"GEOCHEMISTRY OF CARBONATITES AND RELATED ROCKS

FROM SOUTH NYANZA, KENYA".

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A B S T R A C T.

The distribution of 25 trace elements and selected major elements have been investigated in carbonatites, peralkaline silicate rocks and fenites from Homa Mountain, N. Ruri and Wasaki in W. Kenya. Comparison has been made with the distributions of these elements in similar rocks from Budeda, Toror and Tororo carbonatitic complexes, E. Uganda.

The earliest sovitic carbonatites were found to contain greater concentrations of Sr, and generally less Ba, Nb, REE (both Ce- and Y-earths), Fe, Mn, Zn, Zr, Ti, and V than the later alvikitic carbonatites. The later ferruginous alvikites were characteristically enriched in Fe, Mn, Ba, Zn, and REE (Ce-earths) relative to other carbonatites.

All carbonatites were typically strongly Ce-earth enriched.

The peralkaline silicate rocks and fenites were similarly enriched in Sr, Ba, REE, Nb and Ti, and contained generally more Zr and Ga than the carbonatites. These rocks were also Ce-earth enriched.

The concentrations of Sr, Ba, Zr, REE, Ga, and Nb in the fenites indicate that these elements are introduced into the country rock by Na-fenitising solutions. The similarity in trace element content between fenites and nepheline-syenite suggests a genetic relationship between these rock types.

The greater concentration of Cr, Ni and Co in the pyroxenites suggest that these rocks formed early in the crystallisation history of the carbonatite complexes, leading to crystallisation of the ijolitic suite.

The relationship between the carbonatites and silicate rocks remains controversial. However, the concentration Ba, REE, and Nb in the carbonatites indicates that these rocks were formed late in the history of the complexes.

A mechanism involving fractional crystallisation of a

A B S T R A C T, (continued.).

   carbonated silica-undersaturated magma, leading in the later
   stages to liquid immiscibility of carbonate and silicate
   liquids, is favoured for the origin of these rocks.

C O N T E N T S

C H A P T E R   O N E.

1.1   Introduction.

Carbonatites and their associated silicate rocks and
fenites are enriched in a characteristic assemblage of
trace and minor elements relative to other igneous rocks,
(Pecora, 1956; Heinrich, 1966). These elements are either
present as vicarious elements in the lattices of minerals
in the rocks, or more rarely found in the rocks as rare
element minerals (e.g. pyrochlore $CaNaNb_2O_6F$, bastnaesite
$REE_{Ce}CO_3F$, baddeleyite ZrO_2).

The geochemical study which forms the basis of this
thesis is intended to obtain detailed geochemical data
concerning the distribution of trace, minor and major
elements within the carbonatites and their related
peralkaline silicate rocks and fenites, from carbonatitic
complexes in Western Kenya and Eastern Uganda. This work
is intended to complement field mapping and petrographic
study of a number of complexes in W. Kenya and E. Uganda,
carried out by other members of the East African Research
Team at Leicester University and Bedford College, London.

Material was selected for analysis from existing
collections from the carbonatite complexes described
below, (see Fig. 1.1).

Western Kenya.

(i) **Homa Mountain,** (Saggerson, 1952; McCall, 1959;
Clarke, 1968; Flegg, 1969).

Situated on the shores of Lake Victoria, in the
Kavirondo Rift Valley, Homa Mountain is a carbonatitic
centre intruded into Nyanzian lavas in Miocene to early
Pleistocene times. Emplacement of ijolite was followed
by intrusion of carbonatite and carbonatitic breccia
generally in cone sheets. Plugs and dykes of phonolitic
nephelinite and olivine melilitite occur, and fenitisation

