mugearite stage.

In the strongly undersaturated series there is a clear trend from basanites with $K_2O = 1\frac{1}{2}-2\frac{1}{2}\%$ and $SiO_2 = 40-44\%$ to phonolites including the pyroxenephryic flow with K_2O remarkably constant at $5.5-5.8\%$ and $SiO_2 = 53-56\%$. The Tinderet Basanite, 14/1053, with $K_2O = 2\%$ is intermediate between the two trends while the Londiani Plain Basanite with $K_2O = 0.8\%$ lies in the basalts. The most basic rocks analysed were 14/1074, an ankaramite from Ft. Ternan with $K_2O = 2.3\%$ and $SiO_2 = 40.0\%$ and 14/1063 from the basanite flow capping the Lumbwa Phonolitic Nephelinite with $K_2O = 1.4\%$ and $SiO_2 = 40.3\%$.

In contrast to K_2O v SiO_2 the Na_2O v SiO_2 graph shows a much greater scatter. For example the four analysed phonolites range in Na_2O from 5.7% to 8.9% . Among the basic rocks the Tinderet Basanite 14/1053 and the Londiani Plain Basanite 14/903, whose K_2O values are comparable with the basalts, have $Na_2O = 6.1\%$ and 4.8% respectively, much higher than the 3% of the basalts. It is the high Na_2O of these rocks which makes them basanites. The trachytes usually have $Na_2O = 6-7\%$ but the undersaturated

trachyte of Kiborit, 14/581, has $\text{Na}_2\text{O} = 8.1\%$ although it is indistinguishable from the other trachytes in its other major elements. It seems that Na has been added to a normal saturated trachyte liquid by a chlorine rich vapour to produce the sodalite bearing trachyte. The great scatter of Na_2O in contrast to the narrow trends of K_2O is probably due to Na being readily moved about in magmas by a vapour phase. Therefore K_2O v SiO_2 is a more useful variation diagram than total alkalis v SiO_2 for the rocks of the Londiani area.

In the strongly undersaturated trend Al_2O_3 rises from 10% in the basic rocks to 20% in the phonolites. In the mildly undersaturated trend it rises from 15% in the basalts to 18% in the hawaiites and mugearites and then falls through the trachytes to become constant at 14% in the alkali rhyolites. The continued rise in the basanite to phonolite trend is because the crystallising minerals are the Al-free olivine and pyroxene with Al-rich nepheline and feldspar becoming predominant only in the phonolites. In the other trend however feldspar takes over from olivine and pyroxene as the dominant crystallising mineral in the hawaiites so that Al_2O_3 reaches a maximum in the intermediate rocks. The rise and fall of Al_2O_3 is convincing evidence that the intermediate rocks were not formed predominantly by the mixing of basalt and trachyte which would have produced a straight line variation diagram.

Ti, Ca and Mg all drop from the basalts and basanites to the trachytes and phonolites. This is what would be expected if the magmas were generated by fractional crystallisation since these elements go into the early crystallising minerals; Ti into ore and augite, Ca into plagioclase and augite and Mg into olivine and augite. Fe falls along both trends being presumably removed in the olivine and pyroxene but it shows a considerable scatter in the basalt-trachyte trend due probably to volatile transfer. The effect of a volatile phase on Fe and Na is discussed below.

The melilite-bearing rock 14/1034, seems to lie on the basanite phonolite trend for all its major elements except Mg which, at 1.69% is much too low. It may therefore have been formed from a basanite parent liquid by fractionation of a Mg-rich mineral, possibly large amounts of olivine.

The two trends are not clearly distinct on an alkalis/MgO/FeO diagram (fig. 30A) or on a $\text{Na}_2\text{O}/\text{K}_2\text{O}/\text{CaO}$ diagram (fig. 30B). However they are quite separate on a normative feldspar diagram (fig. 25). This is because the lower SiO_2 in the basanite-phonolite trend gives them higher normative nepheline and hence lower normative albite. This emphasises that the principal chemical difference between the two trends is the lower SiO_2 in the strongly undersaturated trend. The relationship between the other major elements is the same in both trends except for the fall in Al_2O_3 in the trachytes.

On the Ne/Ks/ SiO_2 diagram (fig. 31) the trachytes and phonolites plot in the low temperature trough with the trachytes on the feldspar join, the alkali rhyolites trending towards the rhyolite minimum, the phonolites around the phonolite minimum and the trachyphonolites trending towards them. This suggests that these liquids are the products of fractional crystallisation or of partial melting (Tuttle and Bowen 1958). The trachytes, lying on a ridge in the trough, are very unlikely to have formed by partial melting. The alkali rhyolites and trachyphonolites, both trending away from the trachytes, were probably both formed by fractionation of feldspar in a trachyte liquid which was slightly oversaturated in the former case and slightly undersaturated in the latter. The phonolites, lying around the phonolite minimum, could have been formed by partial melting but there is ample evidence, outlined above, that they are the result of fractional crystallisation.

Figure 30. Alkalies/FeO/MgO and Na₂O/K₂O/CaO diagrams for the Lavas

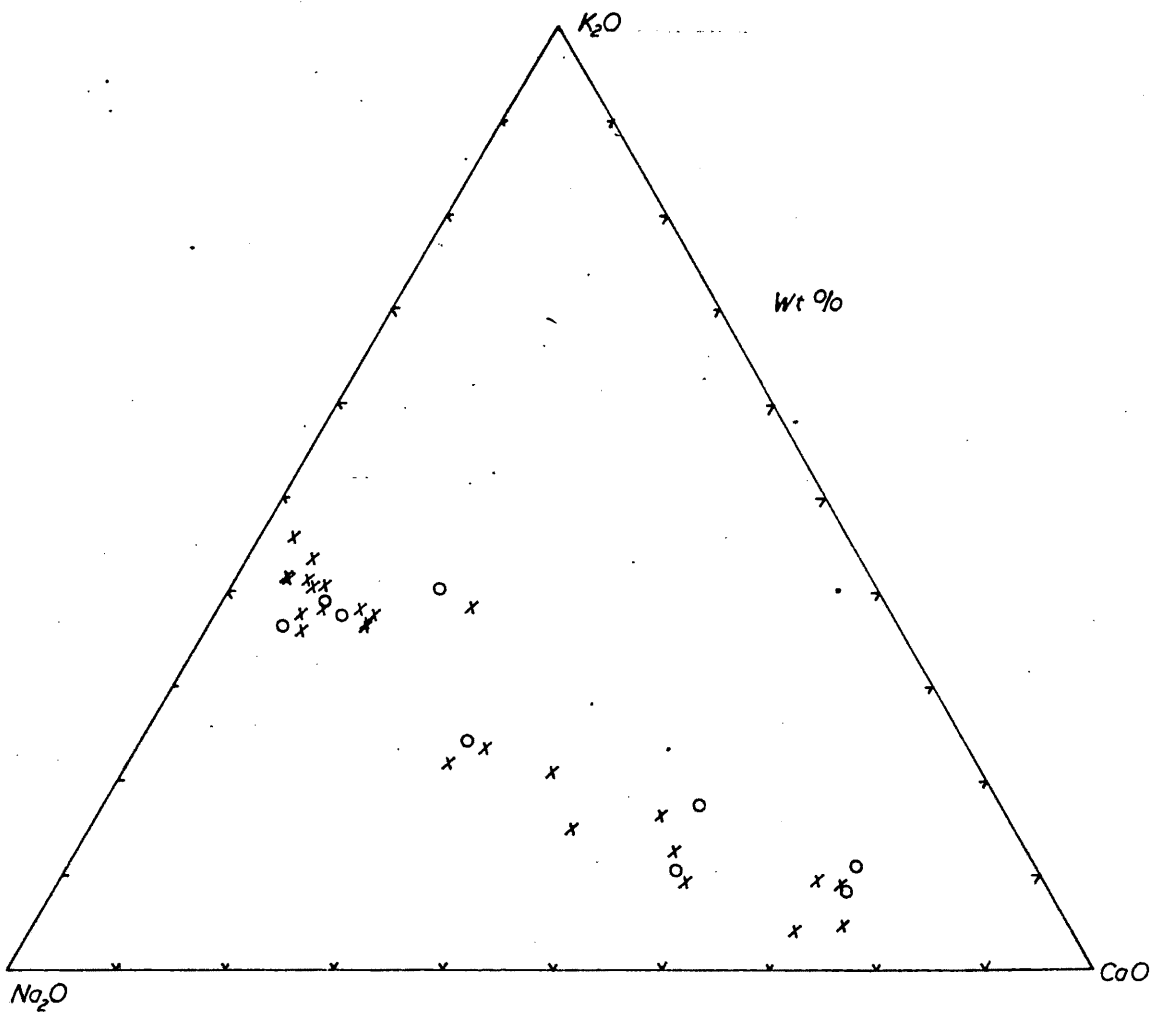
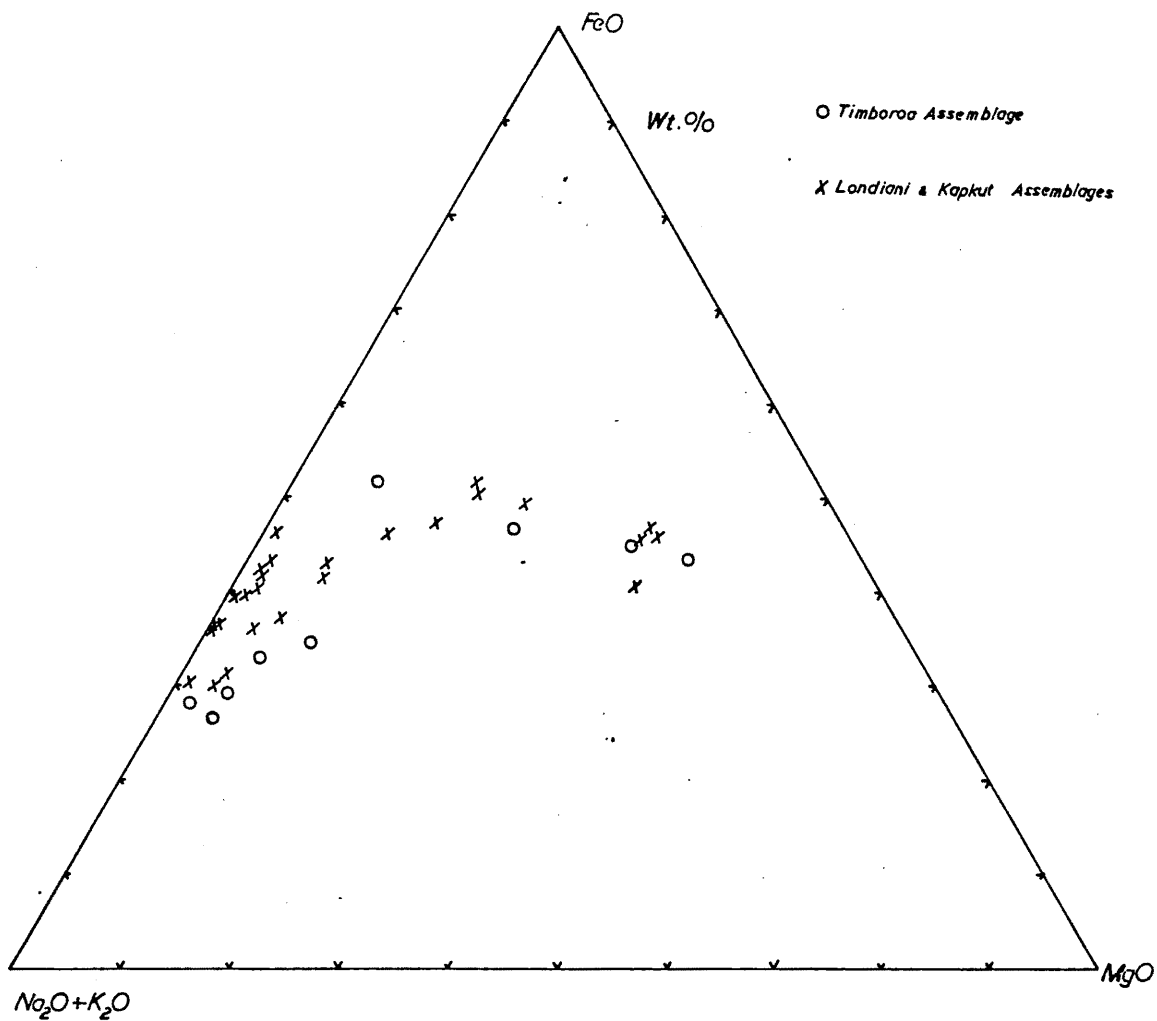
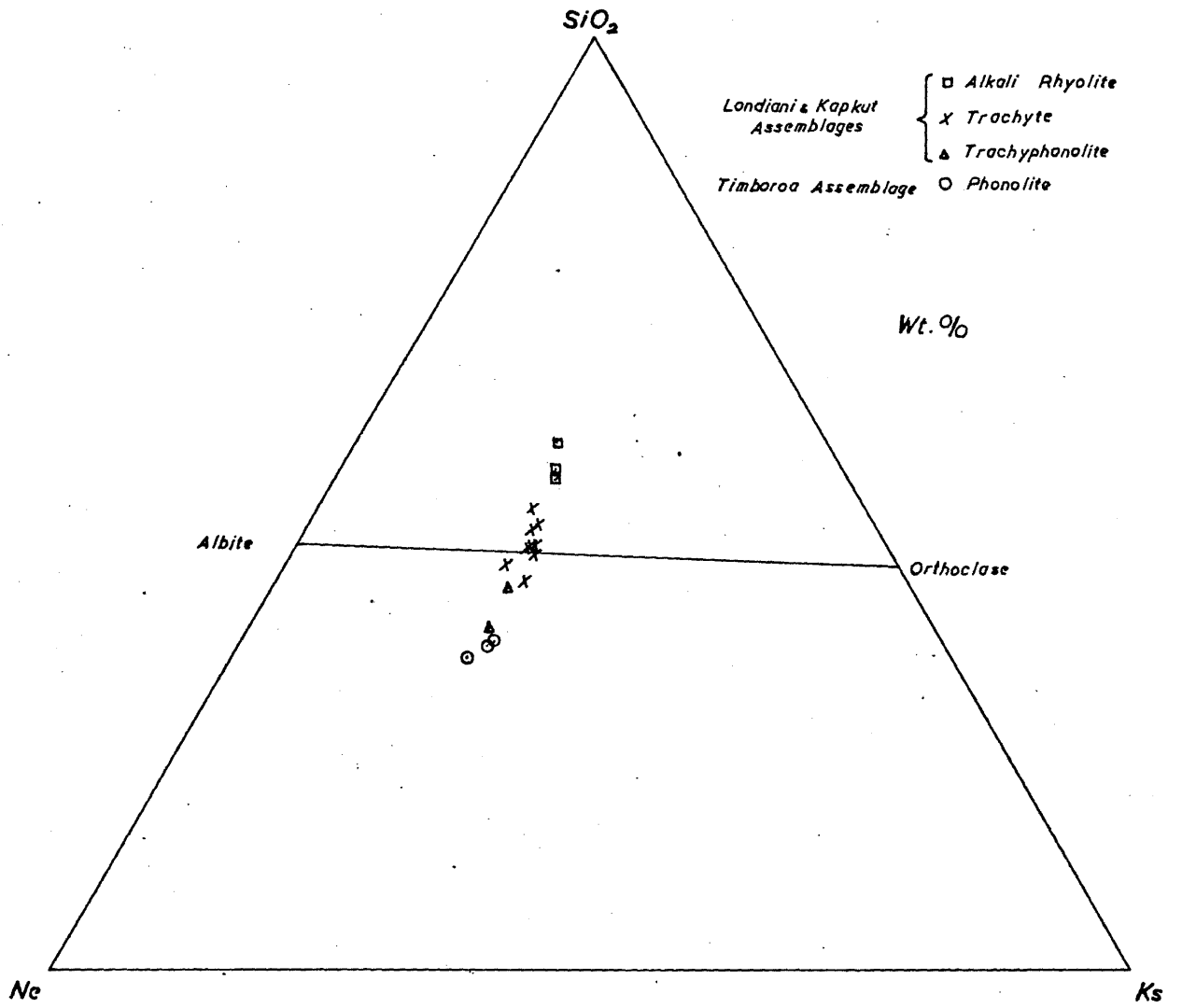


Figure 31. $Ne/Ks/SiO_2$ diagram for Trachytes and Phonolites



The major element chemistry thus supports the origin of the lavas by fractional crystallisation.

Comparison of the Two Series, 2: Trace Elements

Zirconium is known to be a residual element in alkaline lavas (Dietrich 1968, Nicholls & Carmichael 1969), that is it does not enter any of the crystallising minerals except zircon and eudialyte. Therefore in a series of rocks devoid of zircon or eudialyte, as all the lavas of the Londiani area are, zircon may be used as an index of differentiation. If a trachyte with 1000 ppm of Zr is considered to have been derived from a basalt with 100 ppm Zr then there has been a tenfold increase in the concentration of Zr and the trachyte is the liquid left after 90% of the original basalt liquid has crystallised. A plot of another residual element against Zr will be a straight line passing through the origin because they are both being concentrated in the liquid at the same rate and therefore the ratio of the concentrations of the two elements remains the same throughout a series of lavas. Another way of thinking about this is that the crystallisation of minerals not containing any of the residual elements corresponds on the trace element plot to the subtraction from the liquid of crystals whose trace element composition is shown by the origin. The fractionating liquid will therefore move away from the origin and continue to do so so long as the crystallising minerals are devoid of the residual elements.

Such trace element plots have been drawn for several volcanoes in Kenya and Ethiopia showing straight lines connecting basalts, mugearites and trachytes from the same centre and this has been put forward as strong evidence that the series of rocks from any one centre are related by fractional crystallisation (Weaver et al 1972). The Nb/Zr diagram for the Timboroa Assemblage in fig. 32 shows a straight line from the basanites through the Lumbwa Phonolitic Nephelinite, the pyroxene-phyric phonolite

flow and finally the Timboroa Phonolite showing that they are probably related, in that order, by fractional crystallisation. The Kericho Phonolite has lower values than the Timboroa Phonolite. Lippard (1972b) has shown that a similar state of affairs occurs in the Kamasia Hills where the younger phonolites have progressively higher Nb and Zr values. The range of Nb and Zr quoted by Lippard for the Ewalel Formation is the same as that shown here for the Timboroa Phonolite, which is evidence for the suggestion in Chapter II that these two are laterally equivalent.

It has been found that different volcanoes have different ratios of the residual elements and Weaver et al (1972) showed that there seems to be an evolution of the ratio Nb/Zr in Kenya from about 0.4 for the Miocene Plateau Phonolites through 0.3 for Pliocene volcanoes to 0.2 for Quaternary volcanoes. The evidence from the Londiani area is not in accordance with this. The regression coefficient for the Nb/Zr plot for the Timboroa Phonolite of 8-9 m.y. old is 0.316 while the equivalent for the Kilombe Trachyte of 2 m.y. old is 0.305. There is too much scatter on the Nb/Zr plot for the Londiani Trachyte for its regression coefficient to be meaningful but most of the analyses lie on a line which is slightly steeper than that of the Kilombe Trachyte. So, although it is clear that different volcanoes have different Nb/Zr ratios, there is no evidence that there is a systematic variation with time in the Londiani area.

The melilite-bearing glassy rocks lie well off the Nb/Zr line for the basanite to phonolite trend showing that they have a separate origin.

Plots of the lanthanide elements against Zr, e.g. Ce/Zr (fig. 32), for the basanite to phonolite trend are straight lines whereas similar plots for the basalt-trachyte trend show great scatters (fig. 33). This is because the trachytes are affected by volatile transfer, a process not seen in the other trend. Volatile transfer is discussed in a later section.

Figure 32. Nb,Ce,Sr and Ba v Zr for basanite-phonolite trend

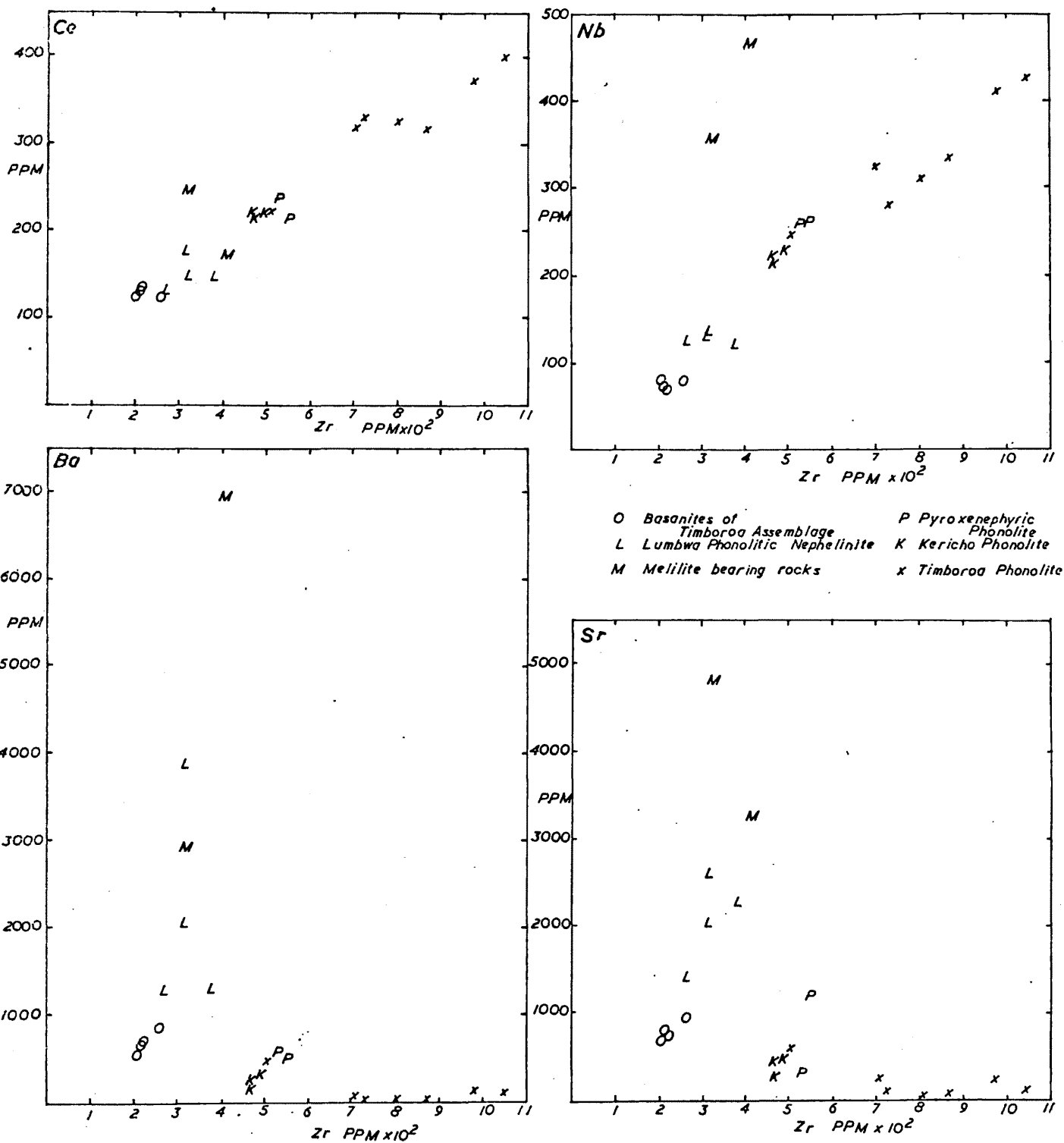


Figure 33. Nb and Ce v Zr for basalt to trachyte trend.

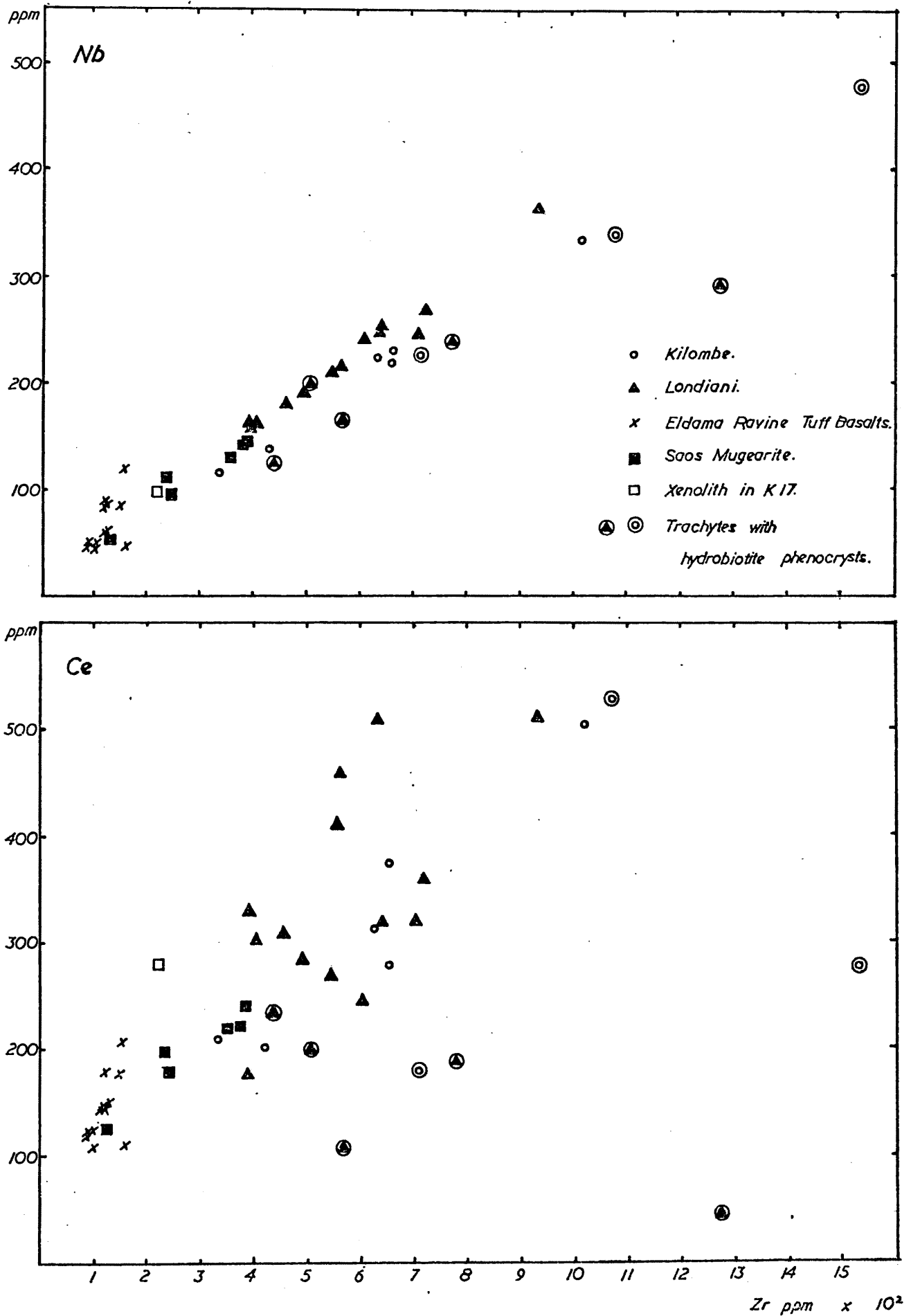


Figure 34. Rb and Y v Zr for basalt to trachyte trend

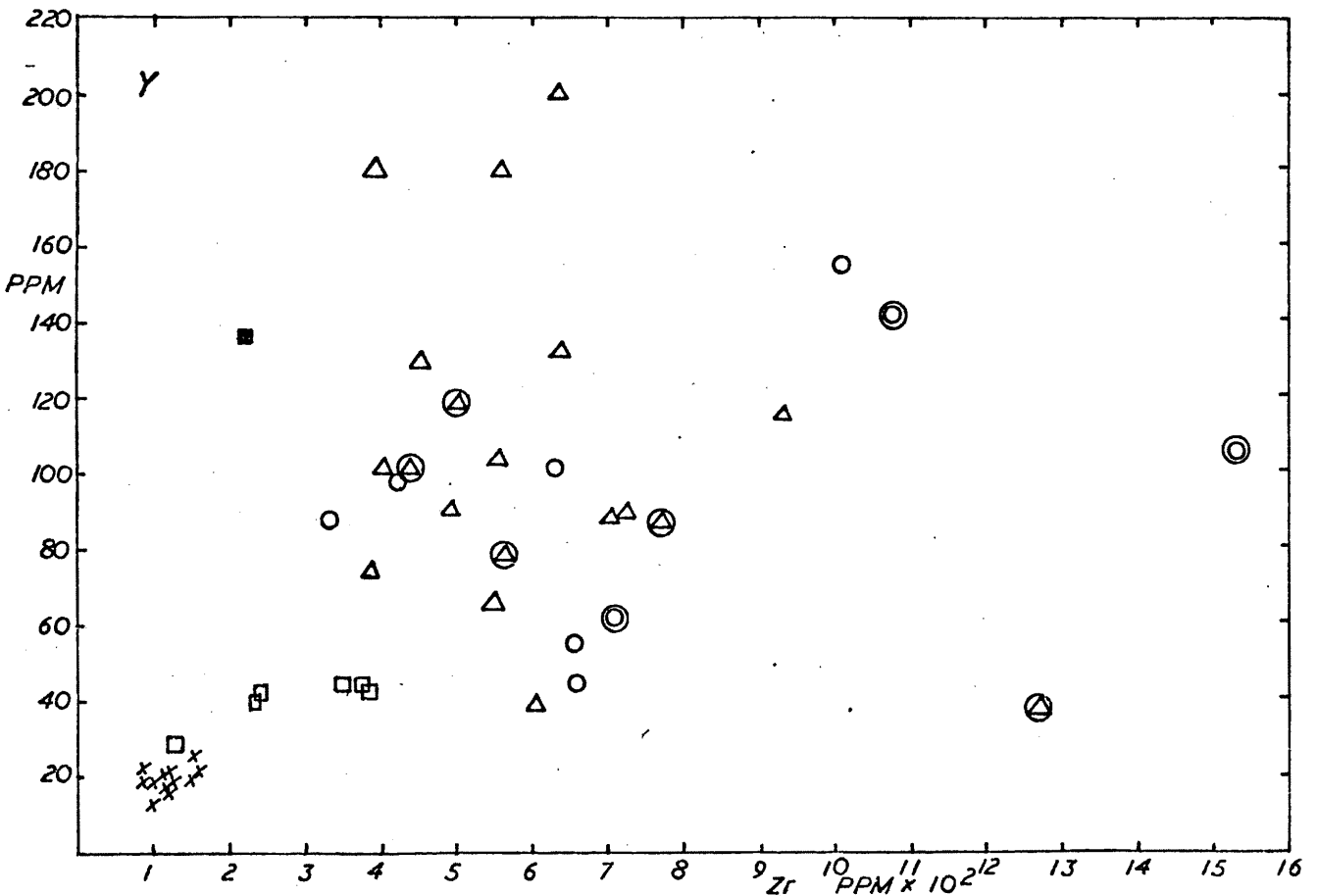
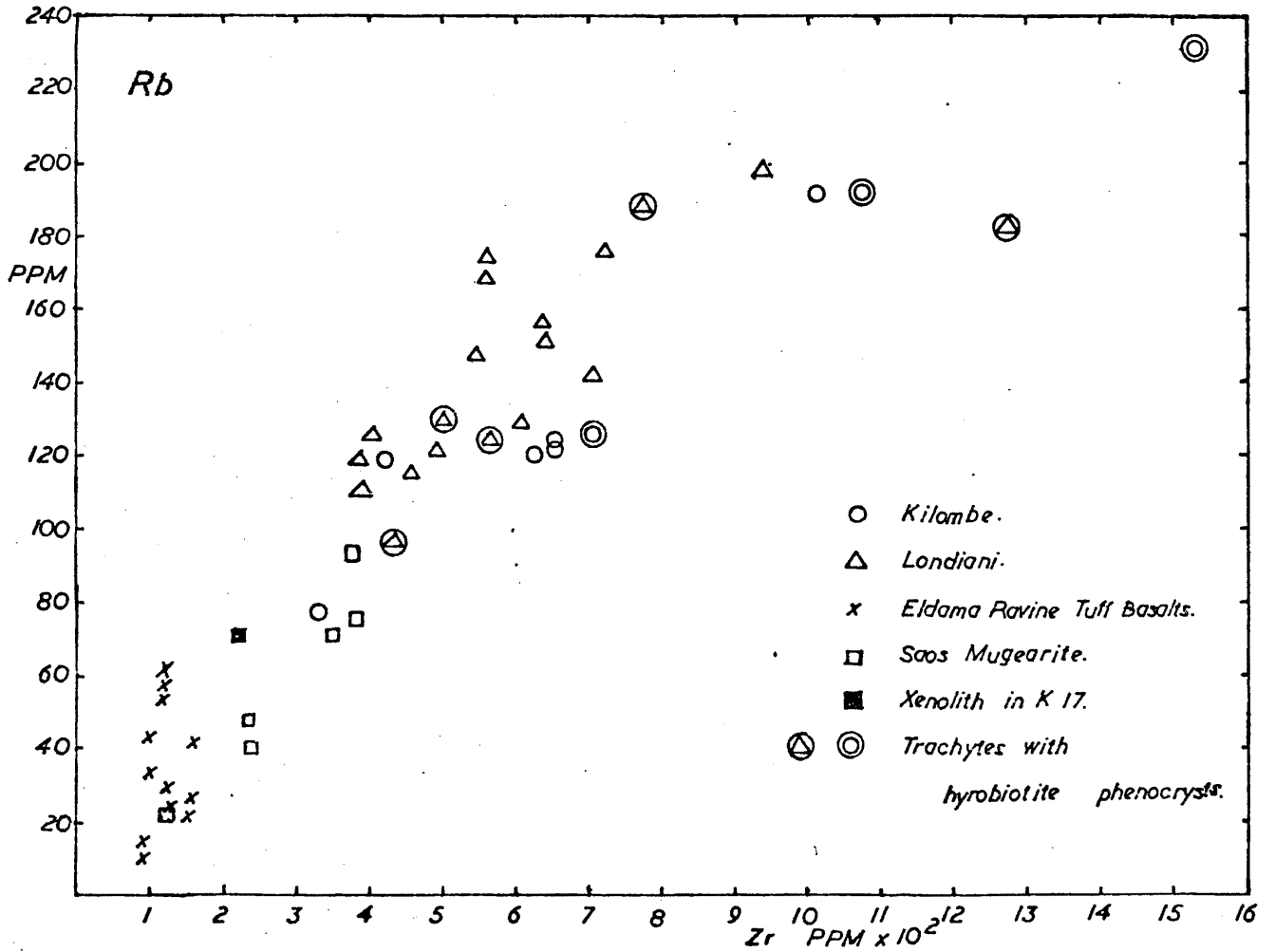


Figure 35. Sr and Ba v Zr for basalt to trachyte trend

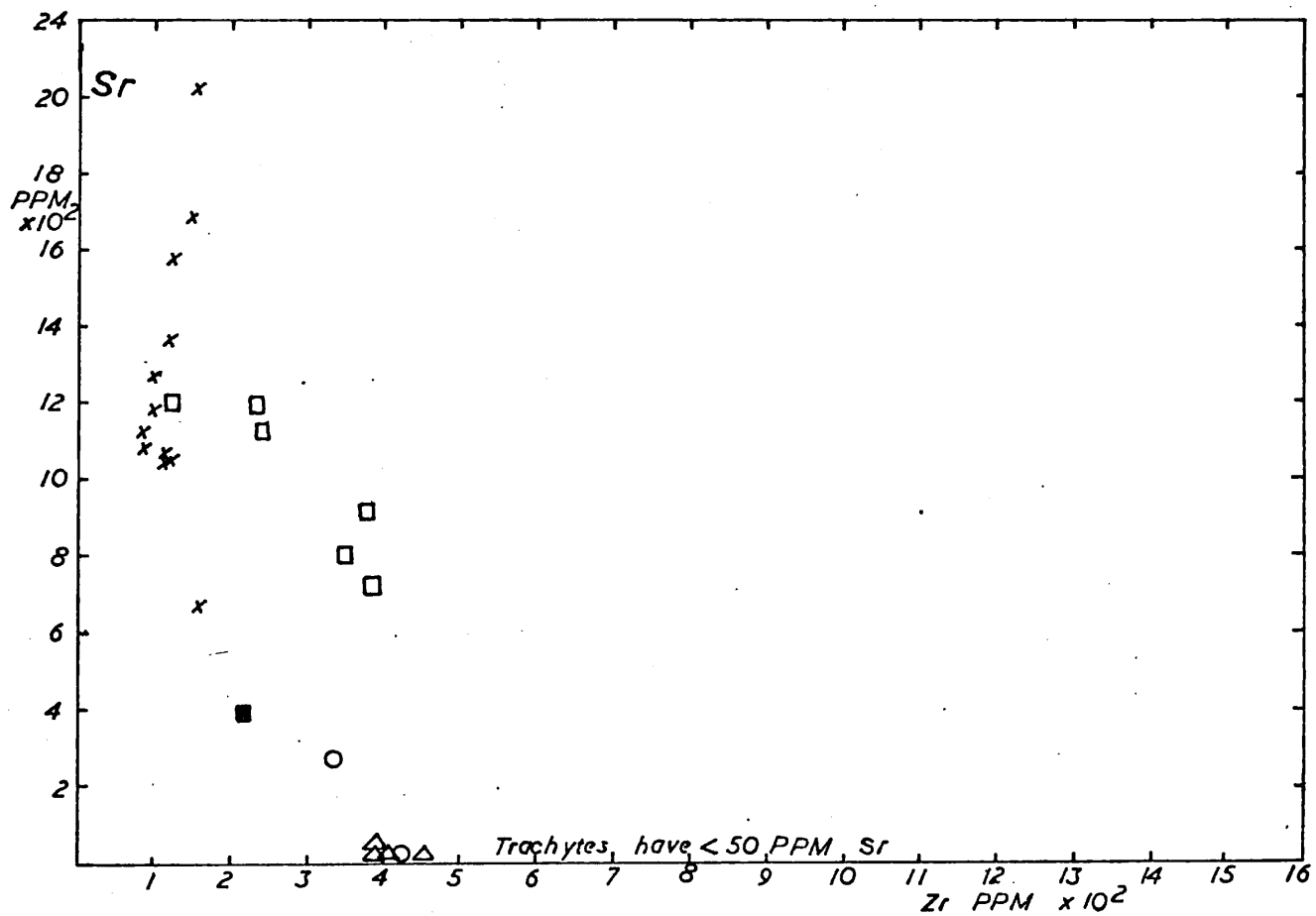
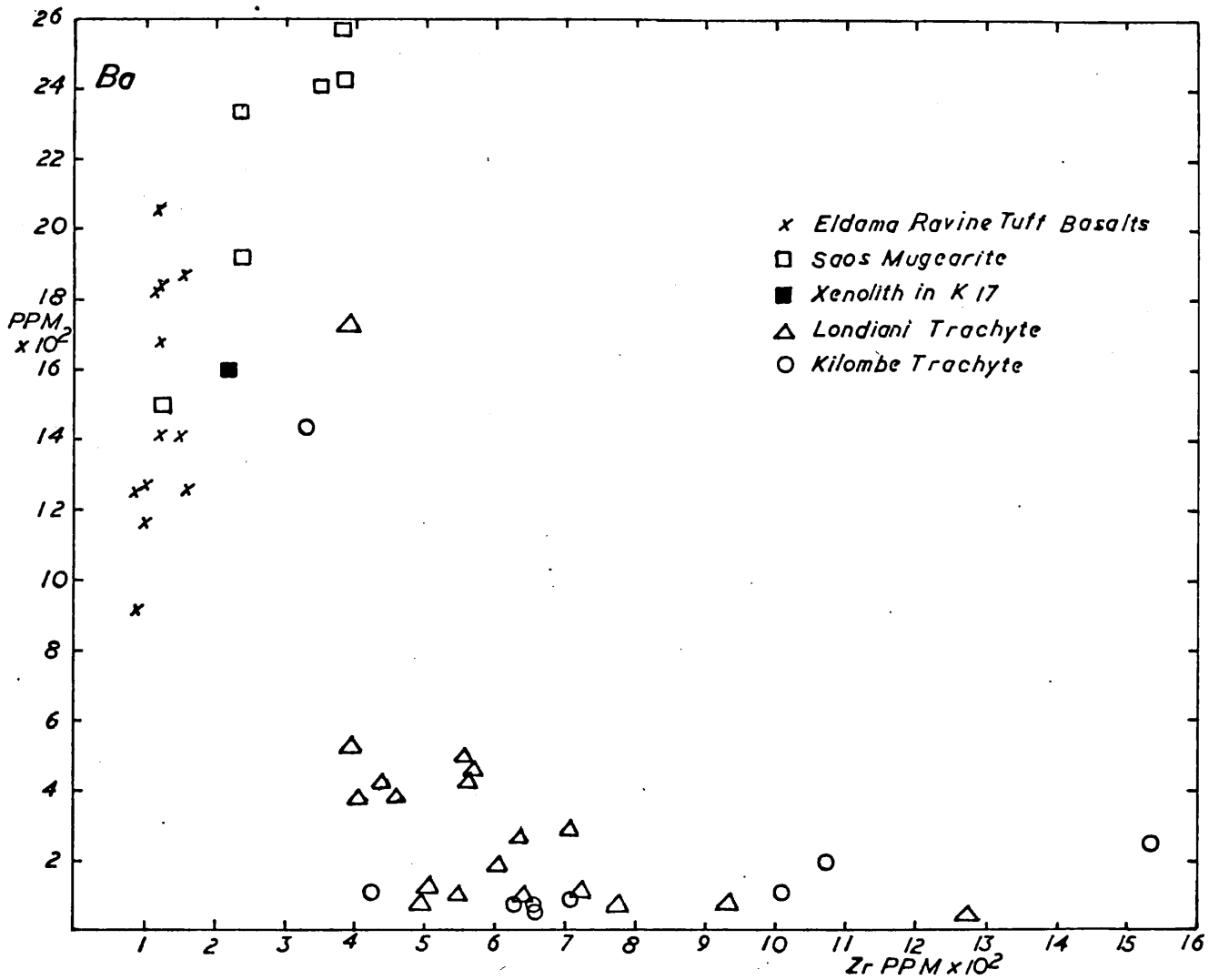
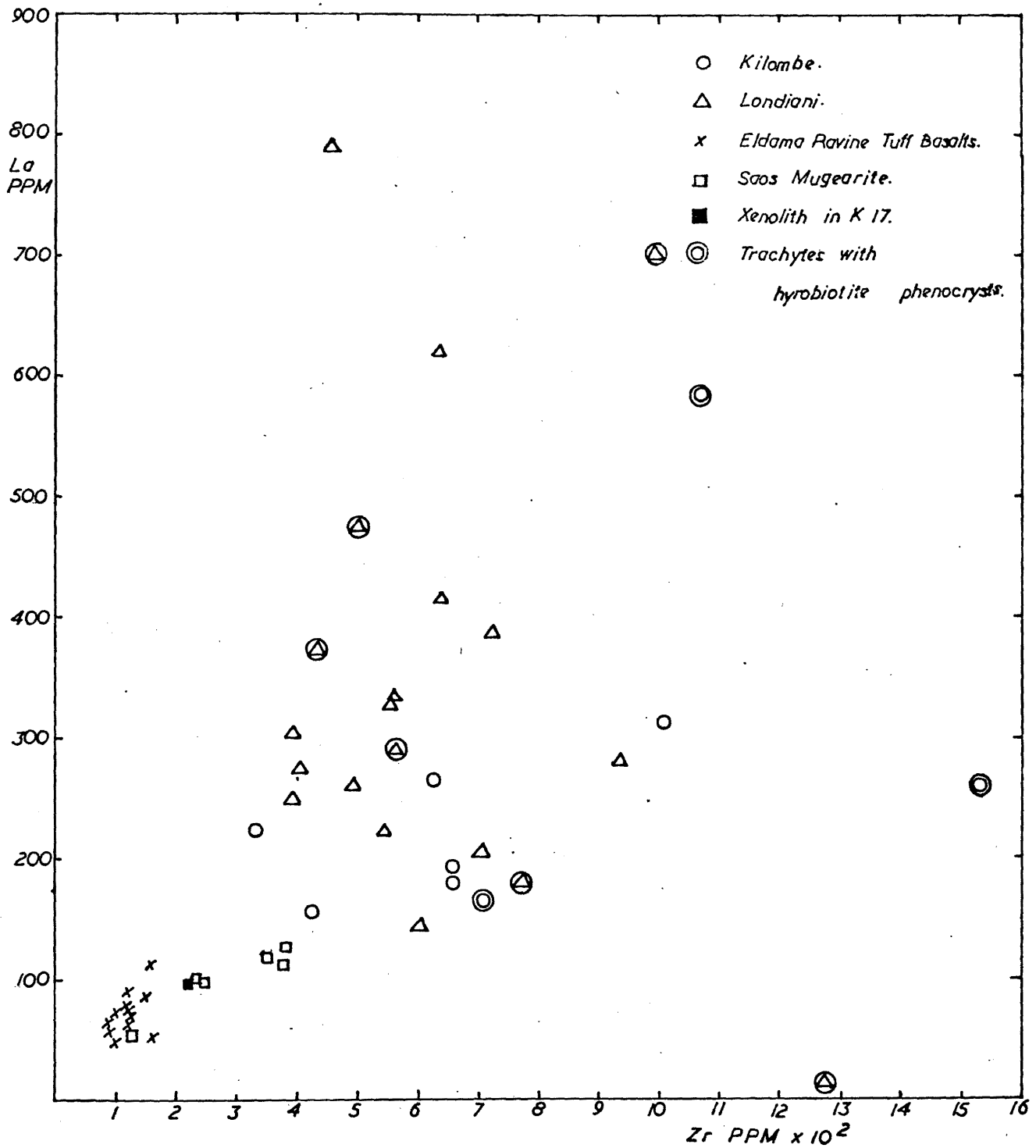


Figure 36. *La v Zr for basalt to trachyte trend*

Finally a comparison of the Ba/Zr and Sr/Zr diagrams for both trends (figs. 32 & 35) shows both these elements rising to a peak in the intermediate rocks and falling off to very low values in the trachytes and phonolites. This is well known in many rock suites and is held to be strong evidence for fractional crystallisation (e.g. Weaver et al 1972). Sr substitutes for Ca in plagioclase and Ba substitutes for K in alkali feldspar. Sr and Ba both increase in the liquid during fractionation until plagioclase begins to crystallise at which point Sr begins to fall. Ba decreases when alkali feldspar begins to crystallise. This means that Sr and Ba both reach their highest values in the intermediate rocks, Ba in more evolved rocks than Sr. In the basalt to trachyte trend Sr reaches its highest concentration in the basalts at about 150 ppm Zr, drops in the mugearites and is very low in the trachytes. Ba rises in the basalts and mugearites to a maximum at about 300 ppm Zr and is very low in the trachytes. On the other hand in the basanite to phonolite trend the maximum Ba is again at about 300 ppm Zr but the maximum Sr is at about 350 ppm Zr. This difference is readily attributable to the fact that plagioclase is a major crystallising mineral almost from the beginning in the basalt-trachyte trend while in the other trend feldspar only begins to crystallise in the phonolites.

Relationships among the Basic Rocks

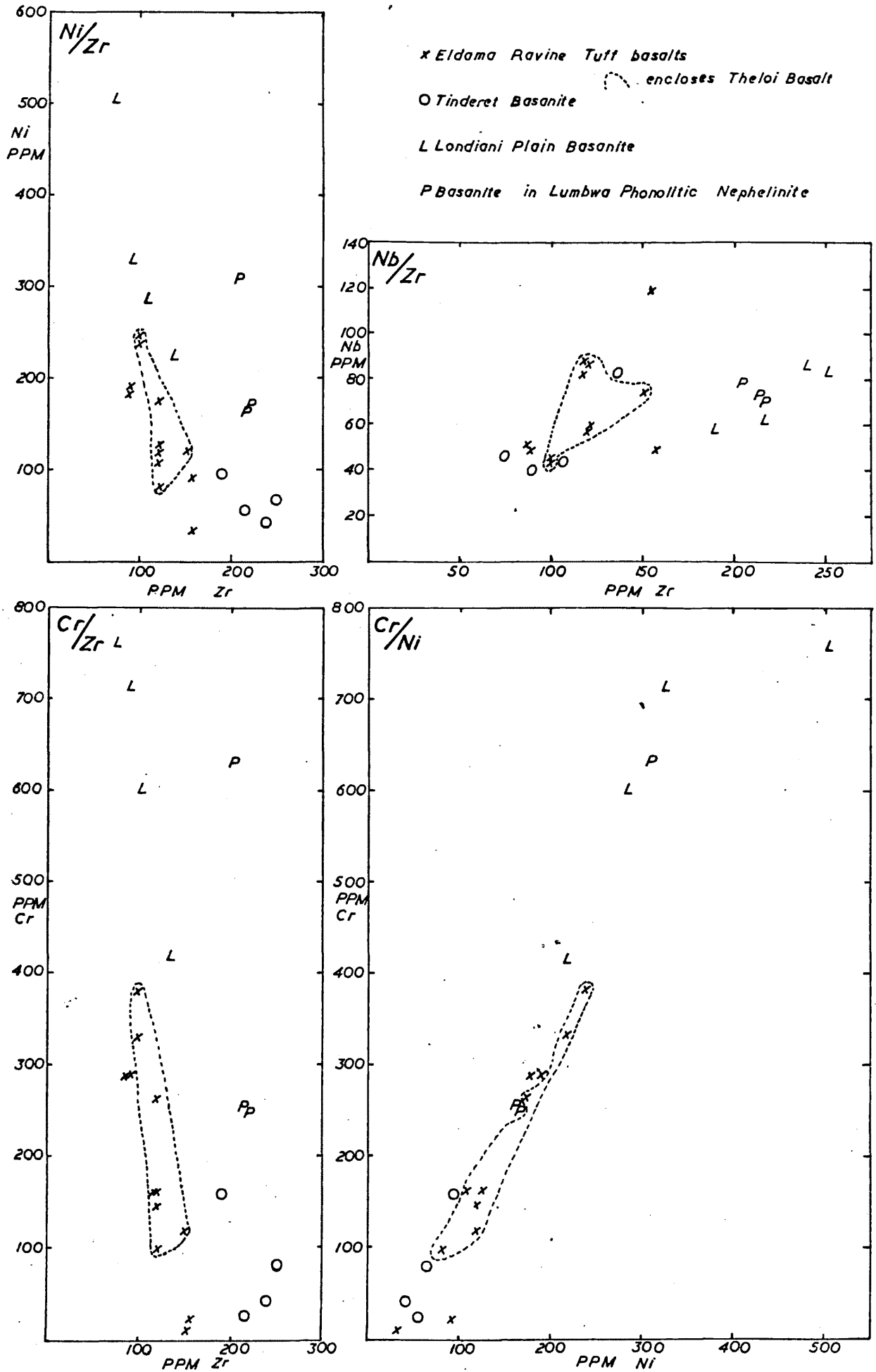
In fig. 37 Cr/Zr, Ni/Zr, Cr/Ni and ^{Nb}/Zr are plotted for the Theloi and other Eldama Ravine Tuff basalts, the Londiani Plain Basanite, the Tinderet Basanite and the basanite flow capping the Lumbwa Phonolitic Nephelinite. Cr and Ni both fall rapidly from high concentrations at low Zr values to very low concentrations at Zr = 300 ppm and both are usually less than 10 ppm in the Saos Mugearite and the Lumbwa Phonolitic Nephelinite. This is to be expected since it is known that Ni enters olivine and pyroxene and Cr enters pyroxene (Burns 1970). The trends for the different

formations are distinct and can be differentiated on the basis of their Zr values at the same Cr or Ni value. The Lumbwa P.N. basanite has the highest Zr, the Londiani Plain Basanite and the Tinderet Basanite have similar intermediate values and the Eldama Ravine Tuff basalts have the lowest values. This suggests that the basic lavas are formed with a range of Zr values, the more undersaturated having more Zr. A possible explanation of this is that the different lavas are produced by different degrees of partial melting of the same source rock. The elements such as Zr not compatible with the mineralogy of the presumably ultrabasic source rock are concentrated in the first formed liquid and become diluted with increasing melting. Therefore the strongly undersaturated basanites, with more Zr, were formed by a smaller degree of partial melting than the basalts.

The basic rocks are also differentiated on the plot of Nb/Zr in fig. 37. The Tinderet Basanite and the Lumbwa P.N. basanite have nearly twice as much Zr as the Eldama Ravine Tuff basalts and the Londiani Plain Basanite although their range of Nb is much the same. This means that the younger rocks have a higher Nb/Zr ratio than the older ones, the opposite of the situation reported by Weaver et al (1972) in the Kamasia Hills.

The Londiani Plain Basanite has the highest values of Ni and Cr suggesting that they are the most primitive of the basic rocks. On the Ni/Cr plot the analyses show approximately linear trends through the origin, the trend for the Londiani Plain Basanite being slightly steeper than that of the Theloi Basalt. The only point to lie far off these trends is 14/859, which contains only olivine phenocrysts. This may be explained as follows: the first mineral to crystallise is olivine which takes in Ni from the magma much more than it does Cr so that Ni drops faster than Cr. When augite also crystallises it takes in Cr more than Ni so that the two minerals together deplete the magma in the two elements at about the same rate, i.e. the partition coefficient

Figure 37. Nb/Zr , Ni/Zr , Cr/Zr and Ni/Cr for basic rocks



between liquid and crystals is about the same for Cr and Ni.

In the Theloi Basalt Cr varies from 100 to 400 ppm and Ni from 80 to 250 ppm. There is no correlation with phenocryst content but the distribution of the analysed rocks over the outcrop of the flow suggests that Cr and Ni values are higher in north west part of the flow than in the south east. The flow can be regarded as constituting a segment of a fractionation trend. Its Zr ranges from about 100 ppm to about 150 ppm. It may therefore represent the draining from a magma chamber of the liquid in the range of Zr 100-150 ppm. A liquid of 150 ppm Zr would be produced by the crystallisation of one third of a liquid of 100 ppm Zr and in the case of the Theloi Basalt the crystallisation of this one third of the liquid has removed 70-80% of the Cr and Ni. An estimate of the volume of the Theloi Basalt, assuming it to be 5 km by 15 km in area and averaging 100 ft thick, is $2\frac{1}{2}$ km³. Assuming that the Theloi Basalt represents the most basic part of the magma chamber and that it is one third of the liquid contained in it, then the magma chamber has a volume of about $7\frac{1}{2}$ km³. These two assumptions are certainly unjustified but this illustrates that rough estimates of volumes of magma chambers can be made knowing the volume of a flow and the variation in residual elements within it. In general one would expect a flow from a large magma chamber to show a lesser chemical variation than a flow from a small magma chamber because in the latter fractionation will involve smaller volumes of magma. This topic is returned to in the next chapter.

The Basalt to Trachyte Trend

The results of the trace element analyses of the Eldama Ravine Tuff basalts, the Saos Mugearite and the Londiani and Kilombe Trachytes are shown as plots against Zr of Nb and Ce (fig. 33), La (fig. 36), Rb and Y (fig. 34) and Ba and Sr (fig. 35) in order to see whether the trace

element chemistry shows them to be an evolutionary sequence as suggested by their superimposed stratigraphic positions.

In the Nb/Zr plot the basalts, mugearites and trachytes form an approximately uniform trend but in detail it is clear that the Londiani Trachyte and Kilombe Trachyte are close but quite separate from each other. The Saos Mugearite is intermediate between the two and distinct from both. Finally the Theloi Basalt has a trend which is much steeper than the others. The relationships of the other Eldama Ravine Tuff basalts is unclear due to lack of information.

In the Ba/Zr and Sr/Zr plots it is again clear that although there is an approximate overall trend each formation is distinct. For the Theloi Basalt Sr and Ba both rise steeply with increasing Zr. In the Saos Mugearite they both begin near the lower end of the Theloi Basalt range and Ba rises while Sr falls. Both elements begin in the trachytes well below the values at which they left off in the Saos Mugearite while Ba falls along the Londiani Trachyte and rises slightly in the Kilombe Trachyte.

Finally, for those elements such as Ce which are very disturbed by volatile effects in the trachytes the Saos Mugearite shows unaltered linear trends. There is thus abundant evidence that there is a chemical hiatus between the mugearites and the trachytes corresponding to the hiatus in the petrography, that the Londiani and Kilombe Trachytes are distinct and that the Theloi Basalt is not directly related to the more evolved rocks. There is no simple fractionation trend linking the basalts to the trachytes and four separate parental magmas must be invoked, characterised by different Nb/Zr ratios, to give rise to the Theloi Basalt, the Saos Mugearite, the Londiani Trachyte and the Kilombe trachyte. The mugearite and trachyte liquids may have fractionated at depth from different batches of basalt before rising to high-level magma chambers in which they fractionated within themselves.

The xenolithic rock in K17, 14/312, lies within the Zr range of the Saos Mugearite but its trace element concentrations are different, especially Y which is much higher and Sr which is much lower. It seems not to belong in the fractionation trend of the Saos Mugearite or of the Londiani or Kilombe Trachytes and may represent a distinct magma body.

Volatile Effects in the Trachytes

Previously when the trace element concentrations in a suite of rocks from Kenyan Trachyte volcanoes have been plotted against one another they have given a straight line passing through the origin (Weaver et al, 1972). However for Londiani and Kilombe this simple pattern has been altered. In the Nb/Zr plot fig. 33 it will be seen that a few of the Londiani trachytes plot below the line of the rest of them. This can be interpreted as these rocks having either more Zr or less Nb than they would need to plot on the main trend. That the latter is the case is shown by the Ce/Zr plot in which rocks which lie below the main trend for Nb lie even further below it for Ce. It seems that there is some effect which alters the concentrations of the residual elements so that they do not give linear plots against Zr. From the figures it can be seen that this effect is small for Nb only a few rocks being affected, greater for Rb and so pronounced for Y and the lanthanides that the presumed original trend has completely disappeared. Zr appears to be unaffected although this cannot be proved as no less volatile element was analysed against which to test it. The most extreme example of this is 14/382 which has lost nearly half its Nb and almost all its La and Ce. If it is assumed that, in the absence of this effect, the trends of the trachytes would have been approximately parallel to the trends of the Saos Mugearite then whereas in the affected rocks Nb was always removed Y and the lanthanides seem to have been added to some rocks and subtracted from others.

The scatter is more marked for Londiani than for Kilombe as shown by the correlation coefficients of the plots of the residual elements against Zr:

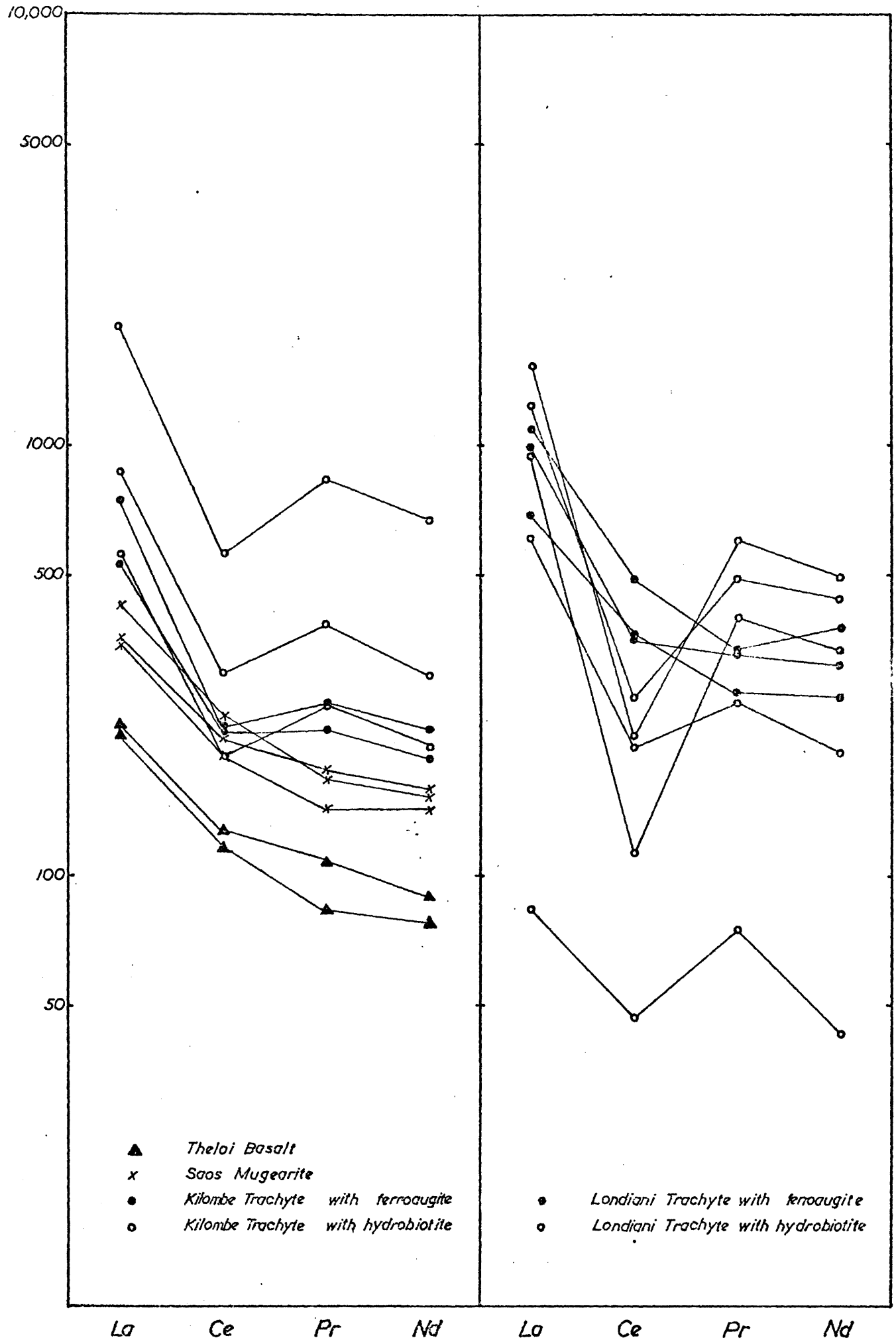
	Nb	Rb	Y	La	Ce	Pr	Nd
Kilombe	.996	.968	.449	.479	.459	.510	.482
Londiani	.805	.736	-.269	-.460	-.117	-.485	-.515

The negative correlation coefficients of Londiani for Y and the lanthanides mean that the slopes of the regression lines are negative. This is because there is a tendency for lanthanides to be added to the low Zr trachytes and removed from the high Zr trachytes.

It was mentioned above that most of the trachytes contain ferroaugite microphenocrysts and that many of these are altered to hydrobiotite. The analysed specimens which contain hydrobiotite phenocrysts have been marked on the trace element diagrams and it can be seen that they are the rocks with low Nb and Ce. The relationship of the alteration of the pyroxene microphenocrysts to the redistribution of the lanthanide elements is well brought out in fig. 38 which shows the chondrite normalised lanthanide patterns for those analysed trachytes which contain pyroxene microphenocrysts. The rocks with hydrobiotite have pronounced negative Ce anomalies while those with unaltered ferroaugite have little or no Ce anomaly. This means that in the rocks with hydrobiotite Ce is behaving differently from the other lanthanides, probable due to its oxidation to Ce^{4+} while the other lanthanides remain as $3+$ ions. Extrapolation of the plots for the Saos Mugearite suggests that Ce may be either added to or subtracted from the rock while Y and La are usually added. This means that the Ce anomalies are produced by the addition of other lanthanides rather than by the removal of Ce.

A rough measure of the degree of alteration can be obtained by dividing the measured Ce concentration in the rock

Figure 38. Chondrite normalised Rare Earth Element plots for basalt - trachyte trend.



by the concentration which would be predicted by extrapolating the Ce/Zr trend of the Saos Mugearite to the appropriate Zr value. In fig. 39 this ratio is plotted against the $\text{Fe}^{3+}/(\text{Fe}^{3+} + \text{Fe}^{2+})$ ratio and $\text{H}_2\text{O}^\dagger$ content of the whole rocks where these are available but there is no correlation with either. In fact there is little variation in the oxidation state of the iron in the whole rock analyses. However the oxidation of the Ce does correlate with the oxidation of the pyroxene involved in the conversion of ferroaugite to hydrobiotite, both being presumably the result of the same process. This means that the presence of hydrobiotite is a sensitive but easily recognisable petrographic indication of probable anomalies in the chemistry.

Of the major elements Na and Fe seem to be similarly affected. Na was measured for all the trachytes for which trace elements were analysed. These Na values are plotted against Zr in fig. 41 which shows that all the hydrobiotite-bearing Londiani Trachytes are deficient in Na compared with the others. However the hydrobiotite-bearing Kilombe Trachytes do not seem to be deficient in Na. There are fewer total Fe analyses but when plotted against Zr (fig. 41) they strongly suggest that Fe is also low in the hydrobiotite-bearing Londiani trachytes.

The redistribution process may have occurred before extrusion, after extrusion but prior to total solidification or after solidification. The third alternative, i.e. weathering, is ruled out by the lack of correlation of the alteration with the water content and oxidation state of the iron in the whole rocks. The second alternative, i.e. a deuteric effect, gains support from the fact that a block of glass from Londiani, 14/323, has all its trace elements at the values which would be predicted by extrapolation from the mugearites. However this block comes out of the early tuff of Londiani and it may be that the redistribution of the trace elements in the magma had not yet begun. Evidence will be presented in the next

Figure 39 $Ce/Predicted\ Ce \ v \ Fe_2O_3/(total\ Fe\ as\ Fe_2O_3)$ and H_2O^+
for trachytes

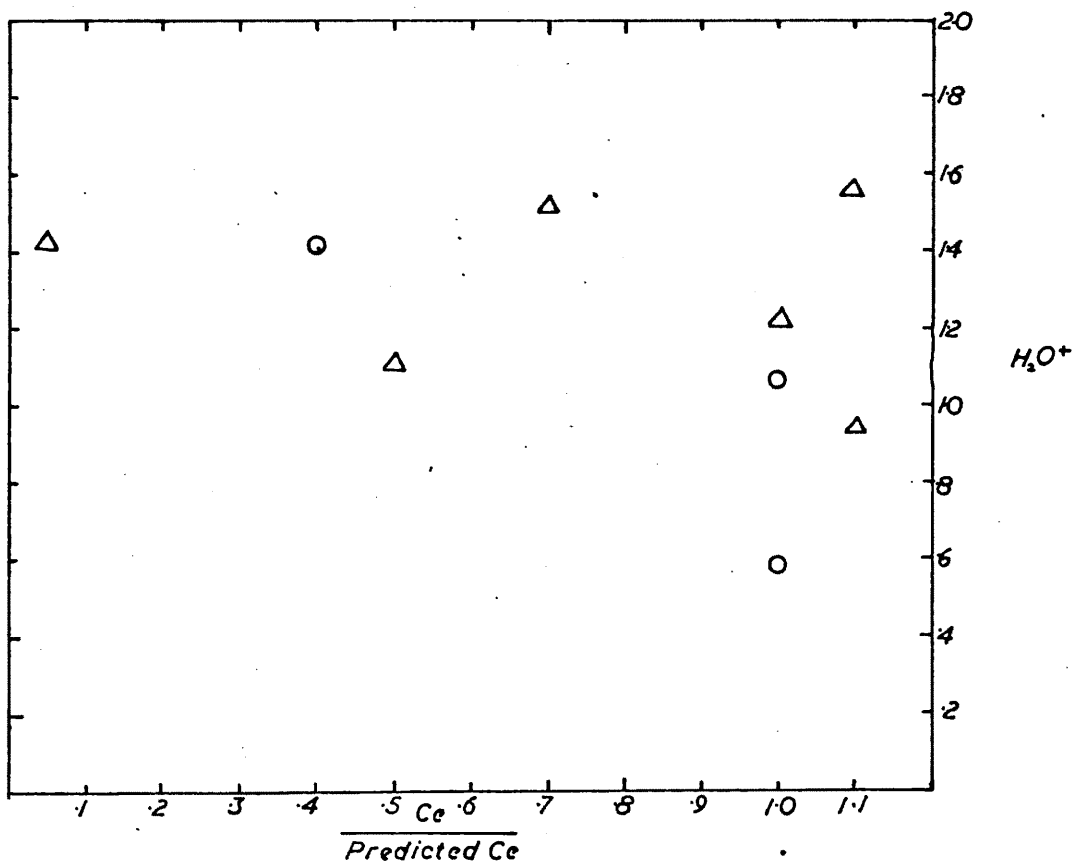
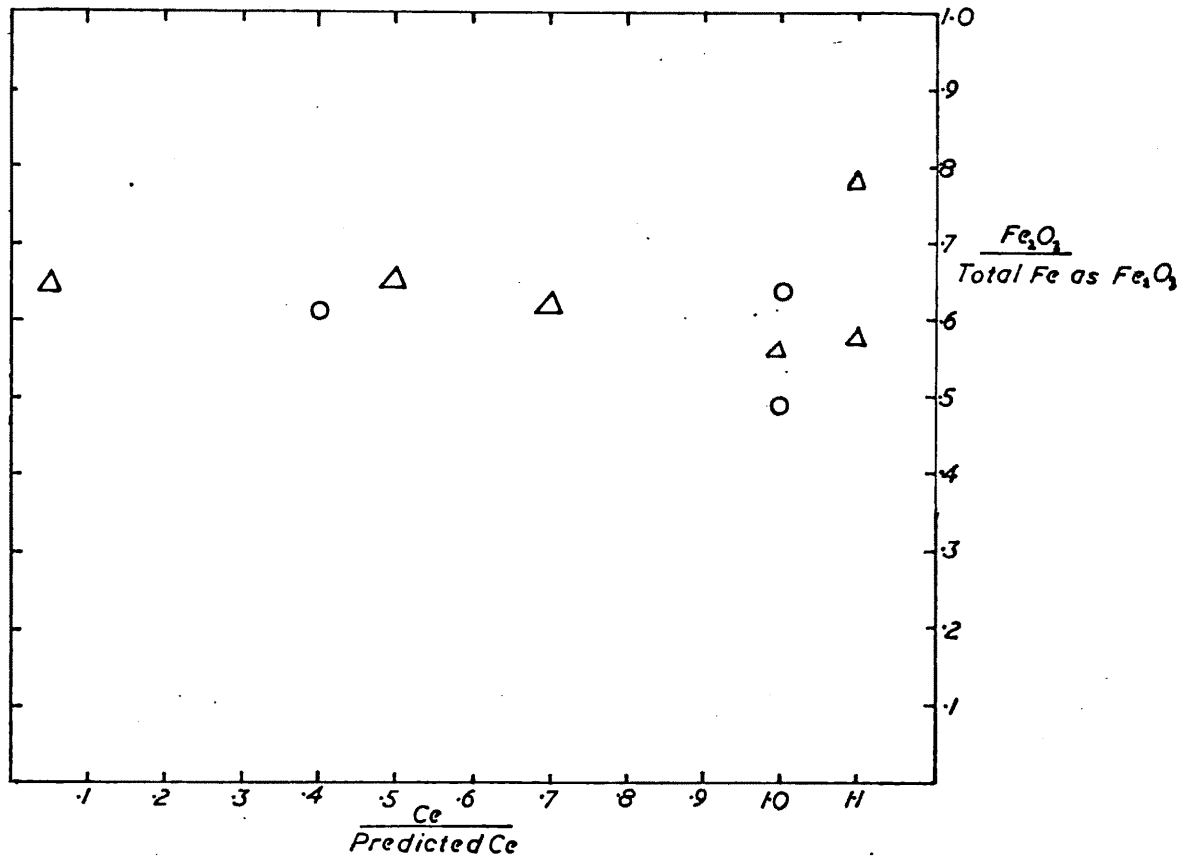


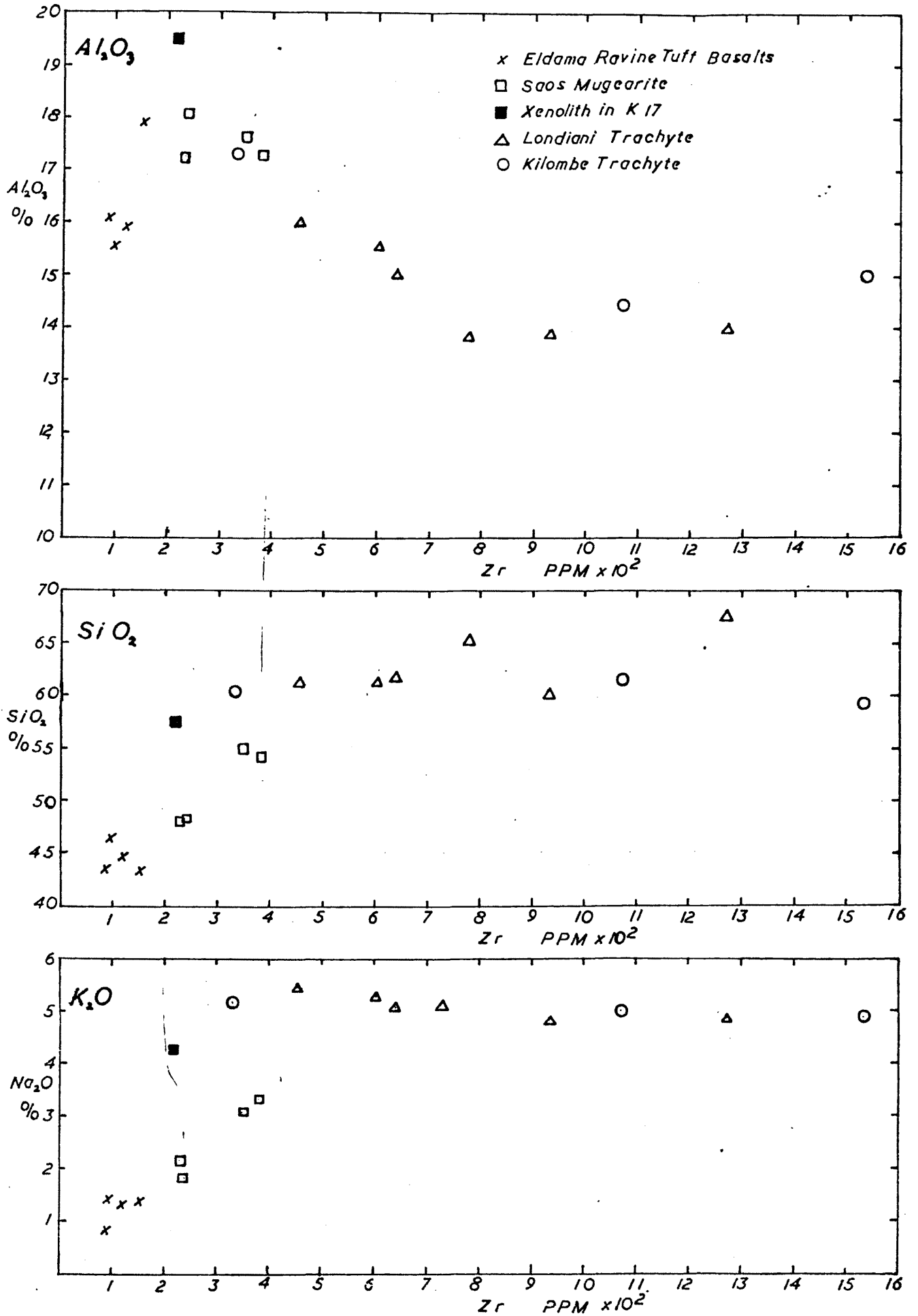
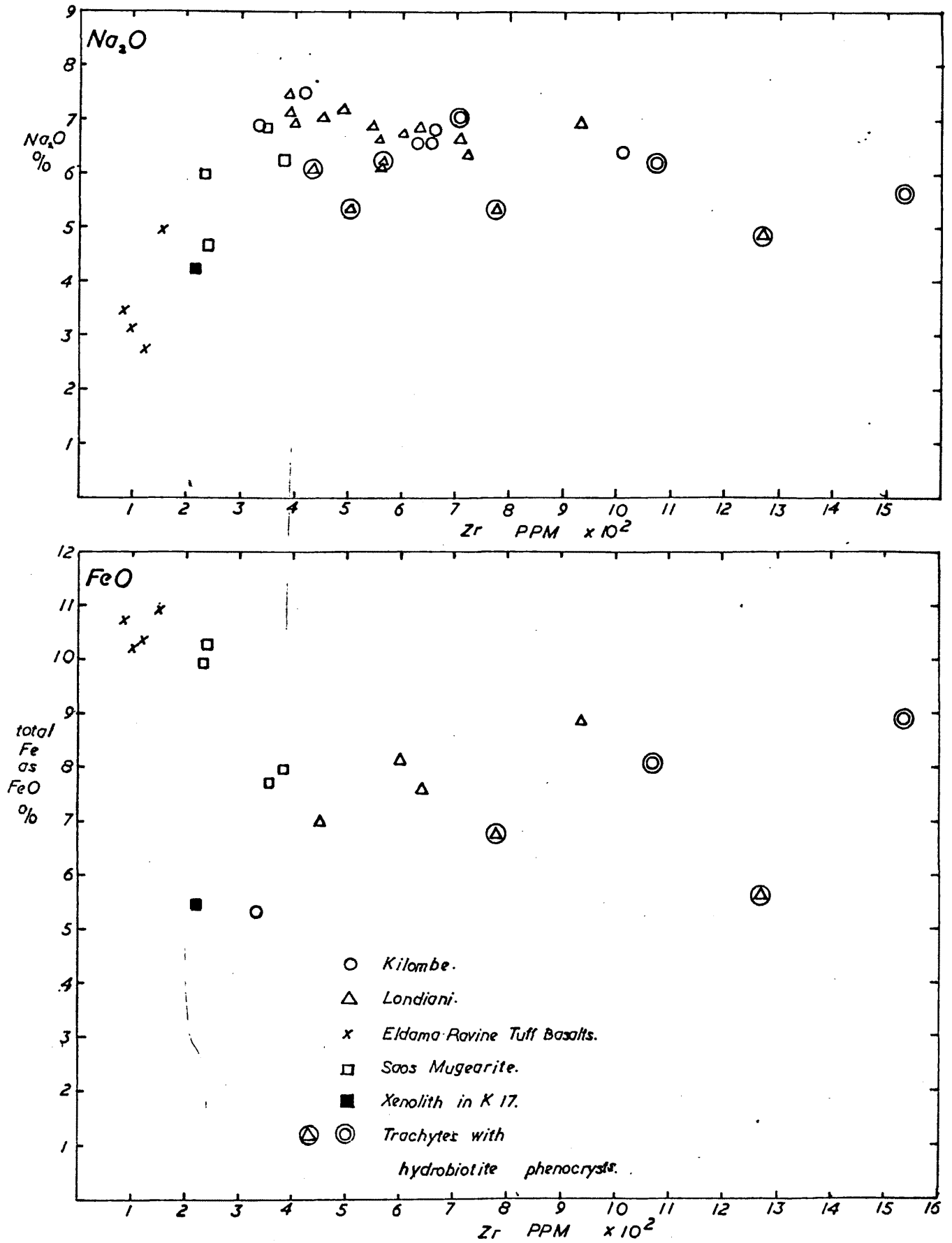
Figure 40. Al_2O_3 , SiO_2 and K_2O v Zr for basalt to trachyte trend

Figure 41. Na_2O and total Fe as FeO v Zr for basalt to trachyte trend



section that in fact the redistribution took place in the magma chambers underlying Kilombe and Londiani.

The Syenite Bombs

Introduction

Syenite boulders were found on both Londiani and Kilombe. On Londiani they are found lying on the south eastern slope of the mountain and at 122796 in the Makutano Tuff at its base where a stream has brought them off the mountainside. On Kilombe they occur all round the caldera but especially on the south slope (plate 14) and also in the two post-caldera flows. One syenite boulder was found on the surface of the Eldama Ravine Tuff at 117123 near Saos and had probably weathered out of the tuff. Similar syenite bombs have been found on other Kenyan trachyte volcanoes: Nasaken, Kafkandal, Ribkwo (Weaver 1973) and Menengai (McCall 1967).

The syenites can be classified by their appearance in hand specimen into five classes: coarse grained syenites, which constitute the great majority of the boulders; fine grained syenites, in which most of the crystals are not megascopically visible; aplitic syenites, forming thin veins in other syenites; melasyenites, dark green glossy rocks; and finally one specimen of fenitised tuff. The greatest variety of syenite types is found at 174921 inside Kilombe caldera weathering out of an exposure of the late tuff of Kilombe.

Petrography

Coarse Grained Syenites

These have about 90% of alkali feldspar as interpenetrating Carlsbad-twinned stubby crystals up to 1 cm long showing strong development of perthitic texture with fresh albite and clouded orthoclase. The perthite

is sometimes, as in 14/338, concentrated around the edges of the feldspars showing that replacement, as well as exsolution, is responsible for its development. Interstitial to the feldspar are amphibole, aegirine and a little aenigmatite. The amphibole is katophorite sometimes grading marginally towards arfvedsonite, just as in the trachytes. Unlike the trachytes however some specimens, e.g. 14/565, also have large green brown hornblende crystals of about the same size as the feldspars. These hornblendes are rimmed by katophorite and katophorite is commonly rimmed by aegirine. There is therefore a reaction series from hornblende to katophorite to aegirine. The aegirine forms squat prisms or radiating aggregates of needles. Commonly there are clots of mafic minerals with aenigmatite surrounded by arfvedsonite, aegirine and yellow brown hydrobiotite. Some specimens also contain red brown hydrobiotite pseudomorphs after ferroaugite, often within the feldspar crystals. Fresh ferroaugite was seen only in 14/565 which also contained the only biotite crystal seen, both within feldspar crystals. Small euhedra of nepheline or interstitial pools of quartz are usually present in small amounts. The order of crystallisation seems to be alkali feldspar with, where present, hornblende, ferroaugite and nepheline followed by aenigmatite, arfvedsonite and finally aegirine and quartz.

These coarse grained syenites were probably formed by solidification of trachyte liquid in magma chambers under Londiani and Kilombe. In the large block on the south side of Kilombe illustrated in plate 15 great variations in grain size and mafic content can be seen. This suggests that the magma was rich in a volatile phase, the coarser parts crystallising in a more volatile rich environment than the finer grained parts. This block also shows a sharp rounded boundary between coarser and finer grained syenites indicating that the finer grained syenite was still plastic when incorporated in, or intruded by, the coarser syenite. The

absence of a linear or banded structure in any of the coarse syenite boulders shows that crystal settling was not important. Therefore the syenites were not formed by accumulation of crystals on the bottom of the magma chamber. Rather they were formed by complete crystallisation of the coolest parts of the magma which would have been in the part of the magma chamber losing most heat, i.e. near the roof. This explains their abundance in the post caldera eruptions since the collapse of the roof of the magma chamber would have broken up much of this syenite body into small pieces.

Fine Grained Syenites

The fine grained syenites consist mostly of laths of feldspar about $\frac{1}{2}$ mm long often with a trachytic texture. They are intermediate in grain size between the coarse grained syenites and the trachytes. The feldspar is simply twinned alkali feldspar sometimes, as in 14/391, mantled or entirely replaced by multiply twinned albite. Aegirine and katophorite form about 5% each usually as small intergrown crystals but sometimes forming large euhedra poikilitically enclosing feldspar laths as in 14/391. 14/328 has mafic clots up to 5 mm across cored by a string of separate but optically continuous remnants of olivine mantled in turn by aenigmatite, katophorite and hydrobiotite demonstrating a discontinuous reaction series starting with olivine. These mafic clots cored by olivine have also been found in syenites from Turkana (Weaver 1973). These rocks are often strongly undersaturated. 14/392 contains rounded phenocrysts of nepheline with reaction rims of analcite and alkali feldspar and large groundmass pools of analcite. 14/391 has 10% pools of analcite with a central clear part and an outer part containing inclusions of groundmass minerals. It seems that nepheline forms phenocrysts in these rocks which act as nuclei for the growth of groundmass analcite and are themselves largely converted to analcite.

In hand specimen the small block 14/328 shows a contact between coarse grained syenite and fine grained syenite. The fine grained is intruding the coarse grained and breaking off fragments of it which become incorporated in the fine grained syenite as phenocryst clusters. The phenocryst clusters show only a slight development of perthitic texture and then only round the edge. This means that the fine grained syenite intruded the coarse grained after the latter had solidified but before it had cooled sufficiently to develop perthite.

The fine grained nature and trachytic texture of many of the fine grained syenites suggests that they were formed by solidification of lava in dykes. Some of these dykes were probably the feeders of the trachyte lavas but others may have only cut the previously solidified coarse grained syenite.

Aplitic Syenites

Two blocks of syenite were found which contained veins of fine grained rock about 1 cm wide. A vein in 14/394 consists of 30% equidimensional quartz grains, 20% aegirine and 50% albite while a vein in 14/392 has 70% albite and 30% aegirine.

Melasyenites

These are found only in the tuff exposure at 174921 in Kilombe caldera. In thin section they consist of dense mats of aegirine needles poikilitically enclosed in large alkali feldspar crystals, probably close to albite. Aegirine may constitute, in different parts of one hand specimen, anything from 50% to 100% of the whole rock.

Fenite

14/197, a block about 20 cm long, shows a sharp straight contact between syenite and tuff. The tuff half of the block contains rounded fragments up to 1 cm long which are easily visible in the hand specimen. In thin section it consists of a fine grained equigranular aggregate of

albite, katophorite, aenigmatite and aegirine with included trachytic fragments in which the alkali feldspar has been converted to albite. There are a few isolated alkali feldspar phenocrysts and these have perthitic inclusions of albite and albite rims. The syenite half of the rock consists of 30% aegirine needles up to 3 mm long in an allotriomorphic groundmass of untwinned alkali feldspar and so is intermediate between the fine grained syenites and the melasyenites. The texture of the syenite remains the same right up to the contact but on the tuff side the original pyroclastic texture has completely disappeared for 2 cm away from the contact. Instead there are flame shaped masses of aegirine a few mm wide which all point parallel to each other in a direction at about 60° to the contact, the intervening space being filled with a fine grained aggregate of albite.

Summary

The coarse grained syenites, which include the great majority of them, are petrographically similar to the trachyte lavas. The main differences are the presence of perthitic texture, absence of trachytic texture and appearance of hornblende in the syenites. Many of the fine grained syenites are just coarse versions of the trachytes but the nepheline and analcite of some of them sets them apart from the lavas which are usually slightly oversaturated. The aplitic syenites and melasyenites have no analogues among the lavas.

The coarse grained syenites are the equivalents of the trachyte lavas and are formed by solidification of the trachyte liquid without any crystal differentiation. The fine grained syenites probably crystallised in dykes and many of them may be later than the coarse grained syenites. The aplitic syenites and melasyenites are probably rocks which crystallised from the final fluid when all the rest of the magma had solidified.

The quartz rich vein and the nepheline and analcite rich rocks were all found on Kilombe. This means that during the evolution of the magma chamber under Kilombe both strongly oversaturated and strongly undersaturated liquids were produced.

There is a clear gradation from the coarse grained syenites, through the fine grained syenites to the aplitic syenites and melasyenites. In the coarse grained rocks the alkali feldspar sometimes shows signs of deuteric alteration to albite, in the fine grained this alteration is quite marked and in the other classes albite crystallises instead of alkali feldspar. This gradation is also shown by the rise in importance of aegirine and disappearance of the other mafic minerals culminating in the melasyenites in which aegirine may constitute the whole rock. This implies that Na and Fe become concentrated in the final fluid phase. The only non syenitic bomb found was a small block of vesicular dolerite on the outer eastern slopes of Kilombe. This rock 14/166 consists of 40% plagioclase of composition An 70%, 30% lilac augite, 20% olivine and 10% ore.

Chemistry

14 syenites from Kilombe, 4 from Londiani and one from the Eldama Ravine Tuff were analysed (Table 4.16-4.19). In general the analyses are very similar to the trachytes, particularly for the coarse grained syenites.

On the Nb/Zr plot (fig.42) the syenites from Londiani and Kilombe lie on the same two distinct trends and have the same range of values as are found for the lavas. This is strong evidence for the syenites being derived from the same two magma bodies as the trachytes.

14/327C, a syenite boulder from Londiani, is an exception to this though. It has 2365 ppm Zr which is much higher than the limit of about 1500 ppm Zr in the trachytes. This block has about 30% mafic minerals

Figure 42. Nb/Zr and Ce/Zr plots for Syenites.

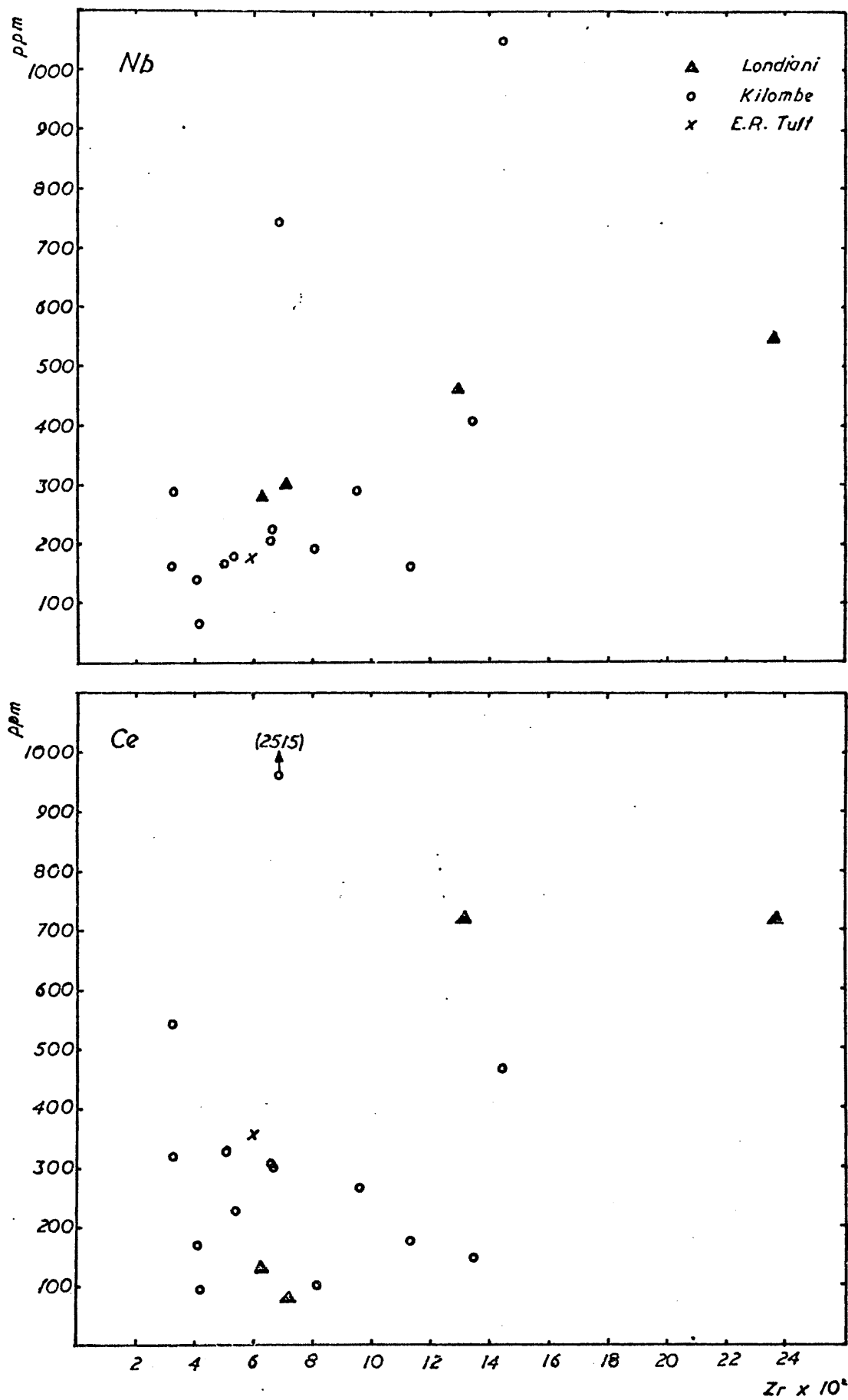


Figure 43. Ni, Ce, FeO and Na₂O v Zr for Kilombe Syenites.

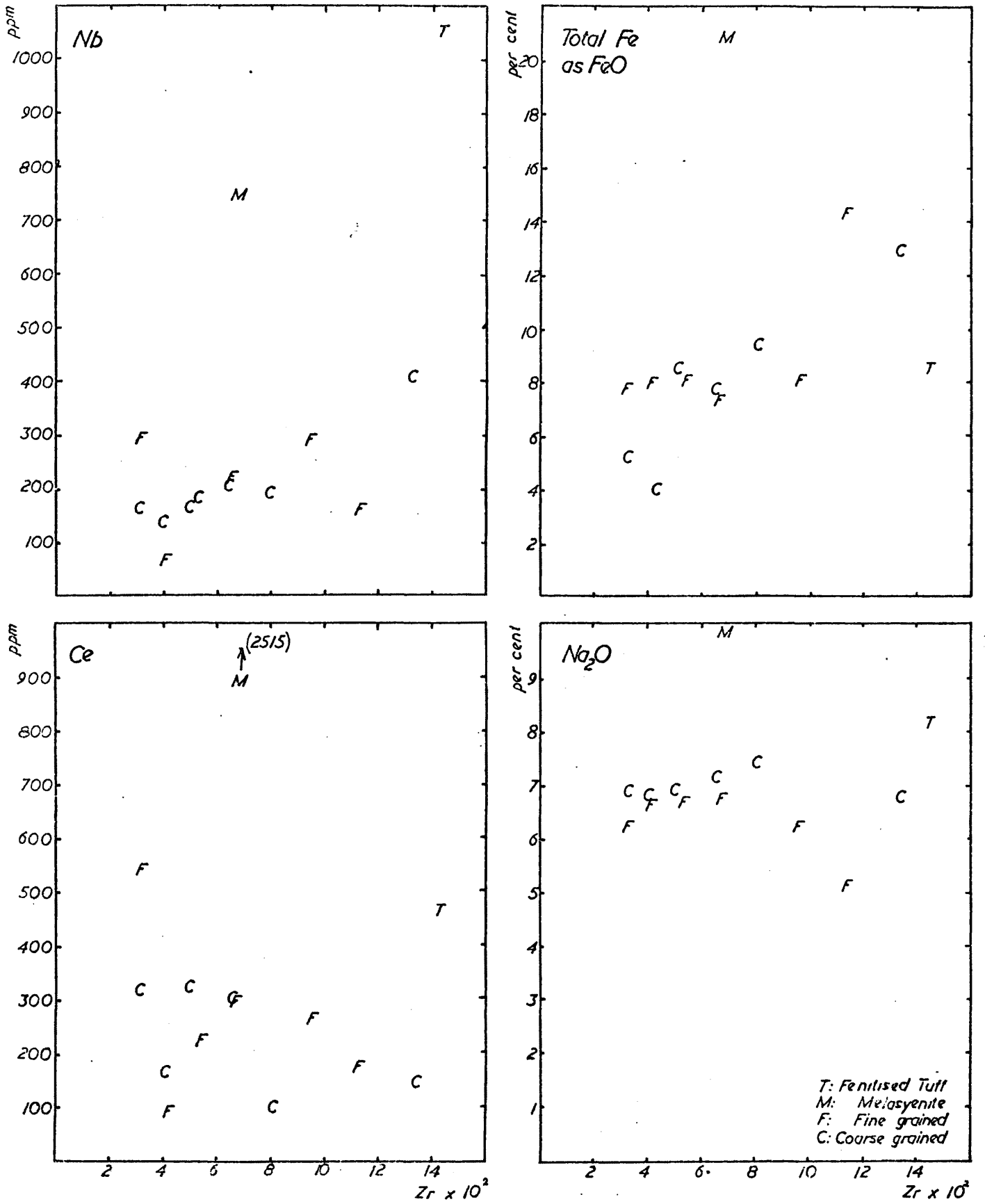
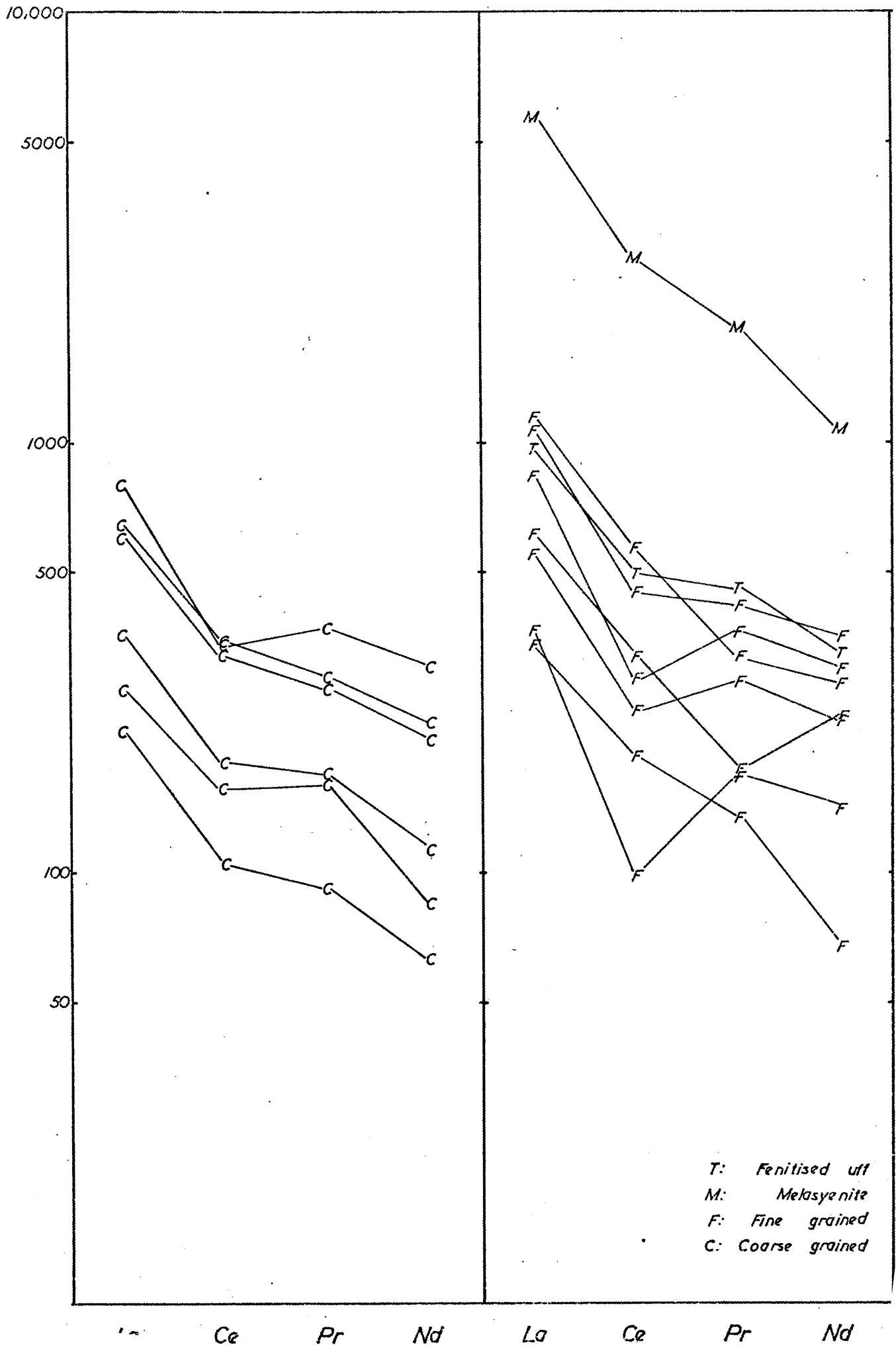


Figure 44. Chondrite normalised Rare Earth Element plots for Kilombe Syenites.



which is much higher than the usual 10% in the coarse grained syenites. This is probably because this particular piece of very coarse grained syenite 10 cm across is too small to represent a liquid composition. In situ it would have been balanced by adjacent syenite with less than average mafic content so that overall the whole mass of syenite, here called the parental rock, would have had a normal mafic content. To see whether the high Zr was related to the high mafic content of this rock, part of it was crushed and the dark and light minerals separated from each other. In this process the margins of the crystals would have been lost in the dust. The two batches, one of feldspar perhaps with a little quartz and the other of hornblende, katophorite and aegirine, were analysed separately for their trace elements with the following result:

	whole rock	light minerals	dark minerals
Ba	226	42	128
Ce	720	332	616
La	227	58	130
Nb	551	261	370
Nd	133	68	78
Pr	41	23	44
Rb	326	551	20
Sr	4	3	0
Y	107	26	57
Zr	2365	397	4007

All of the elements analysed, except Rb and Zr, are lower in both the light minerals and the dark minerals than in the whole rock and must therefore be concentrated in the margins of the crystals and along the boundary layers between them. On the other hand, since the rock has 30% mafic minerals and about 70% feldspar, then almost all the Rb in the rock is within the feldspar crystals and about half the Zr is within one or

more of the mafic minerals. This means that when a body of syenite liquid crystallises the residual elements are concentrated in the remaining liquid until the proportion of liquid is very low and the concentrations of the residual elements is very high. They then begin to enter the crystallising minerals, first nearly all the Rb into the feldspars, then about half the Zr into one or more of the mafic minerals and finally the other elements are incorporated in the margins of the crystals as the last of the liquid is used up.

For 14/327C these analyses show that the excess of Zr in this specimen is due to its having a higher proportion of mafic minerals than its parental rock. This can be further tested as follows. The dark and light minerals have similar concentrations of Nb, both being less than that of the whole rock, so the Nb concentration in the parental rock will not vary much with mafic content. In that case the Nb value of 14/327C can be taken as being representative of the parental rock as a whole. Assuming that the average Nb and Zr values for the parental rock lie on the same straight line as the other three syenites of Londiani, then for its Nb concentration of about 550 ppm it would have a Zr concentration of about 1600 ppm which is two thirds of the value in 14/327C. Assuming that the concentration of Zr in the whole rock due to incorporation of Zr in the margins of crystals is independent of the mafic content then this figure will be the same for the parental rock as for 14/327C which is about 1200 ppm. The concentration of Zr in the dark minerals is 4000 ppm so for the whole rock the concentration of Zr due to Zr held inside the mafic minerals is 400 ppm per 10 % of mafic minerals. Therefore the parental rock with 1600 ppm Zr altogether has $1600 - 1200 \text{ ppm} = 400 \text{ ppm Zr}$ contributed by the mafic minerals implying an average mafic content of 10%. This is what would be expected by comparison with the other coarse grained syenites and thus proves that part of the Zr in a syenite is incorporated in one of the mafic minerals.

In discussing the lavas it was assumed that Zr does not enter any crystallising mineral during fractional crystallisation but the above argument suggests that it does. However in the syenites Zr only enters the crystallising minerals when the liquid is near used up, perhaps when it is 80 or 90% crystallised. On the other hand liquids which become erupted at the surface have probably never been more crystallised than is represented by their phenocrysts, i.e. not more than 30-40%. Therefore the assumption that Zr behaves as a residual element is valid for the lavas.

On the Ce/Zr plot (fig.42) there is a broad scatter instead of two linear trends. This is the same as was found for the lavas and so is probably due to the same cause. In this connection it is noteworthy that 14/565, the syenite boulder from the Eldama Ravine Tuff, is the only syenite in which unaltered ferroaugite was seen. Its Ce concentration lies on the extension of the Saos Mugearite trend and so is probably unaffected by volatile transfer. This suggests that the state of the ferroaugite crystals is as good an indication of the presence or absence of volatile effects in the syenites as it is in the lavas.

In fig.43 are plotted some major and trace element data for the different classes of syenites from Kilombe while the corresponding chondrite normalised lanthanide data are shown in fig.44. The coarse grained syenites show the least disturbed patterns on all the diagrams. The fine grained rocks are more altered and some of them have substantial negative Ce anomalies. However the very coarse grained syenite from Londiani, 14/327C, has a positive Ce anomaly and the analyses quoted above show that this is not due to its high mafic content. The chondrite normalised figures are: La 710, Ce 766, Pr 342 and Nd 222. This is the only case of a positive Ce anomaly found in any of the syenites or trachytes.

The most unusual rock is the melasyenite 14/191. This has 22% Fe_2O_3 , 10% Na_2O and 1% K_2O compared with the usual figures in the syenites of about 10% for total Fe, 7% for Na_2O and 5% for K_2O . It has about ten times the normal quantity of lanthanides and is also very high in Y and Nb. As explained above in discussing the petrography 14/191 probably crystallised from the final fluid phase when the great majority of the syenite had long since solidified. This final fluid phase then, which presumably has a high proportion of volatile elements, is rich in Na, Fe, Y, Nb and lanthanides.

The fenitised tuff 14/197A is high in Na and low in K while the adjacent dyke rock 14/197D is rather low in Na and high in K. The tuff has fairly high Y and lanthanides and Nb very high at 1051 ppm. On the other hand the dyke rock has low lanthanides, Y and Nb. The tuff and the dyke are clearly complimentary with Na, Y, Nb and lanthanides passing from the dyke into the tuff and possibly with K migrating in the opposite direction. This shows that Na, Fe, Y, Nb and the lanthanides can migrate out of the magma into adjacent rocks.

It was suggested in discussing the trachytes that certain elements can be moved about in the magma chamber, being removed from one part and redeposited in another. It is shown here that the same elements can migrate out of the magma into adjacent country rock and are concentrated in the final volatile rich fluid. It is possible that the mobility of these elements is due to their forming volatile compounds with non-metals. For example the lanthanide elements form volatile fluorides (Herrmann 1970).

Since the syenites formed by complete crystallisation of parts of the magma bodies rather than by separation of crystals from the liquid, it is not by their crystallisation that the magmas evolved. If the trachytes evolved by fractional crystallisation then one might expect to find cumulate rocks among the syenites but these were not found. This difficulty can be overcome by assuming that the syenite magma does not

reside in a closed magma chamber but in a cupola atop a large basic magma as hypothesised by Weaver et al. (1972). The crystallising minerals would sink into the basic part of the magma chamber where they are resorbed, a hypothesis supported by the frequent observation of resorbed alkali feldspar crystals in the basic and intermediate lavas of the Londiani Assemblage. As the syenitic cupola is emptied by eruption at the surface the earliest lavas from the top of the magma body, are aphyric and as eruption taps lower levels the lavas become more porphyritic which is what is found in practice.

Chapter VI

THE TUFFS.

Vulcanology

Types of Tuff

Tuffs cover about half of the mapped area the main pyroclastic formations being the Makutano Tuff, the Mau Tuff, the Eldama Ravine Tuff and to a lesser extent the Menengai Tuff.

The Lower Menengai Tuff is all air fall tuff near to Menengai but further away the ash flow appears and in the furthest parts of its outcrop the ash flow predominates over the non ash flow rocks. It was suggested above in discussing the Equator Monocline that the Eldama Ravine Tuff is similar. It probably thickens considerably from the Perkerra Gorge, where it consists mostly of ash flows, to the south east where ash fall tuffs become increasingly important. The Mau Tuff and the Makutano Tuff may be both about half ash flow rocks but it is difficult to tell because of their poor exposure.

The ash flow tuffs are massive rocks which form crags on hillsides, often showing columnar jointing. Along the Perkerra Gorge this columnar jointing can occasionally be seen to radiate out from the centres of flows. In hand specimen unwelded ash flow tuffs are yellow rocks with yellow pumice enclaves and have no planar structure. On the other hand the welded tuffs are hard dark rocks with fiamme which give them a horizontal planar structure.

Ash fall tuff can be seen over a large area in the exposures of Makutano Tuff west of Murungwa. The creamy coloured tuff shows cm scale bedding with dips up to 20° in variable directions. Very fine grained tuff is rare but may be seen near the waterfall in Kilombe caldera, in Londiani caldera where the Visoi stream turns out of the caldera and in a patch of sediment 3 miles east of Maji Mazuri. In these three places there is evidence that the tuff was deposited in a lake. These waterlain

tuffs are bedded on a scale of mm or cm and show graded bedding with coarser grey ash grading up to finer grained creamy ash.

Colour of Tuffs

The general colour of unwelded tuff is yellow while welded tuffs are dark colours, grey, blue, green or purple. However the younger unwelded tuffs are the same colours as the welded tuffs.

The Upper Menengai Tuff is usually black or sometimes dark blue or purple, both when it is welded, as near Menengai, and when it is unconsolidated ash as in the Rongai Black Ash. However it is occasionally yellow. This can be seen along the river Molo north east of Kampi ya Moto at 283944. Here the upper part of the outcrop is massive yellow pumice tuff identical to the ash flow tuffs in the Eldama Ravine Tuff and this grades down into grey unconsolidated ash with black pumice inclusions.

The Lower Menengai Tuff is the usual yellow colour but the pumice enclaves in the ash flow are black. In the Eldama Ravine and Mau Tuffs the pumices are almost always yellow although black cores of pumice were very occasionally found in the Eldama Ravine Tuff. The Makutano Tuff is usually yellow but along the railway between Londiani and Kedowa dark ash can be seen. In a cutting at 882785 grey ash contains a subhorizontal band of yellow tuff 4-6 ins wide and 50 ft long. Another cutting at 876781 is yellow tuff with a 3 ft long section of grey ash. The ash grades laterally over about 1 inch into the yellow tuff on either side.

It seems that these unwelded pyroclastic rocks are originally dark unconsolidated ashes. In a time of the order of 10^5 years they are slowly converted to massive yellow tuff, although patches of dark ash may survive for much longer. The enclosed pumices take longer to be converted, perhaps of the order of 10^6 years. The conversion is probably a process of hydration of the glass particles in the ash to clay minerals by ground-water. This almost certainly involves a volume increase so that the original pore space is eliminated and the final product is a compact yellow rock quite different from the original ash. This hydration process

has only occurred to unconsolidated ash while tuffs which welded during emplacement have retained their original dark colour. This explains why at the tops and bottoms of crags of welded tuff one can often find soft yellow tuff grading into the hard dark welded tuff. The yellow tuff is the hydrated unwelded part of the ash flow.

The Upper Menengai Tuff is thus probably an example of what the unwelded ash flows of the Eldama Ravine Tuff looked like before they were hydrated.

Pumice and Glass

Pumice is almost invariably present in the tuffs and usually forms about 5% of the ash flows. However in air fall deposits it tends to be more abundant and may form the entire rock as in the Lower Menengai Tuff close to Menengai Caldera.

In the Eldama Ravine Tuff flows pumices usually range in length from 5 mm to 2 cm. In the air fall deposits they may be bigger and in the pumice by Menengai Caldera they range up to 5 cm, presumably because they are near their source. The largest pumices seen were boulders up to 100 cm long found lying on the surface of the Upper Menengai Tuff around Kampi ya Moto. These have bulbous surfaces inside which they are almost entirely hollow but for a few thin glass films.

At the other end of the scale the Gogar Tuff consists entirely of round vesicular particles of about 1 mm diameter. These are too small to be properly called pumice so the Gogar Tuff is here called a lapilli tuff.

In the exposure of early tuff on Londiani $1\frac{1}{2}$ miles south of the Visoi stream's gorge there are lumps of glassy trachyte up to 6 cm long showing a complete gradation from very vesicular pumice to nonvesicular glass.

In the Eldama Ravine welded tuffs some contain pumice in various stages of flattening such as E 6 while others such as E 2 and E 7 contain fiamme without vesicles, such as E 2 and E 7. Outcrops of E 7 west of Saos show unflattened glass lumps so the absence of vesicles in the fiamme is not due to their having been squeezed out by the flattening. This means

that some ash flows are erupted with blebs of lava which are strongly vesicular and others have completely nonvesicular blebs.

Thickness, Areas and Volumes of Ash Flows

As stated in the stratigraphy the thickness of the ash flows in the Eldama Ravine Tuff is uniformly about 50 ft. This is at the lower end of the range of thickness usually found for ash flows which is 50-300 ft (Ross and Smith 1961). The ash flow of the Lower Menengai Tuff which is 10 ft thick south of Kilombe and 6 ft thick north of it is very thin compared with the older ones.

Many of the Eldama Ravine Tuff flows cover large areas, particularly E 2, E 7 and E 9. The largest and most complete is E 7. Its outcrop is about 18 miles (30 km) from NE to SW and $7\frac{1}{2}$ miles (12 km) from NW to SE. Where seen near Saos it appears to be close to its source. Its outcrop may therefore be assumed to be approximately semicircular with a radius of 9 miles (15 km). This gives it an area of about 125 square miles (350 km^2). Assuming it to be 50 ft (15 m) thick then it has a volume of about 1.3 cubic miles or 5.25 km^3 . This is of the same order of magnitude as the $2\frac{1}{2} \text{ km}^3$ estimated as the combined volume of the Londiani Trachyte flows L16 and L 17. It seems then that large trachytic ash flows and lava flows have similar volumes. This is to be expected if it is assumed that the volume of magma rising from depth to be erupted at the surface is unrelated to the mode of eruption.

A crude estimate of the total volume of the Eldama Ravine Tuff under the area in which it outcrops may be made by assuming that its outcrop is the same semicircle as for E 7 and its shape is an inverted half cone with depth 1000 ft. This gives it a volume of 20 km^3 or 5 cubic miles. However the Tuff thickness underneath the younger on the floor of the rift valley and its total volume may be several times as much. This is in the range of volumes of pyroclastic flow fields described by Smith (1960) as being associated with calderas and just below the range of fields associated with vulcanotetonic depressions.

Petrography of the Welded Tuffs

Eldama Ravine and Mau Tuffs

In thin section the welded tuffs of the Eldama Ravine and Mau Tuffs consist of fiamme, phenocrysts and xenoliths in a cryptocrystalline base.

The fiamme may be vesicular, as in E 6 or nonvesicular as in E 7. They always have ragged ends but only sometimes, as in E 3, do they look like partitions between vesicles. The fiamme have usually devitrified with tiny crystals growing inwards from the surface and others forming spherulites within them. These crystals are usually alkali feldspar but in the phonolitic flow E 3 the crystals growing inwards from the surface are alkali feldspar while the spherulites inside are natrolite. Interspersed among these feldspar crystals are tiny grains of aenigmatite, katophorite and aegirine. In M 4 the crystals growing in from the margin extend to the centre of the fiamme producing an axiolitic structure. In the two glass fiamme welded tuffs of the Eldama Ravine Tuff E 2 and E 5 the fiamme are isotropic glass.

Phenocrysts of simply twinned alkali feldspar, usually broken, are always present though often only in small quantities. Ferroaugite microphenocrysts are sometimes seen, both fresh and as hydrobiotite pseudomorphs. Flakes of biotite were found only in one section, 14/129. Two welded tuffs have abundant alkali feldspar phenocrysts, E 9 in the last of the Eldama Ravine Tuff welded tuffs with 35% phenocrysts and M 3 with about 20%.

Xenoliths of trachytic rocks are always present and can form up to 20% of the rock as in M 1.

The welded tuffs usually have tiny alkali feldspar laths and a pale green brown cryptocrystalline base with small pools of fine grained feldspar or feldspar and quartz. However the base of E 9 is sufficiently coarse grained to be resolvable at highest magnification into an aggregate of alkali feldspar, aenigmatite, katophorite, quartz and possibly aegirine. 14/129, a vitreous brown tuff, consists of a dark red brown cryptocrystalline material, usually with a very low birefringence but with patches of high birefringence resembling hydrobiotite.

In E 2 and E 5 which have a high proportion of both feldspar phenocrysts and fiamme it is noticeable that the phenocrysts, and also the trachyte xenoliths, are much more common in the groundmass than in the fiamme. This implies that during the separation of the magma into gas rich and gas poor phases the solid particles are differentially taken up in the gas rich phase.

Makutano Tuff

The welded tuffs of the Makutano Tuff are similar to those of the Eldama Ravine and Mau Tuffs except for their phenocrysts. However the fiamme tend to have zeolite accompanying the alkali feldspar in the devitrified fiamme.

The tuff flow on the Mau Highlands P 1 has phenocrysts of nepheline, alkali feldspar, ferroaugite, ore and kaersutite in order of decreasing abundance. This shows that it is equivalent to the augitephyric phonolite. The flows west of Murungwa P 3 and P 5 have alkali feldspar and biotite while P 3 also has kaersutite phenocrysts. These northern Makutano welded tuffs are thus truly phonolitic while those on the Mau are transitional to nepheline mugearite. P 6, which outcrops in the north west of the Londiani Plain and has strongly zoned and altered nephelines, alkali feldspars of which the larger ones are very embayed, and uncorroded fresh microphenocrysts of ore, ferroaugite, biotite and kaersutite, seems to be intermediate between these two types.

Chemistry of the Tuffs

62 specimens of welded tuff, mostly from the Eldama Ravine Tuff, were analysed for their trace elements and 35 of these were also analysed for their major elements. This was done to see how the tuffs were related to the lavas, what variation there is within one ash flow and what variation there is within the tuff formations as a whole.

Comparison with the Lavas

Na_2O and K_2O are plotted against SiO_2 for all the analysed tuffs in fig.45. There is a great scatter in Na_2O but K_2O shows similar values to the lavas. The Makutano Tuff flows have similar SiO_2 to the Plateau Phonolites with P 1 having lower SiO_2 than the others as was to be expected from the petrography. However their K_2O is about 1% higher than the Plateau Phonolites.

The Eldama Ravine Tuff ash flows range in composition from trachyphonolite with $\text{SiO}_2 = 55\%$ to alkali rhyolite with $\text{SiO}_2 = 68\%$, the majority of them being trachyte with $\text{SiO}_2 = 60-63\%$. They have the same K_2O as the corresponding lavas, most of them lying between 5 and 6% and falling gently from the trachyphonolites to the alkali rhyolites. The Mau Tuff and the Upper Menengai Tuff seem to lie within the range of compositions of the Eldama Ravine Tuff. The Rosoga Tuff with SiO_2 about 71% is the most acid rock found in the Londiani area and resembles a comendite flow at Hell's Gate near Lake Naivasha (Table 4.12).

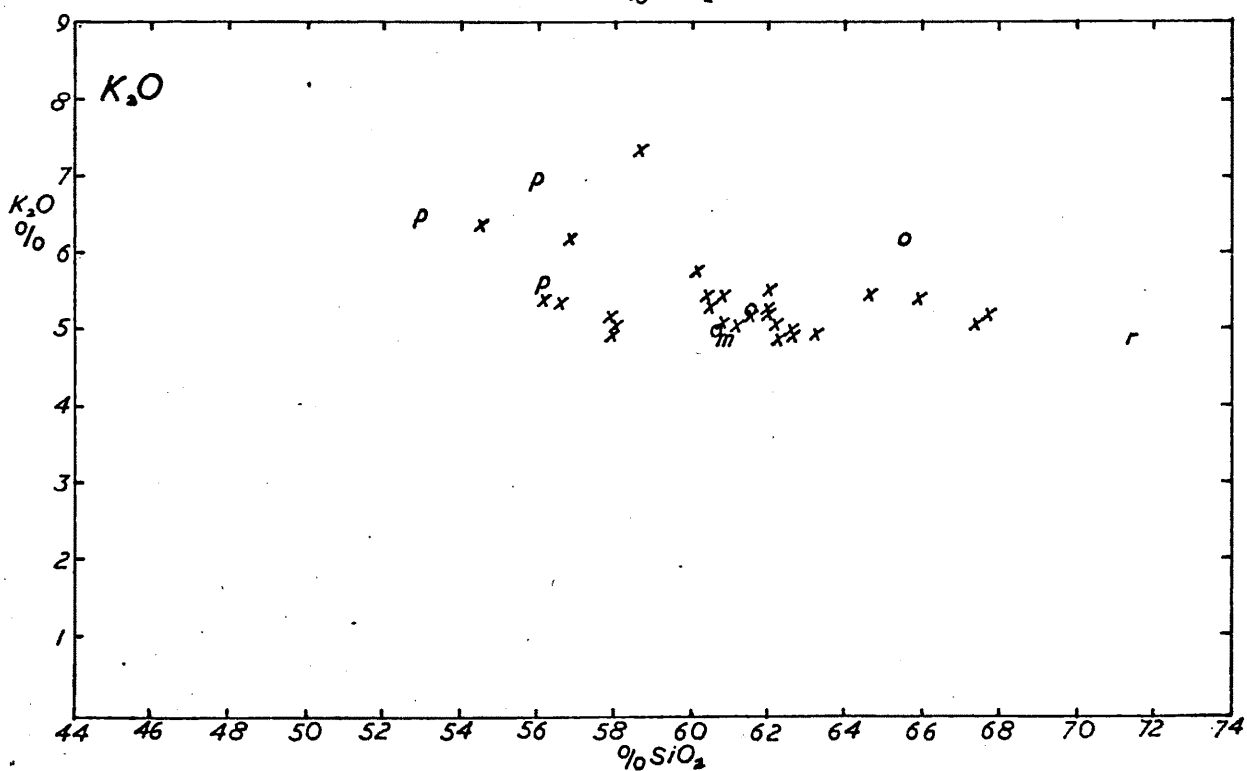
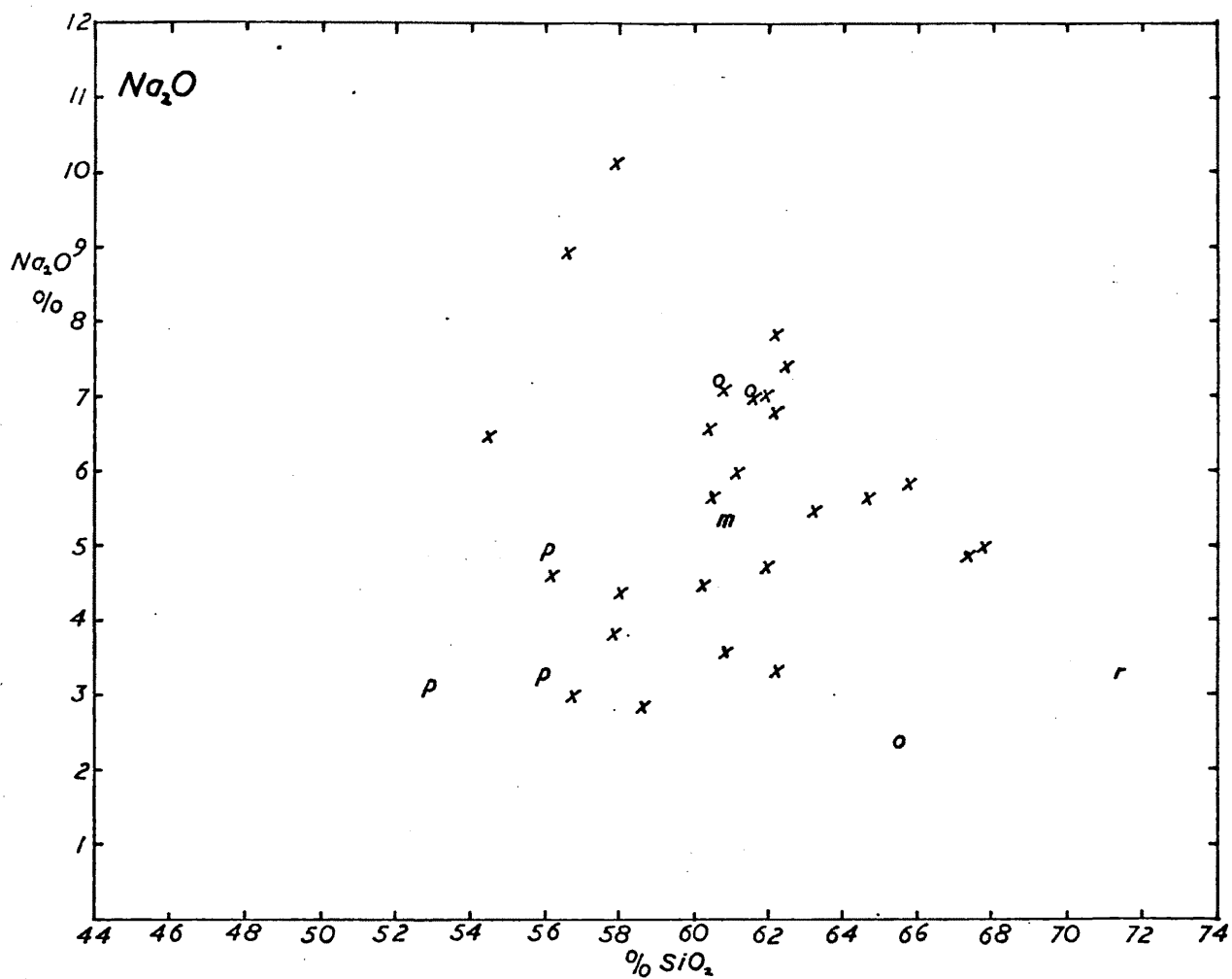
Plots of Nb/Zr , Ce/Zr and $\text{Na}_2\text{O/Zr}$ for the Eldama Ravine and Mau Tuffs are shown in figs.46,47 & 48. Compared with the trachyte lavas whose range of Zr starts at 300 ppm the tuffs have a much higher range starting at 700 ppm suggesting that they are in general more fractionated than the lavas.

The Eldama Ravine tuffs all lie on one Nb/Zr trend except for E 9 which falls below it. This trend is less steep than those of the Londiani and Kilombe Trachytes. In the Mau Tuff M 1 and M 4 lie on much the same trend as the Eldama Ravine Tuff but M 3 forms a quite separate well defined trend at a lower Nb/Zr ratio. In both formations then the abundantly porphyritic flow lies below the Nb/Zr trend of the others.

Variation Within Ash Flows

To ascertain what major element variation there is within ash flows seven specimens of E 7 were analysed for their major elements. The variation is slight, the range of SiO_2 contents measured being 60.8% -

Figure 45. Na_2O and K_2O v SiO_2 for tuffs



x Eldama Ravine Tuff

o Mau Tuff

p Makutano Tuff

m Upper Menengai Tuff

r Rosoga Tuff

Figure 46. Nb v Zr for Eldama Ravine and Mau Tuffs

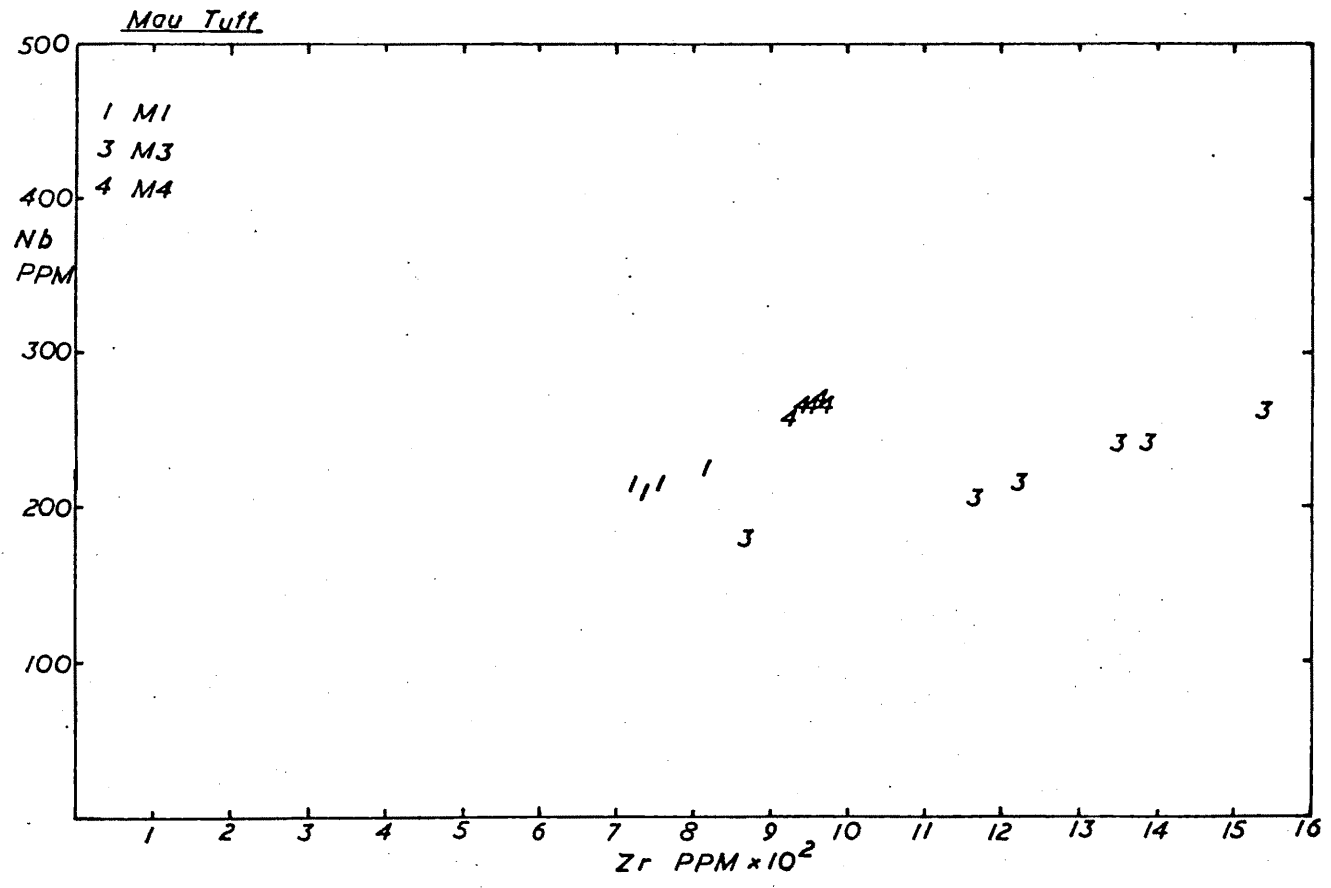
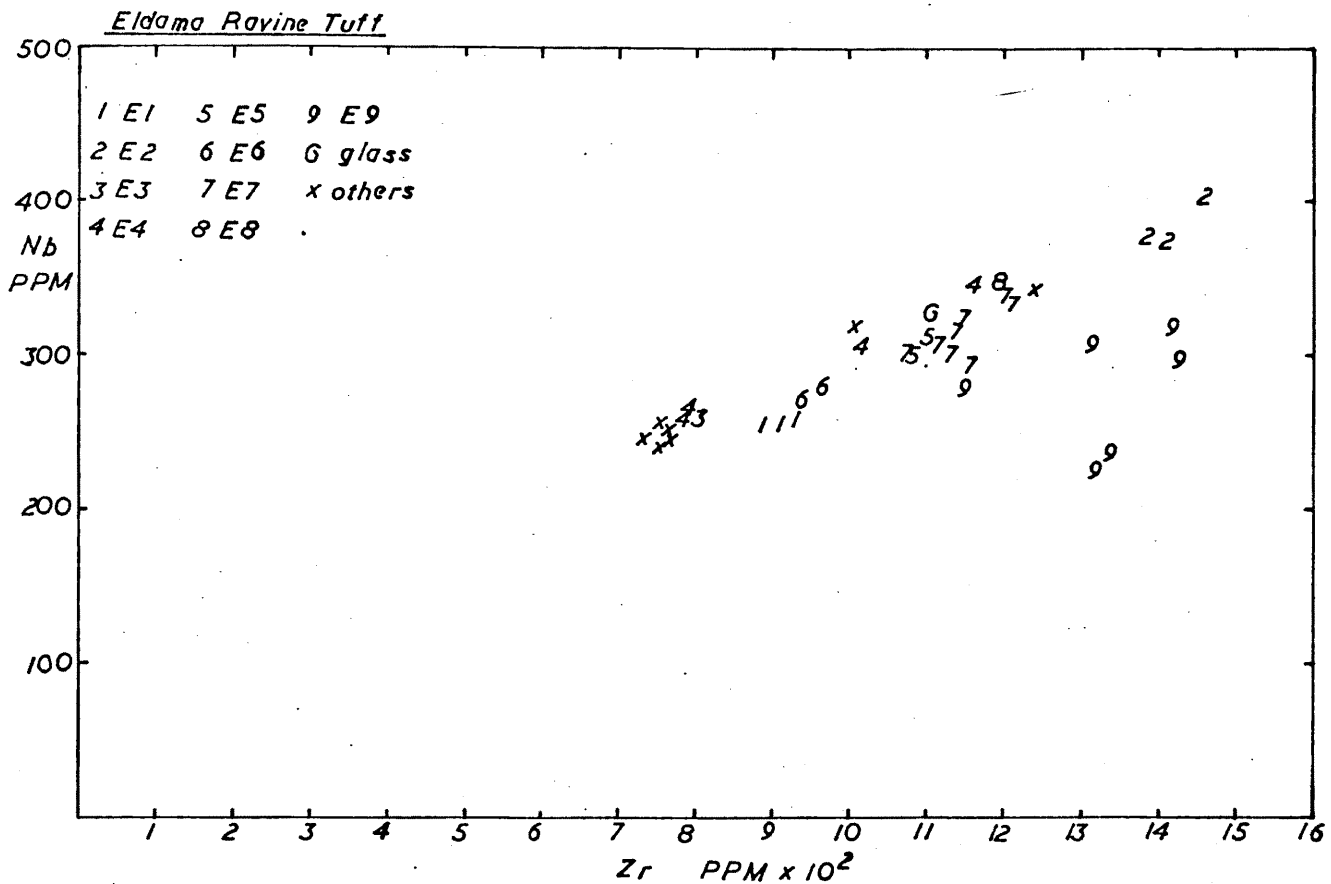


Figure 47. Ce v Zr for Eldama Ravine and Mau Tuffs

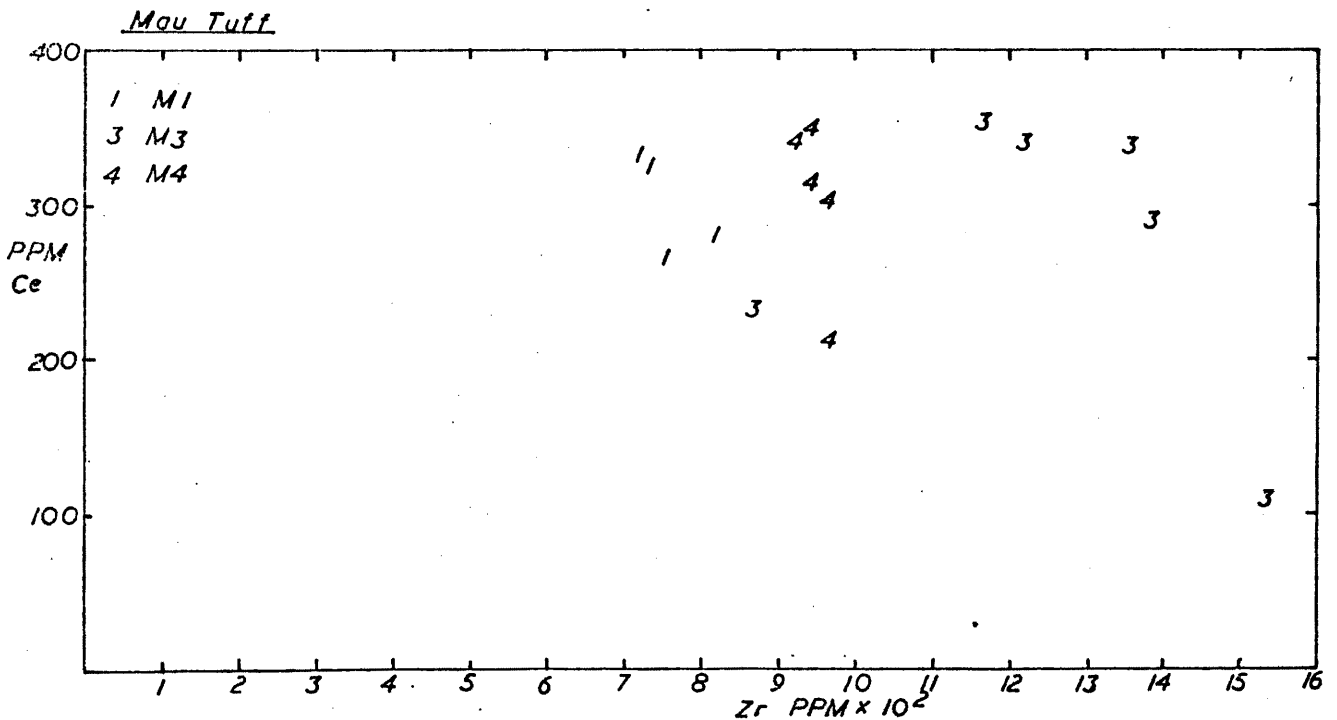
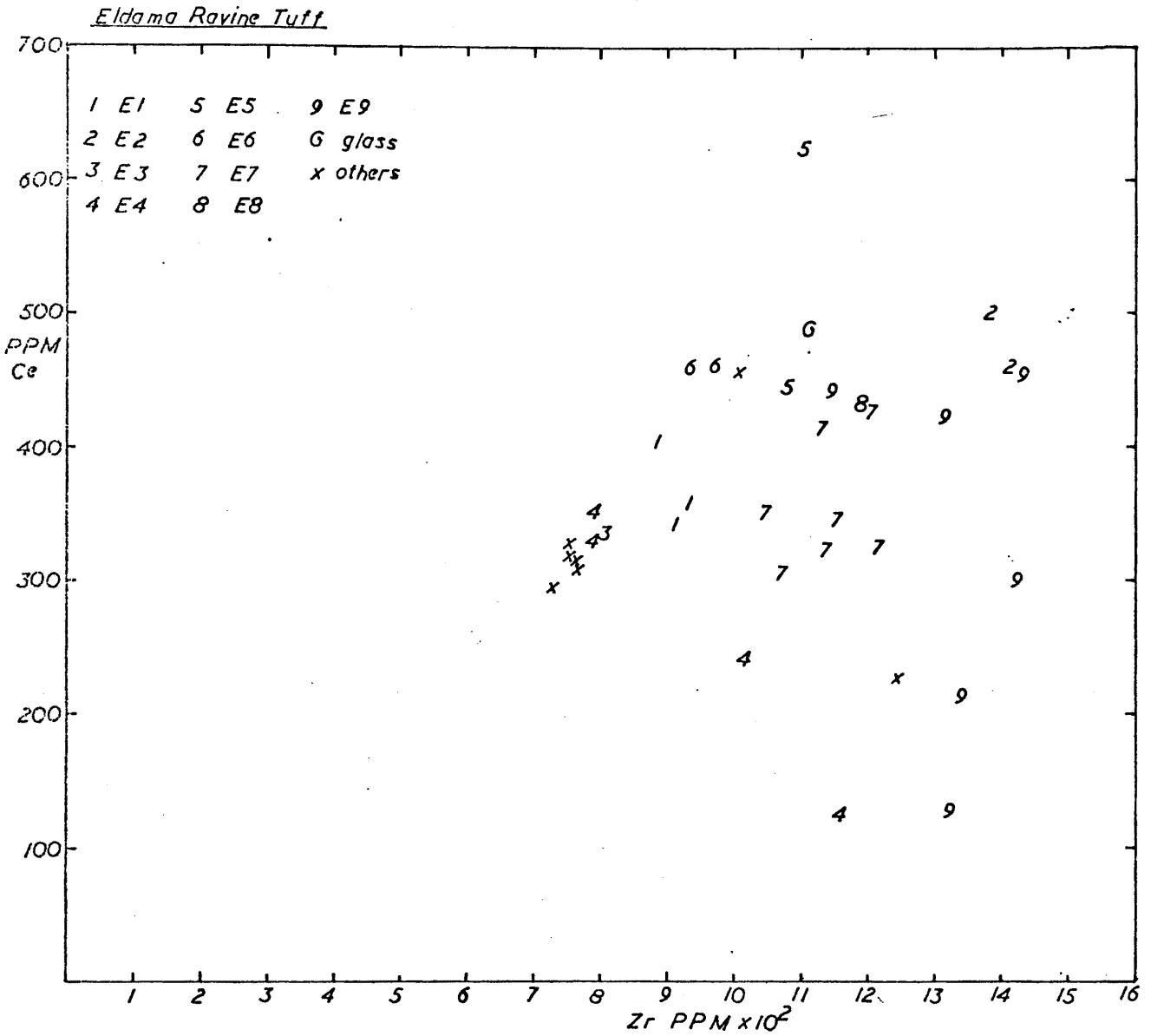
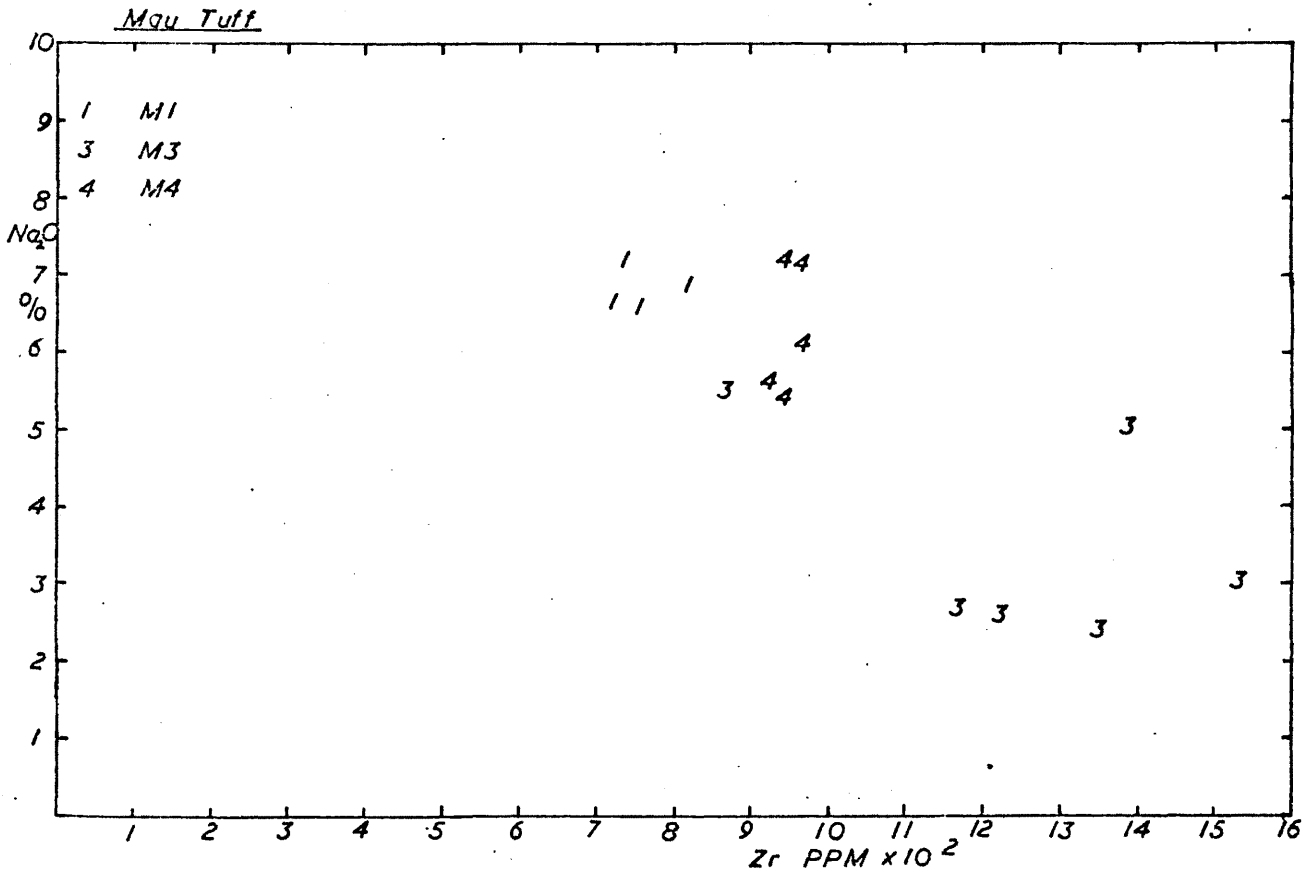
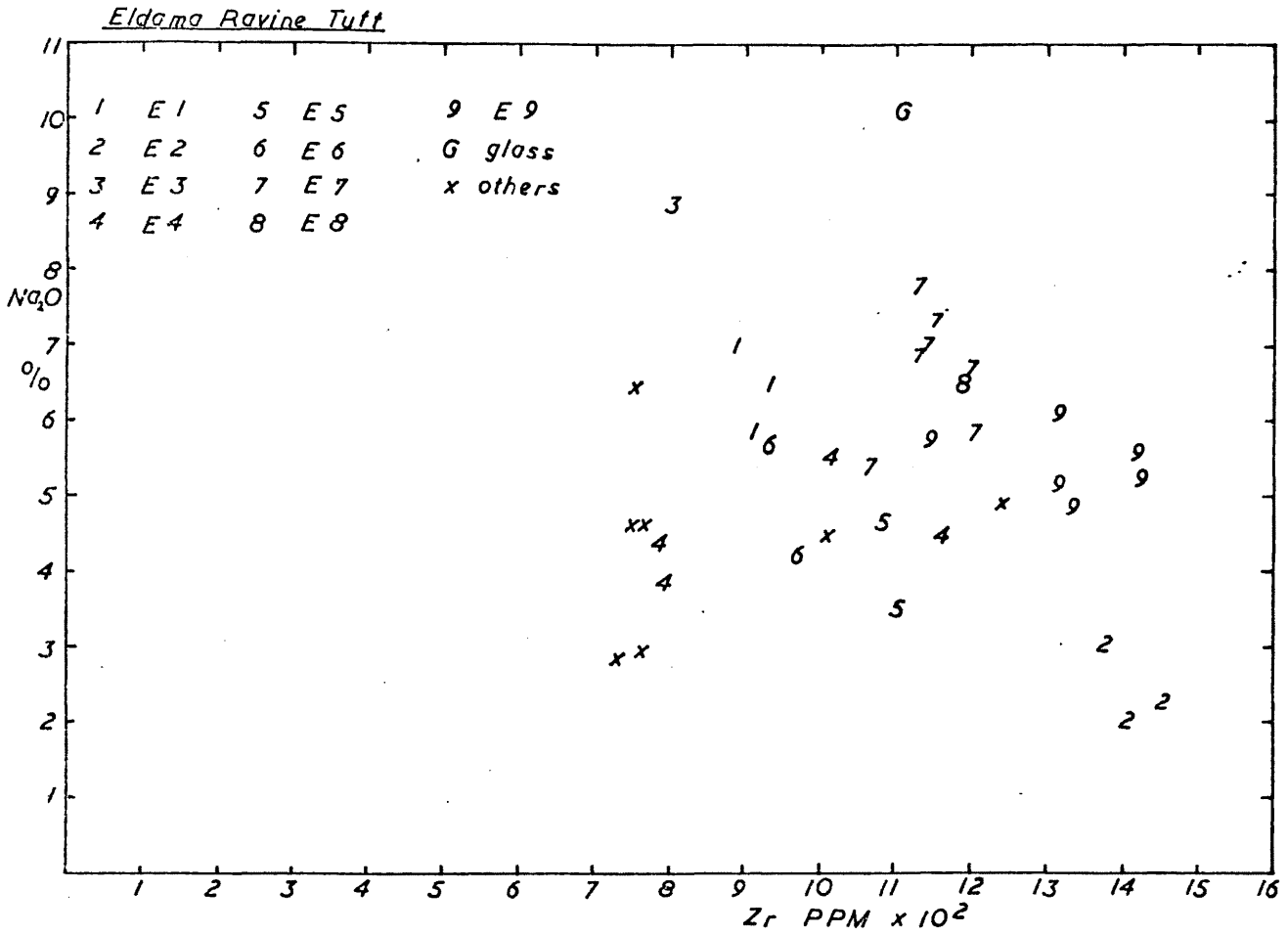


Figure 48. Na_2O v Zr for Eldama Ravine and Mau Tuffs



63.2%. Only Na_2O varies significantly, from 5.4% to 7.8% while K_2O is virtually constant at 4.89 - 5.19%. The variation in Na_2O may be due to volatile transfer as in the lavas.

Ce, and all the other lanthanides, show a considerable variation within flows. The greatest scatter is shown by E 9 in which Ce varies from 127 ppm to 457 ppm.

The variation of Ce and similar elements within one ash flow may be due to their being removed in the gas phase during eruption of the flow. To test this a specimen of E 7, 14/1046, was separated into fiamme (14/1046 F) and groundmass (14/1046 G) and the two analysed separately. If the fiamme and groundmass were originally all part of the same magma then they must have had the same trace element content when they first separated into clots of lava and a gas rich emulsion. The elements susceptible to removal by the gas will be preferentially removed from the tiny drops of lava in the emulsion rather than from the large lava clots because of the higher surface area to volume ratio of the former. The results of this analysis are shown in table 4.25. There is no difference in the major elements except that H_2O^+ is slightly higher in the groundmass. Among the trace elements Y, Ba and the Lanthanides are nearly twice as high in the fiamme as they are in the groundmass, while Rb, Nb and Zr are the same. This means that Y, Ba and the Lanthanides are removed from the ash flows as they flow. However Na_2O is the same in the fiamme as in the groundmass so the variation in Na_2O in E 7 is probably a reflection of inhomogeneities in the magma prior to eruption.

Of the six analysed rocks from E 9 the four with the highest Ce values come from outcrops south east of the Perkerra Gorge and east of Eldama Ravine while the two specimens with the lowest Ce come from south west of Murungwa. This shows that in the case of E 9 at least the ash flows have lower Ce concentrations away from the source which is what would be expected if they are losing Ce all the time that they are flowing.

Variation through the Eldama Ravine Tuff

In fig. 6 the Zr values of the analysed specimens of the Eldama Ravine Tuff are plotted according to their stratigraphic position so as to show the variation in Zr through the formation. There is a general trend towards higher Zr values with height in the succession except for E 2, the most Zr-rich flow, which is near the bottom. The variation is much greater within flows than between flows. The greatest variation in Zr content is shown by E 4 which ranges over 400 ppm, while E 9 covers 300 ppm and E 7 200 ppm. The greatest range of all, though, is displayed by M 3 which varies from 866 ppm to 1533 ppm a range of almost 700 ppm.

This can be explained by assuming that each eruption taps the top of a large magma chamber. This magma chamber contains mostly basic magma but near the roof trachytic liquid would collect as a result of fractionation in the basic magma. The trachyte liquid would be zoned from less fractionated and hence less Zr bearing liquid up into more fractionated Zr-rich liquid at the top. The eruption would remove part or all of this trachyte liquid to produce an ash flow tuff with a range of Zr values. Fractionation in the magma chamber would then produce more trachyte liquid which would in its turn be erupted as an ash flow similar to the previous one. The gradual rise in the Zr content of the ash flows towards the top of the Eldama Ravine Tuff could be because the formation of trachyte liquid by fractionation is slightly faster than its removal by eruption. Eruptions tapping lower levels in the magma chamber would give rise to basic horizons with the tuffs such as the Theloi Basalt and the Murungwa Agglomerate.

The volume of the ash flow E 7 is about 5 km^3 . As explained previously about nine tenths of a basalt liquid must solidify to produce a trachytic residuum. Therefore a basalt magma chamber which has produced 5 km^3 of

trachyte liquid by fractionation must contain at least 50 km^3 of basalt and perhaps several times as much. This means that there existed at the time of the eruption of the Eldama Ravine Tuff a basic magma chamber under the rift whose volume was of the order of $100 \text{ km}^3 - 1000 \text{ km}^3$. This may be the origin of the positive gravity anomaly along the centre of the rift valley (Searle 1970).

SUGGESTIONS FOR FURTHER WORK

As a result of this work the geology of the Londiani area can be said to be fairly well understood. This covers about two thirds of the area of volcanic rocks at the junction of the Kenya and Kavirondo Rifts. The remaining third, which lies to the west and includes Tinderet, has not been mapped in detail except around the fossil sites. There is good exposure over much of that area and it presents an ideal opportunity to investigate the basanite to phonolite trend in the same detail as the basalt to trachyte trend has been investigated in this thesis.

In the field there is much scope for vulcanological work, especially in the Eldama Ravine Tuff. For example the author did not find any pyroclastic surge deposits because at the time he did not know about them. In retrospect however it seems that they were probably present.

In particular useful work could be done on the thicknesses and volumes of lava flows and ash flows which has been only touched on here.

Much interesting information might be derived by K/Ar dating of detailed successions. For example, at present there is no knowing how long trachytic volcanoes are active for. It might be as little as 10^4 years or as much as 10^6 . Dating early and late flows from the same volcanoes would give us some idea since age differences of the order of 10^5 years are just detectable by this method. In the Eldama Ravine Tuff dating ash flows from known positions in the succession, combined with volume estimates, would provide information on rates of eruption.

The large range of Zr values found in the ashflows suggests that a similar range of values might be found in trachyte lavas. In this thesis this possibility was not investigated because usually only one specimen from each flow was analysed. Although several East African volcanoes have been investigated chemically no measurements of the variation within one flow have been done, probably because the volcanoes are not

adequately mapped. Such an investigation might lead to conclusions similar to those arrived at here for the Eldama Ravine Tuff.

The Zr values of flows can also be used, combined with volume estimates, to make crude estimates of the volumes of magma chambers, as has been attempted here for the Eldama Ravine Tuff flow E 7 and the Theloi Basalt. Combining these with the eruption rates derived from K/Ar dating would allow one to arrive at approximate rates of fractionation and production of trachyte magma.

The most unusual feature of the chemistry of the rocks of the Londiani area is the volatile transfer effects in the trachytes. These have not been reported on such a scale from other volcanoes. Perhaps they do occur elsewhere but have not been looked for. This would be worth investigating and if it turns out that Londiani and Kilombe are unique then it would be important to try to find out why.

Finally a thorough chemical and petrographic investigation of the Saos Mugearite could illuminate much about the relative importance of fractionation and mixing of magmas in the production of the intermediate rocks.

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TABLE 1

Potassium - Argon Age Determinations

<u>Sample No.</u>	<u>Locality</u>	<u>Formation</u>	<u>Rock Type or Mineral</u>	<u>Age</u>	<u>Source</u>
<u>Menengai Assemblage</u>					
14 x 4	Menengai caldera	Menengai Trachyte	Trachyte	0.33 ± 0.01	a
<u>Lake Hannington Trachyphonolite</u>					
		Hannington Trachyphonolite	Trphonolite	0.3 ± 0.1	a
		"	"	1.0 ± 0.1	a
		"	"	1.0 ± 0.1	a
		"	"	1.6 ± 0.2	a
<u>Londiani Assemblage</u>					
	Kapsalop	Kapsalop Phonolite	Phonolite	1.8 ± 0.1	a
	"	"	"	1.3 ± 0.1	} a
	"	"	"	1.9 ± 0.2	
	"	"	"	1.6 ± 0.1	
14/369	S.E. of Kilombe	Rongai Plain Phonolite	"	1.7 ± 0.05	a
	W. of Emining Gobat	Gobat Trachyte	Trachyte	1.8 ± 0.1	a
	"	"	"	2.1 ± 0.1	a
	"	"	"	2.8 ± 0.1	a
	Ainapno	Ainapno Trachyte	"	1.9 ± 0.2	a
14/1	Kilombe	Kilombe Trachyte	"	1.9 ± 0.15	a
14/769	Londiani Mt. S.E.	Londiani Trachyte	"	3.1 ± 0.1	a
14/576	Matebei	Matebei Trachyte	"	3.6 ± 0.1	a
	Kindonin	Kindonin Trachyphonolite	Trphonolite	4.0 ± 0.2	a
14/125	Poror	E.R. Tuff E.4	Welded tuff	4.3 ± 0.1	a
14/570	Pekerra Gorge	E.R. Tuff E.3	"	4.3 ± 0.1	a
14/843	E. of Londiani town	Mau Tuff M.4	"	6.0 ± 0.2	a
14/958	S.E. of Kedowa	Mau Tuff M.3	"	5.8 ± 0.2	a
14/903	Limutet	Londiani Plain Basanite	Basanite	5.4 ± 0.2	a
<u>Tinderet Basanite</u>					
42/465	Tinderet Summit	Tinderet Basanite	Basanite	5.6 ± 1.3	} b
				5.5 ± 1.3	
				5.8 ± 1.4	

Table 1 (Cont'd.)

<u>Sample No.</u>	<u>Locality</u>	<u>Formation</u>	<u>Rock Type or Mineral</u>	<u>Age</u>	<u>Source</u>
9/364	Sirwa	Kapkut Trachyte	Trachyte	6.6 \pm 0.2	a
14/678	Perkerra Gorge	"	Mugearite	7.6 \pm 0.2	a
M5	Chepanda	Kaparaina Basalt	Trachyte	5.4 \pm 0.2	a
2/227	Tegit	"	"	5.3 \pm 0.2	a
2/215	Kamsoror	"	Mugearite	8.2 \pm 0.4	a
	Kipting, E. of Kapsalop	"		6.9 \pm 0.2	a
	"	"		6.7 \pm 0.3	a
1/714	Lelyan	Kabarnet Trachyte	Trachyte	6.7 \pm 0.3	a
2/214	Yatya	"	"	6.8 \pm 0.2	a
1/734	Lelyan	"	"	7.1 \pm 0.3	b
				7.3 \pm 0.3	
				7.3 \pm 0.4	
<u>Timboroa Assemblage</u>					
14/898	S. of Mt. Blackett	Makutano Tuff	Welded Tuff	7.9 \pm 0.2	a
14/955	Mt. Blackett	"	Phonolite	7.6 \pm 0.2	a
14/83	E. of Timboroa	Timboroa Phonolite	"	9.4 \pm 0.3	a
14/949	W. of Londiani town	"	"	8.9 \pm 0.2	a
2/210	Yatya	Ewalel Phonolite	"	7.1 \pm 0.4	a
WB 11	Chepkesin	"	"	6.7 \pm 0.7	d
9/545	Tenges	"	"	7.3 \pm 0.3	a
WB 13	Kamuiton	"	"	8.4 \pm .8	d
				9.3 \pm .5	
				8.8 \pm 0.3	
42/431	W. of Kapsalop Lumbwa	Phonolitic Nephelinite	Nephelinite	8.9 \pm 0.5	b
				9.4 \pm 0.5	
				9.2 \pm 0.5	
9/459	Burnt Forest, NW of Timboroa	"	Phonolite		
			Nephelinite	9.4 \pm 0.6	a
WW 30/4	Songhor	"	Basanite	9.9 \pm 0.5	c
14/957	E. of Kedowa	"	Phonolite		
			Nephelinite I	12.4 \pm 0.3	a
KA 427	Ft. Ternan	Nephelinite Agglomerate	Biotite from tuff	14.0 \pm ?	c
MB 15	"	"	"	14.0 \pm 0.7	c
				14.7 \pm 0.2	
				15.0 \pm 0.5	
9/469	Chof	Chof Phonolite	Phonolite		
34/1043	Kitany	Elgeyo	Basanite	15.1 \pm 3.2	b
				15.6 \pm 3.2	
				19.6 \pm 0.3	
MB 18	Koru	Koru Beds	Biotite from tuff	19.5 \pm 0.3	c
				19.9 \pm 0.6	
				19.7 \pm 0.5	

Table 1 (Cont'd.)

<u>Sample No.</u>	<u>Locality</u>	<u>Formation</u>	<u>Rock Type of Mineral</u>	<u>Age</u>	<u>Source</u>
<u>Plateau Phonolite</u>					
14/924	S.W. of Mt. Blackett	Kericho Phonolite	Phonolite	11.7 \pm 0.3	a
MB 11	N.W. of Kericho	"	"	12.4 \pm 0.2	} c
MB 12	"	"	"	12.3 \pm 0.2	
MB 16	Ft. Ternan	"	"	12.1 \pm 0.2	} c
				13.2 \pm 0.3	
				13.4 \pm 0.4	
MB 16	Ft. Ternan	"	"	11.8 \pm 0.2	} c
				11.8 \pm 0.3	
WW 17/2	Ombo, near Kisumu	Kisumu Phonolite	"	13.1 \pm 0.6	c
MB 10	Maseno, N. of Kisumu	"	"	12.3 \pm 0.2	} c
MB 9	Chepkorio	Uasin Gishu Phonolite	"	12.3 \pm 0.2	
MB 8	Tambach	"	"	12.0 \pm 0.3	} c
				12.0 \pm 0.3	
9/623	Nyaruru	"	"	13.6 \pm 0.6	} c
				13.3 \pm 0.3	
				13.5 \pm 0.3	a

a Unpublished dates done at the IGS Isotope Laboratory by S.J. Lippard and Mrs. M. Brook under the direction of N.J. Snelling.

b F.M. Consultants for the Geological Survey of Kenya, quoted from Baker et al. 1971.

c Dates by Curtis in California or Miller in Cambridge, quoted from Bishop et al. 1969.

d Unpublished dates by J.A. Miller and F.J. Fitch.

Bracketed dates are age determinations done on the same sample or on samples from the same outcrop.

TABLE 2

Field Characteristics of Kilombe and Londiani Flows

The feldspar phenocrysts are described by the semi-objective terms used in the field as follows:

- N = none
 VF = very few = one found on a whole outcrop.
 F = few = one or two phenocrysts in a hand specimen.
 FC = fairly common.
 C = common = forming about 5% of the rock.
 FA = fairly abundant.
 A = abundant = forming > 10% of the rock.
 S = small = < 3 mm long
 M = medium = 3-5 mm long
 L = large = > 5 mm long
 S-M = a range of sizes from small to medium; likewise M-L.
 → indicates a variation in the feldspar phenocrysts in different parts of the flow.

The xenoliths are mug = coarsely feldsparphyric mugearite,
 sy = syenite and tr = trachyte
 (probably often autoliths).

Kilombe

<u>Flow No.</u>	<u>Feldspar Phenocrysts</u>	<u>Xenoliths</u>	<u>Position</u>	<u>Other Comments</u>	<u>Analysed Specimens</u>
K1	VF S		N end of graben may be >1 flow	sometimes mottled, cut by quartz veins	
K2	FA S-M		Confined to top of graben	cut by fault	14/254
K3	C M		E. side of graben		
K4	F S		E. side of graben		
K5	C S-M		E. side of graben	hillock 100 yds across	
K6	F S	few mug < 5 cm	S.E. outer slope underlies K7 & K8		
K7	FA S		S.E. outer slope, thin flow above K6 and under K8		
K8	N → AL	rare mug < 5 cm	S.E. outer slope, overlies K11, K6 and K7, underlies K10 and K13		14/183
K9	VF S		Hill on S.E. outer slope		
K10	FC S → VF S		S.E. caldera rim	groundmass shows flow structure	

Table 2 (Cont'd.)

<u>Flow No.</u>	<u>Phenocrysts</u>	<u>Xenoliths</u>	<u>Position</u>	<u>Other Comments</u>	<u>Analysed Specimens</u>
K11	F S		earliest flow on S outer slope, may be >1 flow		
K12	A M → FA S-M	rare sy < 5 cm	thick flow in S. of caldera and thin patches of tuff on S.E. rim and outer slope		14/228
K13	FC S	common sy < 30 cm, few mug < 5 cm. abundant rotten tr	covers most of S and W outer slope and overlies K12 inside caldera	abnormally thin 15 ft. thick along rim of caldera	
K14	FA S-M		two outcrops S.W. of Kilombe, underlies K13		14/362
K15	FC S	common tr	small dome S.W. of Kilombe		
K16	F S-M		two outcrops between Kilombe and Londiani, underlies K13 and K17		
K17	F S-M	ab mug < 30 cm	on low ground between Kilombe and Londiani		14/313
K18	F M-L		thick flow forming W facing spur east of Esageri station		
K19	F S-M	tr	N.W. of Kilombe, underlies K18		
K20	N		N.W. of Kilombe, three hills in a row	sometimes weathering to white powder	
K21	A S-M		N.W. of Kilombe, begins on graben and flows 5 miles to N.W. overlies all adjacent flows	has a few large white feldspar phenocrysts	
K22	FC S-M		N.W. of Kilombe a tongue emerging from beneath K21		
K23	FC M → F S		begins on graben and flows N.W.		

Table 2 (Cont'd.)

Londiani

<u>Flow No.</u>	<u>Phenocrysts</u>	<u>Xenoliths</u>	<u>Position</u>	<u>Other Comments</u>	<u>Analysed Specimens</u>
L1	FCM → F S-M		N. of Londiani	visible groundmass feldspar	14/268 14/262 14/236
L2	FA S		N. of Londiani, overlain by L1 and L3		
L3	C S-M → A M-L		N.E. of Londiani	has a few medium sized white feldspar phenocrysts	14/237
L4	FS → CM		an isolated flow N.E. of Londiani, source marked by hillock on its surface	visible groundmass feldspar	14/239
L5	FA S-M		N.E. of Londiani		14/238
L6	N		N.E. of Londiani		
L7			a dome 200 ft. high E. of Londiani	has tuff dipping off it	
L8	FS	rotten tr	E. slope of Londiani	fine grained with flow structure	
L9	A S		E. slope of Londiani, over- lain by L10		
L10	C S-M → FA S		E. slope of Londiani	mottled violet and green	14/325
L11	VF S		E. slope of Londiani 300 yds x 800 yds		
L12	FC S		S.E. slope of Londiani	divided into several parts by erosion	14/328
L13	A S		S.E. slope of Londiani, origin- ating on a hill 1000 ft. high	phenocrysts often in clusters	14/382
L14	F S		S.E. slope of Londiani overlies L 15		14/380
L15	FC S → C S-M		S.E. end of Londiani	groundmass feldspar sometimes visible, phenocrysts often in clusters	14/385

Table 2 (Cont'd.)

<u>Flow No.</u>	<u>Phenocrysts</u>	<u>Xenoliths</u>	<u>Position</u>	<u>Other Comments</u>	<u>Analysed Specimens</u>
L16	C S		W. of Londiani, large flow flowed onto Londiani Plain, 300 ft. thick at its distal end		14/914
L17	C S		W of Londiani, flowed onto Londiani Plain, 200 ft. thick at its distal end	may be another lobe of L16	14/860
L18	VF S		N of Londiani, traceable for 10 miles along top of Perkerra Gorge		

TABLE 3
Petrography of Analyzed Kilombe and Londiani Trachytes in Order of Increasing Zirconium Content

Specimen Number	Flow Number	Feldspar Phenocrysts	Groundmass Feldspar	Olivine Micro-Phenocrysts	Ore Micro-Phenocrysts	Aenigmatite	Pyroxene Phenocrysts	Amphibole	Quartz	Hydrated Glass	Zr	(a)		(b)		(c)	
												%	Multiple Twinning	%	Multiple Twinning	%	%
14/183	K8	✓	10 + 50	X	✓		F	4	-	5	332	7	4	-	4	-	4
14/816	L	-	75	✓	✓		-	10	-	5	390	10	1	-	1	-	1
14/268	L1	✓	38	✓	✓		F	10	-	15	392	10	4	-	4	-	4
14/237	L3	✓	35 + 30	✓	✓		-	8	-	15	403	8	5	-	5	-	5
14/228	K12	✓	35	✓	✓		F	5	-	1	421	5	1	-	1	-	1
14/262	L1	✓	40 + 32	X	-		H	8	3	5	437	8	5	3	5	5	5
14/325	L10	✓	73	✓	✓		-	5	-	10	455	5	2	-	2	-	2
14/380	L14	✓	75	X	-		-	10	-	2	491	10	5	-	5	-	5
14/266	L	5	57	X	-		F/H	8	1	20	503	8	3	1	3	1	3
14/239	L4	-	20 + 50	X	-		-	13	-	5	547	13	5	-	5	-	5
14/328	L12	✓	60	X	✓		-	10	-	20	558	10	4	-	4	-	4
14/817	L	5	63	✓	✓		F	7	-	15	560	7	4	-	4	-	4
14/860	L17	5	79½	X	✓		H	5	-	5	565	5	2	-	2	-	2
14/319	L	-	65	✓	-		-	10	-	15	604	10	3	-	3	-	3
14/245	K	-	60	X	-		-	20	-	5	627	20	1	-	1	-	1
14/238	L5	✓	55	X	-		-	10	-	20	635	10	5	-	5	-	5
14/236	L1	✓	65	✓	-		-	10	-	15	640	10	4	-	4	-	4
14/253	K	-	70	X	-		-	10	-	10	655	10	2	-	2	-	2
14/199	K	-	75	X	-		-	10	-	5	657	10	-	-	-	-	-
14/914	L16	5	65	✓	-		F	10	-	10	706	10	4	-	4	-	4
14/362	K14	10	50	X	✓		F/H	10	-	20	708	10	5	-	5	-	5
14/385	L15	✓	70	X	-		-	5	-	15	723	5	5	-	5	-	5
14/692	L	2	37½ + 35	X	-		H	5	15	-	779	5	3	15	3	15	3
14/313	K17	✓	45	X	-		-	10	1	35	1010	10	5	1	5	1	5
14/254	K2	15	30	X	✓		F/H	10	-	25	1072	10	6	-	6	-	6
14/382	L13	10	50	X	✓		H	3	25	-	1274	3	10	25	10	25	10
14/225	• K13	✓	10	X	-		H	10	-	70	1532	10	9	-	9	-	9

(a) Where a specimen does not come from an identified flow, its volcano is indicated thus K = Kilombe and L = Londiani.

(b) Two figures are given when two generations of groundmass feldspar are discernible, the first being for the larger crystals.

(c) F = ferroaugite, H = hydrobiotite, F/H = ferroaugite cores with hydrobiotite mantles.

TABLE 4.1
THELOI BASALT

14 65 14 276 14 21 14 30 14 19 14 56 14 108

MAJOR ELEMENT ANALYSES

SI02	44.99	46.66
TI02	2.22	2.21
AL2O3	15.92	15.55
FE2O3	3.64	3.77
FeO	7.10	6.81
MNO	.16	.20
MGO	8.26	7.97
CAO	10.56	10.61
NA2O	2.77	3.12
K2O	1.35	1.43
H2O+	1.34	1.11
P2O5	.81	.68
CO2	.50	.00

TOTAL 99.62 100.12

TRACE ELEMENT ANALYSES PPM

BA	1402	1171	1403	1830	1679	1264	1822
CE	178	109	176	149	143	124	141
CO	72	98	71	55	71	68	64
CR	263	382	118	162	99	332	145
LA	105	64	101	78	86	88	90
NB	58	43	73	87	58	44	86
ND	62	42	68	51	52	63	57
NI	175	240	120	126	81	244	118
PR	17	11	14	13	13	9	9
RB	30	34	21	57	24	18	54
SR	1580	1183	1685	1052	1373	1272	1057
Y	17	13	19	20	21	43	17
ZR	120	98	149	117	120	98	119

PERCENTAGE NORMS

q	-	-
or	8.00	8.45
ab	21.01	20.91
an	27.02	24.20
ne	1.31	2.98
ac	-	-
di	13.55	19.19
hy	-	-
ol	14.90	12.05
il	4.22	4.20
mt	5.28	5.47
hm	-	-
ap	1.88	1.58
cc	1.14	-
H ₂ O	1.34	1.11

GRID REFERENCES

031081 964027 899034 013038 990045 005076 996015

TABLE 4.2

THELOI BASALT	ELDAMA RAVINE TUFF BASALTS				LONDIANT PLAIN BASANITE		
	14 630	14 147	14 275	14 745	14 145	14 903	14 862
	MAKUTANO	ARAMA	ARAMA	MAJI	MAZURI		
MAJOR ELEMENT ANALYSES							
SiO ₂	43.44	43.63				44.18	
TiO ₂	2.04	1.75				1.76	
Al ₂ O ₃	17.91	16.09				14.79	
Fe ₂ O ₃	4.02	4.21				4.85	
FeO	7.31	6.95				5.75	
MnO	.25	.22				.00	
MgO	5.01	8.18				9.09	
CaO	8.62	12.17				13.32	
Na ₂ O	4.95	3.42				4.81	
K ₂ O	1.40	.81				.78	
H ₂ O ⁺	1.73	1.11				.91	
P ₂ O ₅	1.22	.85				.75	
CO ₂	.09	.42				.00	
TOTAL	97.99	99.81				100.99	

TRACE ELEMENT ANALYSES PPM

BA	2057	1870	915	1244	1246	1117	900
CE	146	205	133	122	110	159	118
CO	49	53	87	85	71	85	82
CR	162	10	288	288	22	417	601
LA	90	129	80	72	68	91	67
NB	81	118	48	49	48	81	44
ND	58	81	51	54	46	54	41
NI	109	34	182	190	92	222	286
PR	12	18	8	13	10	12	7
RB	61	26	11	15	42	42	23
SR	1064	2031	1091	1128	675	1114	991
Y	17	26	18	22	21	19	19
ZR	116	153	66	87	156	135	103

PERCENTAGE NORMS

q	-	-				-	
or	8.27	4.79				4.61	
ab	20.93	14.25				5.82	
an	22.51	26.16				16.46	
ne	11.35	7.96				18.90	
ac	-	-				-	
di	9.52	20.84				35.36	
hy	-	-				-	
ol	10.94	12.35				6.82	
il	3.87	3.32				3.34	
mt	5.83	6.10				7.03	
hm	-	-				-	
ap	2.83	1.97				1.74	
cc	.20	.95				-	
H ₂ O	1.73	1.11				.91	

GRID REFERENCES

061115	957929	948045	941044	998964	812878	884867
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TABLE 4.3

LONDIANI PLAIN BASANITE.

TIMBOROA ASSEMBLAGE BASANITES

TINDERET
BASANITE

14 859 14 855

14 1063 14 1039 14 992, 14 77

14 1053

BASANITE OF LUMBWA RN.

ARAMA

MAJOR ELEMENT ANALYSES

SiO ₂	40.28	43.82
TiO ₂	3.15	3.01
Al ₂ O ₃	11.44	14.96
Fe ₂ O ₃	4.59	5.46
FeO	7.97	7.05
MnO	.21	.21
MgO	11.41	5.93
CaO	12.26	10.21
Na ₂ O	3.18	6.08
K ₂ O	1.40	1.94
H ₂ O ⁺	2.09	1.25
P ₂ O ₅	.53	.59
TOTAL	98.51	100.51

TRACE ELEMENT ANALYSES PPM

BA	1190	787	534	613	680	843	839
CE	134	111	124	130	132	123	145
CO	88	90	98	91	126		61
CR	759	713	632	253	251		80
LA	149	63	75	78	74	70	80
NB	46	40	78	72	70	79	83
ND	121	42	51	50	50	46	66
NI	505	328	310	163	167		66
PR	19	7	12	14	13	15	15
RB	38	40	43	36	41	44	35
SR	929	1030	672	787	747	953	922
Y	112	17	21	20	24	26	26
ZR	75	90	204	214	217	259	252

PERCENTAGE NORMS

q	-	-
or	3.25	11.46
ab	-	7.22
an	2.81	7.80
ne	14.58	23.96
ac	-	-
di	35.38	31.10
hy	-	-
ol	12.60	2.73
il	5.98	5.72
mt	6.65	7.92
hm	-	-
ap	1.23	1.37
cc	-	-
H ₂ O	2.09	1.25
lc	3.94	-

GRID REFERENCES

902861 875858 803795 797824 803806 948076 685928

TABLE 4.4

	TINDERET BASANITE			FORT TERNAN				
	14 1054	14 1055	14 1056	14 1074	14 1072	14 1069	14 1070	
				ANKARAMITE	LAVAS	JOLITE		
MAJOR ELEMENT ANALYSES								
SiO ₂				39.88				
TiO ₂				3.62				
Al ₂ O ₃				9.94				
Fe ₂ O ₃				6.32				
FeO				6.62				
MnO				.19				
MgO				9.59				
CaO				15.34				
Na ₂ O				3.47				
K ₂ O				2.33				
H ₂ O ⁺				1.38				
P ₂ O ₅				.60				
TOTAL				99.28				
TRACE ELEMENT ANALYSES PPM								
BA	853	551	664	1131	726	1418	1625	
CE	133	112	119	127	156	157	148	
CO	61	79	74			45		
CR	40	158	25			4		
LA	78	66	71	77	92	98	64	
NB	85	57	61	84	83	96	383	
ND	50	42	45	51	62	70	83	
NI	44	97	57			12		
PR	14	15	11	9	7	12	17	
RB	80	22	44	70	54	78	64	
SR	1167	803	721	831	1200	1324	371	
Y	21	22	22	16	17	25	22	
ZR	240	190	217	190	163	194	352	
PERCENTAGE NORMS								
q				-				
or				-				
ab				-				
an				4.67				
ne				15.91				
ac				-				
di				37.91				
cs				5.92				
ol				5.29				
il				6.87				
mt				9.16				
hm				-				
ap				1.39				
cc				-				
H ₂ O				1.38				
lc				10.80				
GRID REFERENCES								
	650976	600944	600944	576778	552763	715791	605758	

TABLE 4.5

	CHEMUSUSU HAWAIIITE	LEMBUS MUGEARITE	SAOS MUGEARITE				
	14 706	14 678	14 597	14 575	14 243	14 244	14 598

MAJOR ELEMENT ANALYSES

SI02	49.30	53.54	48.24	48.15	54.09	54.92	
TI02	2.40	1.82	2.56	2.36	1.41	1.35	
AL2O3	17.43	17.59	18.07	17.23	17.29	17.64	
FE2O3	4.63	4.13	7.24	5.72	4.23	4.47	
FEO	5.92	4.68	3.77	4.80	4.15	3.68	
MNO	.19	.29	.26	.29	.28	.47	
MGO	3.61	2.14	3.45	3.26	1.41	1.53	
CAO	7.21	5.22	7.85	6.49	4.49	4.13	
NA2O	4.33	5.26	4.65	5.98	6.23	6.81	
K2O	2.21	2.78	1.82	2.18	3.31	3.07	
H2O+	1.78	1.16	1.03	1.57	1.33	1.23	
P2O5	.39	.60	1.20	1.02	.37	.31	
CO2					.57		
TOTAL	99.20	99.21	100.14	99.05	99.16	99.61	

TRACE ELEMENT ANALYSES PPM

BA	751	1020	1922	2328	2431	2410	2586
CE	120	163	176	197	239	218	220
CO	59	19	40	32	19	18	19
CR	22	0	10	0	4	0	0
LA	73	98	114	115	142	132	127
NB	65	105	92	110	142	129	141
ND	56	81	86	91	90	90	92
NI	27	4	9	7	5	4	4
PR	11	15	17	21	25	20	20
RB	50	75	40	48	75	71	93
SR	640	867	1127	1201	729	800	912
Y	27	41	42	40	42	44	44
ZR	238	332	240	234	383	351	379

PERCENTAGE NORMS

q	-	-	-	-	-	-	-
or	13.06	16.43	10.76	12.88	19.56	18.14	
ab	35.35	44.51	37.36	34.61	46.87	47.00	
an	21.60	16.18	23.06	13.73	9.44	8.50	
ne	0.70	-	1.08	8.66	3.17	5.76	
ac	-	-	-	-	-	-	
di	8.55	4.70	6.26	9.27	5.57	8.05	
hy	-	4.46	-	-	-	-	
ol	6.00	0.95	3.99	3.18	2.67	1.18	
il	4.56	3.46	4.86	4.48	2.68	2.56	
mt	6.71	5.99	5.58	8.29	6.13	6.48	
hm	-	-	3.40	-	-	-	
ap	0.90	1.39	2.78	2.36	0.86	0.72	
cc	-	-	-	-	1.30	-	
H ₂ O	1.78	1.16	1.03	1.57	1.33	1.23	

GRID REFERENCES

938104	089140	140054	141122	136012	148017	142016
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TABLE 4.6

SAOS MUGEARITE	XENOLITH IN K17		LUMBWA PHONOLITIC NEPHELINE				
	14 591	14 312	14 957	14 1036	14 1047	14 1066	14 1034

GLASSY

MAJOR ELEMENT ANALYSES

SiO ₂	57.46	49.18					43.15
TiO ₂	1.61	1.54					1.35
Al ₂ O ₃	19.49	19.49					14.48
Fe ₂ O ₃	4.73	3.55					7.95
FeO	1.19	4.00					3.43
MnO	.12	.25					.50
MgO	.89	2.24					1.69
CaO	2.58	5.16					10.53
Na ₂ O	4.22	7.82					5.36
K ₂ O	4.27	4.14					3.32
H ₂ O ⁺	2.37	1.14					5.40
P ₂ O ₅	.40	.42					.50
TOTAL	99.33	98.93					97.66

TRACE ELEMENT ANALYSES PPM

BA	1497	1595	1298	1337	3879	2046	2939
CE	125	278	129	141	141	175	246
CO	44		33	11	34	0	43
CR	7		2	0	2	3	16
LA	70	96	85	124	97	142	199
NB	52	96	123	122	135	130	359
ND	58	179	59	52	71	62	74
NI	14		8	4	6	4	6
PR	14	44	11	5	16	11	13
RB	23	71	116	171	135	183	87
SR	1202	394	1417	2223	2559	1985	4813
Y	28	136	22	27	24	40	20
ZR	123	219	267	377	318	312	321

PERCENTAGE NORMS

q	10.85	-					-
or	25.23	24.46					19.62
ab	35.71	17.32					12.52
an	10.19	5.85					5.65
ne	-	26.46					17.79
ac	-	-					-
di	-	13.70					9.08
hy	2.22	-					-
ol	-	0.95					-
il	2.77	2.92					2.56
mt	-	5.15					8.77
hm	4.73	-					1.90
ap	0.93	0.97					1.16
cc	-	-					-
H ₂ O	2.37	1.14					5.40
wo	-	-					13.22
GRID REFERENCES	co	4.19					
	ru	0.15					
	129065	121909	893739	793814	789770	783796	791805

TABLE 4.7

LUMBWA P.N. PYROXENE PHONOLITE
 14 1046 14 1037 14 1051
 GLASSY

MAJOR ELEMENT ANALYSES

SI02	53.62
TI02	.52
AL2O3	20.62
FE2O3	2.82
FEO	2.23
MNC	.27
MGO	.93
CAO	2.73
NA2O	5.73
K2O	5.72
H2O+	3.52
P2O5	.18
TOTAL	98.89

TRACE ELEMENT ANALYSES PPM

BA	6951	533	606
CE	172	214	236
CO	36	9	11
CR	26	0	0
LA	159	138	160
NB	465	262	261
ND	47	82	89
NI	8	1	2
PR	7	19	15
RB	145	251	200
SR	3248	1201	296
Y	13	37	38
ZR	409	547	525

PERCENTAGE NORMS

q	-
or	33.80
ab	31.13
an	12.37
ne	9.40
ac	-
di	-
co	0.47
ol	2.71
il	0.99
mt	4.09
hm	-
ap	0.42
cc	-
H ₂ O	3.52

GRID REFERENCES

794764 795822 807780

TABLE 4.8

KILOMBE TRACHYTE

	14 183	14 225	14 254	14 362	14 199	14 228	14 245
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MAJOR ELEMENT ANALYSES

SiO ₂	60.43	59.56	61.90				
TiO ₂	.88	.63	.58				
Al ₂ O ₃	17.36	15.04	14.46				
Fe ₂ O ₃	3.78	6.09	4.43				
FeO	1.90	3.44	4.11				
MnO	.15	.31	.30				
MgO	.64	.20	.41				
CaO	1.98	.69	1.06				
Na ₂ O	6.84	5.64	6.22	7.03	6.80	7.50	6.55
K ₂ O	5.16	4.91	5.01				
H ₂ O ⁺	.58	1.41	1.07				
P ₂ O ₅	.24	.08	.15				
TOTAL	99.96	98.00	99.70	7.03	6.80	7.50	6.55

TRACE ELEMENT ANALYSES PPM

BA	1435	252	198	86	51	109	77
CE	207	276	526	178	374	200	313
CO			11				
CR			1				
LA	237	277	600	179	193	169	280
NB	113	480	341	228	228	135	224
ND	131	174	399	119	140	112	203
NI			2				
PR	30	46	100	30	35	26	51
RB	77	232	192	126	122	119	120
SR	268	34	18	18	11	22	11
Y	87	105	141	61	54	97	104
ZR	332	1532	1072	708	657	421	627

PERCENTAGE NORMS

q	-	6.40	4.13
or	30.61	29.01	29.61
ab	53.05	47.72	46.49
an	1.37	1.22	-
ne	2.61	-	-
ac	-	-	5.42
di	3.44	1.41	3.71
hy	-	0.61	4.13
ol	-	-	-
il	1.67	1.20	1.10
mt	4.06	8.83	3.71
hm	0.98	-	-
ap	0.56	0.19	0.35
cc	-	-	-
H ₂ O	0.58	1.41	1.07
wo	1.03	-	-

GRID REFERENCES

176018	153906	160986	129884	179924	165914	157994
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TABLE 4.9

KILOMBE TRACHYTE

LONDIANI TRACHYTE

	14 253	14 313	14 325	14 319	14 236	14 323	14 692
MAJOR ELEMENT ANALYSES							
SiO ₂			61.20	61.22	61.84	60.16	65.15
TiO ₂			.76	.62	.65	.56	.50
Al ₂ O ₃			16.00	15.52	15.02	13.89	13.82
Fe ₂ O ₃			6.05	5.63	4.75	5.67	4.87
FeO			1.54	3.05	3.30	3.73	2.35
MnO			.16	.35	.24	.38	.17
MgO			.12	.51	.29	.43	.13
CaO			.64	.99	.59	.99	.47
Na ₂ O	6.52	6.40	7.01	6.74	6.54	6.94	5.37
K ₂ O			5.43	5.27	5.08	4.81	5.11
H ₂ O ⁺			.95	1.51	1.21	1.55	1.12
P ₂ O ₅			.08	.13	.15	.18	.02
TOTAL	6.52	6.40	99.94	101.54	99.66	99.29	99.08

TRACE ELEMENT ANALYSES PPM

BA	67	116	380	168	99	74	76
CE	277	500	306	243	317	510	187
CO				11			
LA	206	327	804	159	429	294	194
NB	232	337	180	241	251	365	240
ND	142	233	447	110	262	184	116
NI				6			
PR	35	50	102	24	61	38	30
RB	124	192	115	129	151	198	188
SR	11	17	22	8	6	4	7
Y	44	154	129	39	132	116	87
ZR	655	1010	455	604	640	935	779

PERCENTAGE NORMS

q			0.56	0.70	3.55	0.66	14.11
or			32.09	31.14	30.02	28.42	30.20
ab			52.07	50.49	48.98	44.67	42.64
an			-	-	-	-	-
ne			-	-	-	-	-
ac			6.39	5.76	5.61	12.38	2.47
di			0.65	3.42	1.68	3.24	1.62
hy			-	1.76	2.96	4.87	-
ol			-	-	-	-	-
il			1.44	1.18	1.23	1.06	0.95
mt			3.28	5.27	4.08	2.01	5.82
hm			1.58	-	-	-	-
ap			0.19	0.30	0.35	0.42	0.05
cc			-	-	-	-	-
H ₂ O			0.95	1.51	1.21	1.55	1.12
w ₀			0.76	-	-	-	0.12

GRID REFERENCES

159993	119907	103860	087951	080968	094877	094018
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TABLE 4.10

LONDIANI TRACHYTE

14 382 14 914 14 860 14 817 14 816 14 385 14 380

MAJOR ELEMENT ANALYSES

SiO ₂	67.80						
TiO ₂	.39						
Al ₂ O ₃	14.01						
Fe ₂ O ₃	4.05						
FeO	1.99						
MnO	.11						
MgO	.10						
CaO	.32						
Na ₂ O	4.94	6.62	6.20	6.03	7.42	6.34	7.15
K ₂ O	4.88						
H ₂ O ⁺	1.42						
P ₂ O ₅	.02						
TOTAL	100.03	6.62	6.20	6.03	7.42	6.34	7.15

TRACE ELEMENT ANALYSES PPM

BA	46	291	429	428	1724	110	80
CE	44	337	106	459	176	360	281
LA	27	219	304	347	264	400	275
NB	292	247	165	214	160	269	190
ND	26	154	203	227	158	224	173
PR	9	32	47	39	34	51	37
RB	182	142	124	169	119	176	122
SR	4	3	10	24	42	14	15
Y	38	88	78	180	74	89	90
ZR	1274	706	565	560	390	723	491

PERCENTAGE NORMS

q	19.61
or	28.84
ab	41.80
an	1.46
ne	-
ac	-
di	-
hy	0.25
ol	-
il	0.74
mt	5.65
hm	0.16
ap	0.05
cc	-
H ₂ O	1.42
co	0.07

GRID REFERENCES

097825 917834 916874 026846 024826 102794 108811

TABLE 4.11

LONDIANI TRACHYTE

	14 328	14 268	14 266	14 262	14 239	14 238	14 237
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MAJOR ELEMENT ANALYSES

NA2O	6.57	7.09	5.31	6.04	6.87	6.83	6.90
TOTAL	6.57	7.09	5.31	6.04	6.87	6.83	6.90

TRACE ELEMENT ANALYSES PPM

BA	490	537	125	429	105	263	380
CE	410	329	198	235	266	508	301
LA	341	318	487	397	237	633	288
NB	214	157	199	125	211	248	162
ND	206	183	297	264	154	309	171
PR	55	39	72	59	37	74	40
RB	174	110	130	96	147	157	126
SR	18	26	11	8	7	14	23
Y	103	180	118	107	65	200	108
ZR	558	392	503	437	547	635	403

GRID REFERENCES

	098848	079991	054974	076013	100985	100976	094975
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TABLE 4.12

TRACHYTES					COMENDITE		
14 581	14 576	14 26	14 650	14 636	14X13	14X12	
KIBORIT	MATEBEI	KAPKUT	LATE KAPKUT		HELL'S GATE		

MAJOR ELEMENT ANALYSES

SiO ₂	60.65	61.95		66.93		72.02
TiO ₂	.48	.77		.50		.15
Al ₂ O ₃	15.50	15.53		14.14		11.01
Fe ₂ O ₃	4.42	4.23		2.24		1.30
FeO	3.31	3.08		2.71		2.24
MnO	.34	.38		.12		.06
MgO	.85	.82		.20		.22
CaO	1.28	.90		.35		.19
Na ₂ O	8.05	6.80		5.78		5.50
K ₂ O	5.24	5.37		5.19		4.48
H ₂ O ⁺	1.15	1.17		.26		.96
P ₂ O ₅	.03	.16		.12		.13
CL	.13	.00		.00		.00
TOTAL	100.51	101.18		98.54		98.26

TRACE ELEMENT ANALYSES PPM

BA	76	115	21	37	31	0	10
CE	315	501	232	279	239	282	298
CO				8			
LA	227	318	168	171	199	146	163
NB	208	311	211	229	176	387	385
ND	146	228	113	133	161	133	138
NI				2			
PR	29	46	23	29	34	29	31
RB	126	161	155	156	108	473	466
SR	47	8	19	1	6	0	0
Y	119	141	38	58	59	205	237
ZR	603	1022	687	787	572	1694	1684

PERCENTAGE NORMS

q	-	0.01		12.38		27.76
or	30.96	31.73		30.67		26.47
ab	40.68	50.09		43.84		31.69
an	-	-		-		-
ne	5.35	-		-		-
ac	12.79	6.57		4.47		3.76
di	5.47	2.88		0.83		0.08
hy	-	4.06		3.86		4.48
ol	5.47	-		-		-
il	0.91	1.46		0.95		0.29
mt	-	2.84		1.01		-
hm	-	-		-		-
ap	0.70	0.37		0.28		0.30
cc	-	-		-		-
H ₂ O	1.15	1.17		0.26		0.96
ns	0.71	-		-		2.46

GRID REFERENCES

155075	185142	007068	049143	064130	-	-
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TABLE 4.13

KERICHO PHONOLITE

TIMBOROA PHONOLITE

KERICHO PHONOLITE			TIMBOROA PHONOLITE			
14 924	14 894	14 930	14 949	14 83A	14 1031	14 1012

MAJOR ELEMENT ANALYSES

SiO ₂	54.10		53.57	55.35		
TiO ₂	.75		.38	.18		
Al ₂ O ₃	19.91		18.92	20.47		
Fe ₂ O ₃	2.14		4.89	3.35		
FeO	2.84		2.29	2.49		
MnO	.28		.46	.31		
MgO	.98		1.38	.54		
CaO	1.40		1.74	1.11		
Na ₂ O	7.45		7.55	8.88		
K ₂ O	5.64		5.57	5.65		
H ₂ O ⁺	3.30		2.23	1.74		
P ₂ O ₅	.20		.19	.11		
CL	.01		.00	.00		
TOTAL	98.99		99.17	100.18		

TRACE ELEMENT ANALYSES PPM

BA	167	308	260	126	23	122	0
CE	217	219	214	372	322	399	332
CO				9			
CR				1			
LA	143	144	140	241	192	264	197
NB	214	228	221	412	311	428	283
ND	82	87	85	130	122	136	130
NI				3			
PR	18	19	16	24	27	24	27
RB	141	120	121	217	355	348	311
SR	297	465	477	212	8	138	94
Y	39	37	41	70	73	73	72
ZR	469	490	466	977	801	1046	725

PERCENTAGE NORMS

q	-			-		
or	33.33			32.91	33.39	
ab	31.50			30.47	29.91	
an	4.23			1.29	-	
ne	17.09			18.10	23.80	
ac	-			-	1.14	
di	1.17			4.81	4.04	
hy	-			-	-	
ol	3.39			1.11	1.28	
il	1.42			0.72	0.34	
mt	3.10			7.09	4.29	
hm	-			-	-	
ap	0.46			0.44	0.26	
cc	-			-	-	
H ₂ O	3.30			2.23	1.74	

GRID REFERENCES

908769	924771	900765	824796	910065	810016	884991
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TABLE 4.14

TIMBOROA PHONOLITE

 14 1000 14 995 14 845 \

TRACE ELEMENT ANALYSES PPM

BA	70	488	22
CE	318	221	315
LA	206	212	196
NB	323	249	336
ND	125	103	111
PR	24	18	25
RB	197	275	221
SR	276	599	61
Y	56	60	72
ZR	707	508	867

GRID REFERENCES

790836 811811 935790

TABLE 4.15

TRACHYPHONOLITES

14 369	14 609	14 608	14 599	14 600
RONGAI PLAIN	KILELWA HILL		EMINING	

MAJOR ELEMENT ANALYSES

SiO ₂	55.73	55.92
TiO ₂	.42	.47
Al ₂ O ₃	19.75	17.12
Fe ₂ O ₃	4.03	6.32
FeO	2.34	2.57
MnO	.33	.45
MgO	.81	.59
CaO	1.31	2.04
Na ₂ O	7.60	6.64
K ₂ O	5.53	5.24
H ₂ O ⁺	2.20	2.50
P ₂ O ₅	.14	.18
CL	.18	.26

TOTAL 100.19 100.04

TRACE ELEMENT ANALYSES PPM

BA	31	83	341	87	149
CE	322	588	477	511	607
CO	9	11			
LA	194	338	285	233	362
NB	297	458	353	211	462
ND	128	220	186	188	231
NI	2	5			
PR	28	48	41	38	48
RB	202	255	173	100	205
SR	59	14	67	18	193
Y	87	182	138	97	188
ZR	963	1562	1199	596	1586

PERCENTAGE NORMS

q	-	-
or	32.68	30.96
ab	36.76	43.36
an	3.44	1.43
ne	14.93	6.95
ac	-	-
di	1.73	3.17
hy	-	-
ol	1.50	-
il	0.80	0.89
mt	5.84	8.38
hm	-	0.53
ap	0.32	0.42
cc	-	-
H ₂ O	2.20	2.50
wo	-	1.44

GRID REFERENCES

193906 221969 213975 167052 187031

TABLE 4.16

SYENITE IN
ER TUFF

LONDIANI SYENITES

14 565 (14 327C 14 327F 14 331 14 338)

C C C F C

MAJOR ELEMENT ANALYSES

SiO ₂	59.35	61.41	61.05	64.07	62.28
TiO ₂	.69	.64	.39	.32	.43
Al ₂ O ₃	17.86	11.91	14.67	17.29	16.07
Fe ₂ O ₃	3.00	9.06	8.56	2.83	2.87
FeO	2.30	1.93	.39	1.84	3.28
MnO	.30	.37	.31	.09	.23
MgO	.75	.01	.46	.23	.36
CaO	.73	.53	.36	.15	.59
Na ₂ O	6.53	6.48	8.44	4.78	7.90
K ₂ O	5.55	4.59	4.75	5.39	5.42
H ₂ O ⁺	1.39	.74	.70	1.23	.88
P ₂ O ₅	.20	.01	.21	.06	.11
TOTAL	98.67	97.68	100.31	98.28	100.42

TRACE ELEMENT ANALYSES PPM

BA	130	226	96	326	399
CE	356	720	720	79	125
CO			15		
LA	290	227	473	76	80
NB	178	551	463	303	281
ND	193	133	249	52	57
NI			3		
PR	38	41	66	10	13
RB	183	326	286	268	236
SR	15	4	1	18	78
Y	81	107	109	68	28
ZR	591	2365	1304	715	630

PERCENTAGE NORMS

q	-	9.74	-	14.84	-
or	32.80	27.12	28.07	31.85	32.03
ab	51.56	35.71	45.60	40.45	48.74
an	2.32	-	-	0.35	-
ne	2.00	-	1.85	-	2.03
ac	-	16.85	19.74	-	8.30
di	-	1.00	0.32	-	1.93
hy	-	-	-	1.25	-
ol	2.21	-	0.70	-	4.29
il	1.31	1.21	0.97	0.61	0.82
mt	4.35	4.69	1.14	4.10	-
hm	-	-	-	-	-
ap	0.46	0.02	0.49	0.14	0.26
cc	-	-	-	-	-
H ₂ O	1.39	0.74	0.70	1.23	0.88
co	0.28	-	-	3.46	-
wo	-	0.60	-	-	-
ns	-	-	-	-	1.15

GRID REFERENCES

117123 107847 108843 122796 122796

TABLE 4.17
KILOMBE SYENITES

	14 160	14 169	14 187	14 189	14 190	14 191	14 192
	C	C	C	C	C	M	F
MAJOR ELEMENT ANALYSES							
SiO ₂	62.16	60.73	59.32	62.65	63.16	51.22	62.04
TiO ₂	.56	.67	.44	.26	.53	.80	.49
Al ₂ O ₃	15.33	14.88	11.06	13.84	16.52	8.62	14.54
Fe ₂ O ₃	4.83	7.32	11.55	9.13	4.43	21.98	7.19
FeO	3.19	1.91	2.53	1.23	1.18	.90	1.51
MnO	.30	.46	.33	.15	.21	.25	.26
MgO	.00	.00	.39	.00	.09	.25	.21
CaO	.46	.33	1.52	.97	.59	.46	1.24
Na ₂ O	7.16	6.91	6.79	7.41	6.89	9.86	6.65
K ₂ O	5.33	5.47	4.70	4.92	5.59	1.05	5.39
H ₂ O+	.74	1.05	.75	.58	1.12	3.03	.74
P ₂ O ₅	.00	.00	.00	.00	.00	.19	.00
TOTAL	100.06	99.73	99.38	101.14	100.31	98.61	100.26

TRACE ELEMENT ANALYSES PPM

BA	94	266	154	168	87	488	225
CE	299	322	145	98	319	2515	92
CO	9						
LA	192	206	84	68	249	1832	117
NB	207	168	407	190	167	744	65
ND	122	133	51	38	181	650	84
NI	5						
PR	32	34	19	11	44	219	20
RB	160	116	210	232	231	112	154
SR	8	9	77	92	21	66	100
Y	44	44	15	13	80	174	46
ZR	658	503	1343	814	329	688	418

PERCENTAGE NORMS

q	0.24	1.94	4.97	4.01	1.94	-	3.72
or	31.50	32.32	27.77	29.07	33.03	6.21	31.85
ab	49.18	46.09	30.72	43.80	53.85	37.68	44.78
an	-	-	-	-	-	-	-
ne	-	-	-	-	-	0.44	-
ac	10.04	10.91	23.55	16.65	3.92	39.58	10.12
di	2.03	0.61	5.32	-	0.48	0.81	1.13
hy	3.28	-	-	-	-	-	-
ol	-	-	-	-	-	0.17	-
il	1.06	1.27	0.84	0.49	1.01	1.52	0.93
mt	1.97	5.14	4.94	3.70	2.95	1.40	4.29
hm	-	-	-	0.82	1.04	7.34	0.73
ap	-	-	-	-	-	0.44	-
cc	-	-	-	-	-	-	-
H ₂ O	0.74	1.05	0.75	0.58	1.12	3.03	0.74
wo	-	0.40	0.51	2.01	0.96	-	1.96

GRID REFERENCES

159918	167938	174921	174921	174921	174921	174921
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TABLE 4.18

KILOMBE SYENITES

	14 193 F	14 194 F	14 197A FENITE	14 197D F	14 390 F	14 391 F
MAJOR ELEMENT ANALYSES						
SiO ₂	61.18	61.53	60.93	58.32	60.25	60.47
TiO ₂	.76	.70	.83	.46	.69	.16
Al ₂ O ₃	14.66	15.03	15.04	10.73	15.76	15.48
Fe ₂ O ₃	7.12	4.76	4.08	14.64	4.04	5.04
FeO	1.70	3.76	4.83	1.09	3.62	3.21
MnO	.34	.35	.77	.16	.28	.33
MgO	.31	.26	.33	.13	.62	.08
CaO	1.15	1.37	.53	.71	1.38	.45
Na ₂ O	6.20	6.69	8.13	5.08	6.72	6.22
K ₂ O	4.91	5.35	3.44	6.30	5.46	7.07
H ₂ O+	1.14	.76	1.40	.84	.72	1.07
P ₂ O ₅	.06	.03	.17	.00	.21	.00
TOTAL	99.53	100.59	100.48	98.46	99.77	99.58

TRACE ELEMENT ANALYSES PPM

BA	330	220	326	187	237	243
CE	264	223	462	174	299	540
LA	267	176	307	108	195	369
NB	292	182	1051	161	225	287
ND	179	133	205	40	134	164
PR	43	33	55	16	20	38
RB	178	131	220	413	168	408
SR	81	71	136	44	51	50
Y	95	85	136	17	87	62
ZR	959	538	1446	1134	664	323

PERCENTAGE NORMS

q	5.72	0.25	-	8.95	-	-
or	29.01	31.61	20.33	37.23	32.26	41.78
ab	48.07	47.52	58.21	20.12	47.42	36.13
an	-	-	-	20.15	1.81	-
ne	-	-	-	-	-	2.24
ac	3.87	8.00	9.33	-	5.37	10.90
di	1.67	5.77	1.33	0.70	4.68	1.98
hy	-	2.38	1.24	-	-	-
ol	-	-	5.43	-	2.54	3.34
il	1.44	1.33	1.58	0.87	1.31	0.30
mt	4.38	2.89	1.24	2.70	3.17	1.85
hm	2.76	-	-	5.81	-	-
ap	0.14	0.07	0.39	-	0.49	-
cc	-	-	-	-	-	-
H ₂ O	1.14	0.76	1.40	0.84	0.72	1.07
wo	1.33	-	-	1.10	-	-
ns	-	-	-	-	-	-

GRID REFERENCES

174921	174921	174921	174921	168916	168916
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TABLE 4.19

KILOMBE SYENITE

14 394	14 327C	14 327C
C	(L)	(D)

MAJOR ELEMENT ANALYSES

SiO ₂	65.85
TiO ₂	.56
Al ₂ O ₃	15.99
Fe ₂ O ₃	1.77
FeO	2.38
MnO	.12
CaO	.51
Na ₂ O	6.83
K ₂ O	5.47
H ₂ O ⁺	.42

TOTAL	99.80
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TRACE ELEMENT ANALYSES PPM

BA	524	42	128
CE	168	332	616
LA	113	58	130
NB	137	261	370
ND	68	68	78
PR	20	23	44
RB	227	551	20
SR	116	3	0
Y	38	26	57
ZR	403	397	4007

PERCENTAGE NORMS

q	4.56
or	32.32
ab	51.79
an	-
ne	-
ac	5.12
di	2.28
hy	2.19
ol	-
il	1.06
mt	-
hm	-
ap	-
cc	-
H ₂ O	0.42
ns	0.43

GRID REFERENCES

173920

TABLE 4.20

ELDAMA RAVINE TUFF

	14 641 E1	14 625 E1	14 687 E1	14 686 E2	14 645 E2	14 574 E2	14 570 E3
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MAJOR ELEMENT ANALYSES

SI02	61.96			62.19			56.58
TI02	.63			.70			.36
AL2O3	15.47			12.62			18.90
FE2O3	4.60			6.81			2.66
FE0	2.85			1.12			3.17
MNO	.66			.34			.26
MGO	.44			.32			.65
CAO	1.01			.82			1.26
NA2O	6.98	5.84	6.47	3.30	2.08	2.25	8.89
K2O	5.22			5.04			5.32
H2O+	.79			3.59			1.45
P2O5	.18			.09			.16
TOTAL	100.79	5.84	6.47	96.94	2.08	2.25	99.66

TRACE ELEMENT ANALYSES PPM

BA	118	23	37	74	169	122	18
CE	403	344	357	500	463	463	337
LA	240	228	206	295	302	343	195
NB	254	253	259	377	375	402	258
ND	182	150	150	213	206	226	128
PR	32	26	31	44	46	56	26
RB	181	134	136	205	703	461	184
SR	13	6	6	12	31	32	22
Y	93	95	94	135	156	152	79
ZR	887	910	931	1380	1408	1453	803

PERCENTAGE NORMS

q	0.14			21.72			-
or	30.85			29.79			31.44
ab	50.51			27.92			30.18
an	-			3.48			-
ne	-						20.27
ac	7.53						6.72
di	3.30						4.48
hy	3.17			0.80			-
ol	-						3.59
il	1.20			1.33			0.68
mt	2.89			2.69			0.49
hm	-			4.95			-
ap	0.42			0.21			0.37
cc	-						-
H ₂ O	0.79			3.59			1.45
			co	0.46			

GRID REFERENCES

	023115	059119	057116	057116	042144	115156	117154
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TABLE 4.21

ELDAMA RAVINE TUFF

	14 125 E4	14 511 E4	14 52 E4	14 53 E4	14 680	14 568	14 566
MAJOR ELEMENT ANALYSES							
SI02	57.95	57.83			56.17	58.63	60.07
TI02	.36	.35			.35	.36	.48
AL2O3	19.15	19.48			19.07	19.19	17.52
FE2O3	3.44	3.62			4.69	4.47	5.68
FE0	2.39	2.27			.99	.64	.75
MNO	.24	.25			.25	.11	.21
MGO	.57	.17			.51	1.02	.99
CAO	1.12	1.01			1.06	1.14	.64
NA2O	4.37	3.84	4.47	5.50	4.61	2.84	4.41
K2O	4.98	5.16			5.39	7.34	5.77
H2O+	3.33	5.87			4.13	3.62	2.58
P2O5	.12	.03			.14	.13	.14
TOTAL	98.02	99.88	4.47	5.50	97.36	99.49	99.24

TRACE ELEMENT ANALYSES PPM

BA	39	22	87	172	34	10	73
CE	331	353	127	241	329	295	457
CO	11						
LA	258	257	212	465	218	210	427
NB	261	267	347	308	254	245	320
ND	163	165	109	263	147	152	219
NI	2						
PR	30	33	23	55	32	33	22
RB	166	154	166	140	462	170	175
SR	30	44	14	22	71	35	28
Y	97	122	49	119	86	76	95
ZR	788	794	1161	1016	756	730	1009

PERCENTAGE NORMS

q	9.93	12.93			1.20	10.43	9.89
or	29.43	30.49			29.19	43.37	34.10
ab	36.98	32.49			48.21	24.03	37.32
an	4.77	4.82			-	4.81	2.26
ne	-	-			-	-	-
ac	-	-			13.66	-	-
di	-	-			0.85	-	-
hy	2.82	1.49			5.23	2.54	2.47
ol	-	-			-	-	-
il	0.68	0.66			1.10	0.68	0.91
mt	4.99	5.25			-	1.38	1.71
hm	-	-			-	3.52	4.50
ap	0.28	0.07			0.44	0.30	0.32
cc	-	-			-	-	-
H ₂ O	3.33	5.87			1.10	3.62	2.58
CO ₂	4.82	5.81			-	4.81	3.19
ns	-	-			0.20	-	-

GRID REFERENCES

043087	042091	005065	008063	097135	114150	114149
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TABLE 4.22

ELDAMA RAVINE TUFF

	14 683 E5	14 577 E5	14 510 E6	14 509 E6	14 557 E7	14 529 E7	14 675 E7
MAJOR ELEMENT ANALYSES							
SiO2	60.79	61.96	60.42		62.52	62.30	60.82
TiO2	.59	.55	.61		.56	.57	.57
Al2O3	14.61	14.07	17.25		14.15	14.22	14.81
Fe2O3	5.22	5.48	5.00		4.29	3.89	4.74
FeO	1.76	1.71	.99		3.51	3.18	3.31
MnO	.42	.33	.26		.25	.32	.23
MgO	.53	.79	.55		.52	.44	.50
CaO	.78	1.20	.87		.63	.67	.51
Na2O	3.51	4.66	5.62	4.27	7.40	7.83	7.06
K2O	5.45	5.49	5.35		4.98	4.89	5.08
H2O+	3.63	3.16	2.49		.64	.52	1.27
P2O5	.18	.16	.16		.17	.17	.14
TOTAL	97.47	99.56	99.57	4.27	99.62	99.00	99.04

TRACE ELEMENT ANALYSES PPM

BA	1786	124	110	319	81	317	51
CE	624	446	458	460	348	415	351
LA	375	333	274	284	215	250	303
NB	315	304	272	280	294	301	325
ND	251	186	191	195	136	173	193
PR	51	19	37	36	30	38	38
RB	855	173	172	170	178	180	185
SR	33	26	38	7	5	14	9
Y	199	98	103	93	70	93	86
ZR	1102	1080	936	968	1151	1130	1144

PERCENTAGE NORMS

q	17.56	11.34	5.02		1.69	1.67	-
or	32.21	32.44	31.61		29.43	28.90	30.02
ab	29.70	39.43	47.56		45.06	45.92	47.90
an	2.69	1.26	3.27		-	-	-
ne	-	-	-		-	-	-
ac	-	-	-		12.41	11.25	10.43
di	-	2.84	-		1.75	1.92	1.39
hy	1.32	0.65	1.37		6.37	5.59	4.44
ol	-	-	-		-	-	0.54
il	1.12	1.04	1.16		1.06	1.08	1.08
mt	5.33	4.99	2.27		-	-	1.64
hm	1.54	2.04	3.43		-	-	-
ap	0.42	0.37	0.37		0.39	0.39	0.32
cc	-	-	-		-	-	-
H2O	3.63	3.16	2.49		0.63	0.52	1.27
co	1.95	-	1.02		-	-	-
ns	-	-	-		0.81	1.76	-

GRID REFERENCES

999136	173128	051085	046078	094098	099108	080158
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TABLE 4.23

ELDAMA RAVINE TUFF

	14 9 E7	14 719 E7	14 1009 E7	14 549 E7	14 584 E8	14 593 E9	14 679 E9
MAJOR ELEMENT ANALYSES							
SiO ₂	61.54	62.09	61.17	63.18	60.35	65.84	64.62
TiO ₂	.58	.61	.60	.53	.67	.45	.45
Al ₂ O ₃	15.13	15.38	15.73	13.69	15.18	15.51	15.41
Fe ₂ O ₃	3.46	5.00	4.89	6.76	5.26	4.16	2.96
FeO	3.99	2.54	2.68	.37	2.24	1.13	2.30
MnO	.29	.37	.26	.25	.35	.17	.17
MgO	.57	.46	.43	.63	.49	.45	.37
CaO	.47	.44	.40	.59	.60	.19	.31
Na ₂ O	6.98	6.76	5.94	5.43	6.54	5.80	5.61
K ₂ O	5.16	5.19	5.02	4.93	5.43	5.41	5.47
H ₂ O+	1.22	1.22	1.85	1.55	1.06	1.54	1.05
P ₂ O ₅	.15	.16	.15	.16	.14	.15	.15
TOTAL	99.54	100.24	99.12	98.07	98.31	100.80	98.87

TRACE ELEMENT ANALYSES PPM

BA	55	131	35	87	251	89	34
CE	326	427	326	307	433	445	302
LA	251	261	315	266	267	285	180
NB	317	338	337	302	342	281	321
ND	163	164	190	164	183	179	120
PR	35	35	38	37	39	42	26
RB	184	187	181	175	186	222	234
SR	7	1	3	21	31	4	4
Y	87	66	86	52	108	68	64
ZR	1135	1204	1211	1070	1191	1147	1419

PERCENTAGE NORMS

q	-	2.65	6.16	12.07	1.53	10.74	9.65
or	30.49	30.67	29.66	29.13	32.09	31.98	32.32
ab	49.10	50.22	50.26	42.97	47.85	49.07	47.47
an	-	-	1.00	-	-	0.04	0.56
ne	-	-	-	-	-	-	-
ac	8.78	6.15	-	2.62	6.60	-	-
di	1.17	0.96	-	1.47	1.70	-	-
hy	4.66	2.68	1.45	0.89	1.57	1.12	2.27
ol	2.06	-	-	-	-	-	-
il	1.10	1.16	1.14	1.00	1.27	0.85	0.85
mt	0.62	4.16	7.09	0.47	4.32	2.89	4.29
hm	-	-	-	5.53	-	2.17	-
ap	0.35	0.37	0.35	0.37	0.32	0.35	0.35
cc	-	-	-	-	-	-	-
H ₂ O	1.22	1.22	1.85	1.55	1.06	1.54	1.05
co	-	-	0.16	-	-	0.13	-

GRID REFERENCES

024054	964062	905972	068124	142097	100097	097133
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TABLE 4.24

ELDAMA RAVINE TUFF

14 106 14 101 14 556 14 561 14 649 14 621 14 622
 E9 E9 E9 E9

MAJOR ELEMENT ANALYSES

SiO ₂	67.77				67.35		54.49
TiO ₂	.34				.43		.32
Al ₂ O ₃	14.50				12.96		18.31
Fe ₂ O ₃	2.49				4.98		3.77
FeO	1.64				2.06		1.78
MnO	.08				.17		.26
MgO	.28				.40		.39
CaO	.25				.35		1.79
Na ₂ O	4.97	5.20	6.12	5.28	4.85	4.60	6.44
K ₂ O	5.21				5.05		6.35
H ₂ O+	1.12				1.64		4.18
P ₂ O ₅	.13				.15		.16
TOTAL	98.78	5.20	6.12	5.28	100.39	4.60	98.24

TRACE ELEMENT ANALYSES PPM

BA	50	65	144	85	84	31	12
CE	215	127	425	457	227	316	318
LA	158	114	210	362	217	199	186
NB	238	230	310	301	341	247	243
ND	121	85	143	233	143	135	131
PR	26	18	29	50	31	29	25
RB	199	192	224	238	250	272	224
SR	5	4	8	12	7	15	9
Y	45	55	95	111	74	77	69
ZR	1335	1316	1315	1425	1240	764	753

PERCENTAGE NORMS

q	18.09				19.63		-
or	30.79				29.84		37.52
ab	42.06				38.55		32.48
an	0.39				-		2.30
ne	-				-		11.93
ac	-				2.20		-
di	-				0.59		2.30
hy	1.23				0.72		-
ol	-				-		-
il	0.65				0.82		0.61
mt	3.61				5.95		5.46
hm	-				0.12		-
ap	0.30				0.35		0.37
cc	-				-		-
H ₂ O	1.12				1.64		-
co	0.54				-		-
wo	-				-		1.09

GRID REFERENCES

959985 909021 077123 115116 045143 045112 046113

TABLE 4.25

ELDAMA RAVINE TUFF

14 564 14 129 14 1076 14 1076
(G) (F)

MAJOR ELEMENT ANALYSES

SiO ₂	57.94	56.78	62.32	63.43
TiO ₂	.54	.33	.59	.58
Al ₂ O ₃	16.51	19.13	14.83	14.72
Fe ₂ O ₃	1.97	3.99	4.91	4.72
FeO	4.16	1.64	2.45	2.67
MnO	.35	.25	.24	.23
MgO	.61	.48	.52	.52
CaO	.80	1.10	.45	.45
Na ₂ O	10.11	2.97	7.56	7.63
K ₂ O	5.03	6.15	5.16	4.94
H ₂ O ⁺	.45	6.13	1.40	1.10
P ₂ O ₅	.17	.15	.16	.19
TOTAL	98.64	99.10	100.59	101.18

TRACE ELEMENT ANALYSES PPM

BA	24	17	39	58
CE	490	313	326	566
LA	283	201	256	469
NB	326	252	308	313
ND	195	136	167	292
PR	41	26	37	69
RB	197	352	186	184
SR	0	75	1	0
Y	97	81	82	135
ZR	1108	762	1116	1191

PERCENTAGE NORMS

q	-	13.32	-	1.20
or	29.72	36.34	30.49	29.19
ab	37.27	25.13	47.55	48.21
an	-	4.48	-	-
ne	10.64	-	-	-
ac	5.70	-	14.21	13.66
di	2.48	-	1.02	0.85
hy	-	1.20	3.20	5.23
ol	5.80	-	1.16	-
il	1.03	0.63	1.12	1.10
mt	-	5.14	-	-
hm	-	0.44	-	-
ap	0.39	0.35	0.37	0.44
cc	-	-	-	-
H ₂ O	0.45	6.13	1.40	1.10
ns	5.16	-	0.07	0.20
co	-	5.95	-	-

GRID REFERENCES

106114 046096 992970 992970

TABLE 4.26

MAU TUFF

	14 807 MI	14 961 MI	14 813 MI	14 833 MI	14 1003 M3	14 848 M3	14 933 M3
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MAJOR ELEMENT ANALYSES

SI02	61.50				65.54		
TI02	.85				.34		
AL2O3	14.53				14.74		
FE2O3	6.52				1.86		
FeO	2.52				2.00		
MNO	.29				.08		
MGO	.56				.12		
CAO	.61				.39		
NA2O	7.16	6.85	6.65	6.54	2.42	5.09	2.62
K2O	5.23				6.20		
H2O+	1.09				3.50		
P2O5	.17				.08		
TOTAL	101.03	6.85	6.65	6.54	97.27	5.09	2.62

TRACE ELEMENT ANALYSES PPM

BA	90	83	98	103	69	95	95
CE	329	283	333	268	341	293	344
LA	376	166	216	271	203	180	252
NB	209	226		213	244	243	217
ND	236	131	157	198	167	146	191
PR	46	26	33	43	33	28	44
RB	118	135		122	198	196	206
SR	9	14		8	11	10	15
Y	141	87		167	89	79	100
ZR	739	817		755	1352	1389	1220

PERCENTAGE NORMS

q	1.04				26.16		
or	30.91				36.64		
ab	45.62				20.48		
an	-				1.41		
ac	13.18				-		
di	1.61				-		
hy	2.73				2.02		
ol	-				-		
il	1.61				0.65		
mt	2.85				2.70		
hm	-				-		
ap	0.39				0.19		
cc	-				-		
H2O	1.09				3.50		
co	-				3.53		

GRID REFERENCES

084754	908802	044750	997750	831753	943785	810868
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TABLE 4.27

MAU TUFF

	14 958	14 985	14 1014	14 822	14 835	14 843	14 858
	M3	M3	M3	M4	M4	M4	M4

MAJOR ELEMENT ANALYSES

SiO ₂				60.72			
TiO ₂				.83			
Al ₂ O ₃				15.30			
Fe ₂ O ₃				4.98			
FeO				3.41			
MnO				.31			
MgO				.66			
CaO				.71			
Na ₂ O	3.07	5.52	2.70	7.14	6.06	7.17	4.59
K ₂ O				4.97			
H ₂ O+				.95			
P ₂ O ₅				.18			
TOTAL	3.07	5.52	2.70	100.16	6.06	7.17	4.59

TRACE ELEMENT ANALYSES PPM

BA	180	289	67	49	42	47	43
CE	112	235	357	305	213	317	343
LA	72	215	216	344	271	270	207
NB	263	181	206	268	267	265	256
ND	65	163	163	251	171	173	139
PR	12	31	32	58	37	40	32
RB	150	152	173	152	155	162	149
SR	3	29	8	2	5	2	11
Y	42	80	93	95	72	79	101
ZR	1533	866	1168	963	969	948	923

PERCENTAGE NORMS

q	-
or	29.37
ab	51.03
an	-
ac	8.27
di	1.99
hy	0.89
ol	2.59
il	1.58
mt	3.08
hm	-
ap	0.42
cc	-
H ₂ O	0.95

GRID REFERENCES

888728	846767	868967	015751	982790	937804	899856
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TABLE 4.28

MAU TUFF	U. MENENGAI TUFF		ROSOGA TUFF
14 968	14 774	14 794	14 588
<i>M4</i>			

MAJOR ELEMENT ANALYSES

SiO ₂		60.79	71.34
TiO ₂		.67	.38
Al ₂ O ₃		13.28	10.93
Fe ₂ O ₃		5.90	1.93
FeO		3.35	3.46
MnO		.42	.13
MgO		.24	.34
CaO		.94	.27
Na ₂ O	5.41	5.31	3.29
K ₂ O		4.89	4.89
H ₂ O ⁺		1.48	2.30
P ₂ O ₅		.14	.14
TOTAL	5.41	97.41	99.40

TRACE ELEMENT ANALYSES PPM

BA	42	49	34	124
CE	350	440	406	359
LA	224	239	231	212
NB	264	287	273	205
ND	264	176	162	170
PR	33	38	36	36
RB	230	190	181	182
SR	4	1	0	14
Y	102	125	120	123
ZR	943	989	904	1011

PERCENTAGE NORMS

q	10.03	30.81
or	28.90	28.90
ab	41.08	27.84
an	-	0.43
ac	3.39	-
di	3.22	-
hy	0.86	5.22
ol	-	-
il	1.27	0.72
mt	6.85	2.80
hm	-	-
ap	0.32	0.32
cc	-	-
H ₂ O	1.48	2.30
co	-	0.70

GRID REFERENCES

875796	291869	313838	158136
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TABLE 4.29

MAKUTANO TUFF

14 718	14 869	14 1013	14 750	14 753
P3	P1		P3	P5

MAJOR ELEMENT ANALYSES

SiO ₂	56.03	52.89	55.81		
TiO ₂	.87	.35	.24		
Al ₂ O ₃	18.27	20.48	20.18		
Fe ₂ O ₃	5.00	2.72	3.25		
FeO	.45	2.13	1.54		
MnO	.30	.26	.24		
MgO	.67	.48	.48		
CaO	.72	4.65	2.00		
Na ₂ O	4.96	3.12	3.29		
K ₂ O	5.63	6.49	6.94		
H ₂ O+	4.19	4.59	4.18		
P ₂ O ₅	.16	.07	.14		
CO ₂	.00	.25	.00		
TOTAL	97.25	98.48	98.29		

TRACE ELEMENT ANALYSES PPM

BA	194	351	220	118	45
CE	504	212	292	500	399
CO		12			
LA	432	143	261	526	267
NB	409	197	219	408	252
ND	216	84	148	237	165
NI		1			
PR	50	14	30	49	39
RB	505	338	787	971	147
SR	55	761	312	53	22
Y	135	34	82	134	88
ZR	1289	503	613	1276	792

PERCENTAGE NORMS

q	3.54	-	5.42		
or	33.30	38.35	41.01		
ab	41.97	26.40	27.84		
an	2.53	21.03	9.01		
ac	-	-	-		
di	-	-	-		
hy	0.03	0.41	1.39		
ol	-	1.74	-		
il	1.59	0.66	0.46		
mt	-	3.94	4.71		
hm	5.00	-	-		
ap	0.37	0.16	0.32		
cc	-	0.57	-		
H ₂ O	4.19	4.59	4.18		
co	3.09	0.62	3.96		
ru	0.03	-	-		

GRID REFERENCES

979068	940768	859987	944019	956063
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TABLE 4.30

STANDARD ROCKS

	NIM D	NIM G	NIM N	NIM S	G 2	G A	G H
TRACE ELEMENT ANALYSES PPM							
BA	0	105	55	2524	1810	719	17
CE	47	201	29	6	153	70	58
CO					16		
CR					10		
LA	17	128	19	18	100	48	39
NB	1	51	2	1	10	10	95
ND	0	95	9	26	76	51	55
NI					7		
PR	0	19	2	5	17	8	8
RB	0	341	2	518	170	158	403
SR	0	8	266	60	498	277	6
Y	0	135	7	8	11	17	78
ZR	1	264	14	2	320	115	151

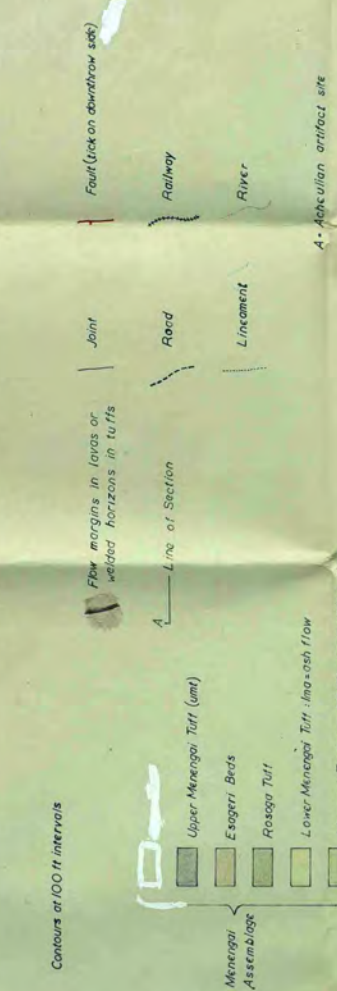
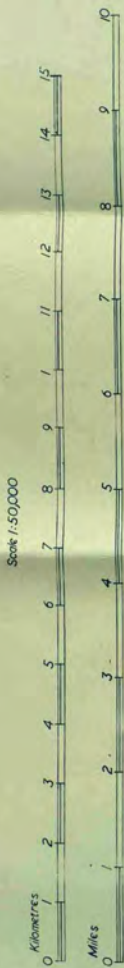
PCC 1 AGV 1 BCR 1 GSP 1 DTS 1

TRACE ELEMENT ANALYSES PPM

BA	0	1240	731	1289	0
CE	42	75	78	339	41
CO	201	26	60	13	190
CR	3929	15	35	16	3531
LA	18	65	41	149	15
NB		12	12	18	0
ND	3	44	31	177	0
NI	3405	31	28	16	3475
PR	3	10	11	38	0
RB		68	48	255	1
SR		691	323	243	0
Y		19	31	27	0
ZR		205	185	551	0

GEOLOGY OF THE LONDIANI AREA, KENYA.

W. B. JONES OCT. 1970 - JUN. 1971 & NOV. 1971 - MAY 1972



THE GEOLOGY

GEOLOGICALLY SURVEYED BY W. B. JONES