FIG. I.
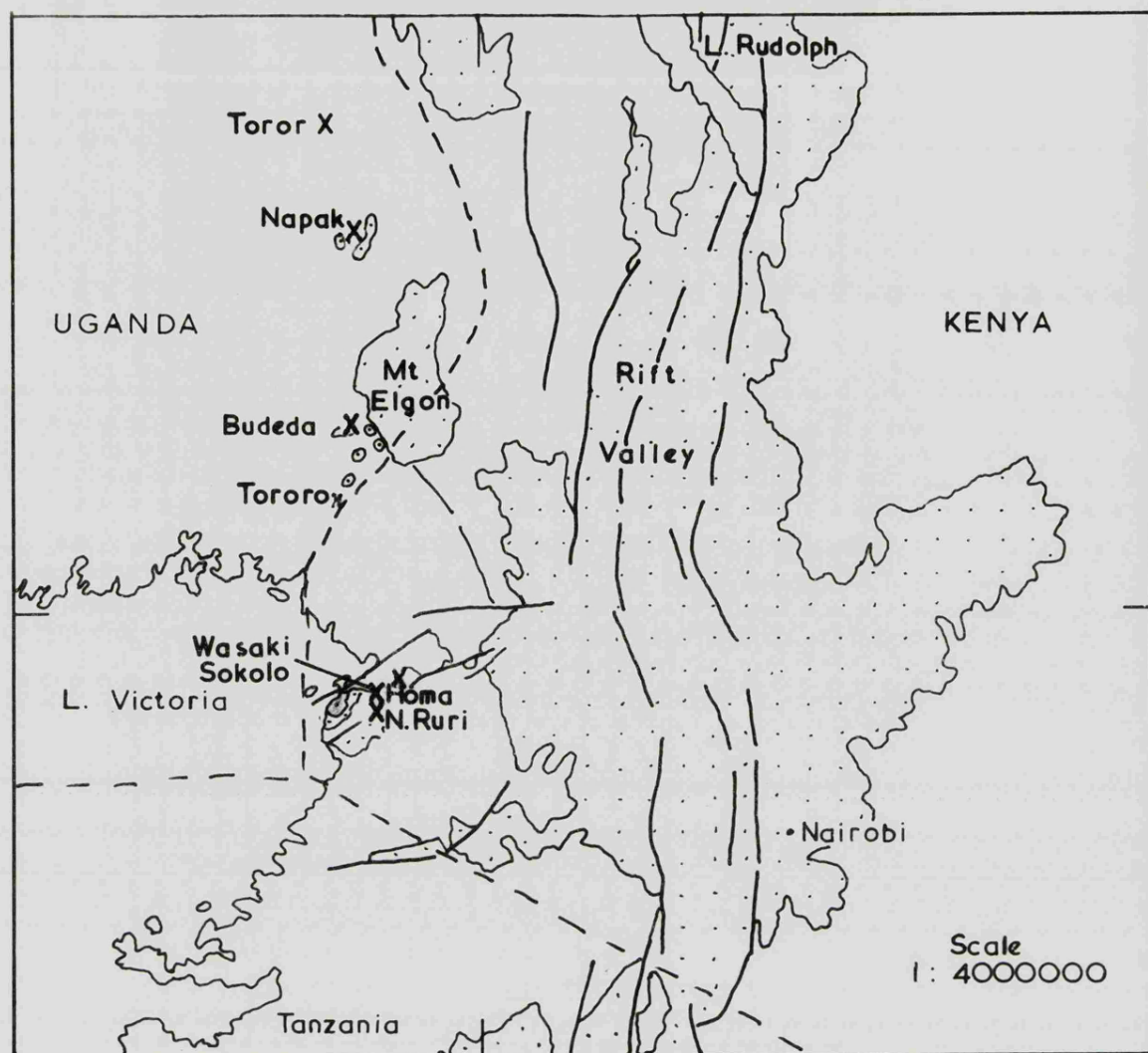
Key to fig. I.

: ·	Tertiary to Recent alkaline igneous rocks.
x	Carbonatitic centres investigated.

Figure I.   Map showing centres of carbonatite activity
in Kenya and Uganda, and Tertiary to Recent
volcanic activity in East Africa.

of country rock is widespread.

Specimens chosen for analysis have prefixed HF or
HC numbers.

(ii) North Ruri and Okuge, (McCall, 1958; Dixon, 1968).

The North Ruri complex is situated adjacent to the South
Ruri complex, 11 miles east of the Rangwa centre and the
Kisingiri volcano. It consists of early nepheline-syenite,
a suite of carbonatitic cone sheets and carbonatitic breccias,
and numerous plugs of phonolitic nephelinite intruded into
Pre-cambrian metabasalt. Fenitisation of metabasalt is
apparent. Okuge is a much smaller complex, consisting of
a mass of carbonatite cone sheets, with "scattered outcrops
of melanephelinite lava and agglomerate from the Kisingiri
volcano, and phonolitic nephelinite lava surrounding it",
(Dixon, 1968 abstract).

Analysed specimens have prefixed N numbers, (e.g. N142).

(iii) Wasaki centres, (Pulfrey, 1950, 1954; McCall, 1958;
Heinrich, 1966 p.483; Le Bas 1966).

Three miles north-east of the North Ruri complex lies
the ijolite mass of Usaki surrounded by fenites, a carbonatite
mass at Sokolo, and the Phonolitic volcanic remnant of
Nyamaji. The complex is intruded into Pre-cambrian granite
rocks.

Analysed specimens have prefixed U numbers.

In addition to these centres in Western Kenya, samples
were chosen from several carbonatitic centres in Eastern
Uganda, which are briefly described below.

(i) Budeda (Sutherland, 1966; King and Sutherland,
1966).

The Budeda complex, only half a mile across, is a
Tertiary carbonatite complex intruded into granitic basement
which has been fenitised. The central part of the complex
ranges from pyroxenite (melteigite) to ijolite and urtite,
with small carbonatite intrusions less than forty feet across.
Small ijolite intrusions, separated from the main mass lie
within a wide area of syenitic fenite. Cancrinite syenite
is often found marginal to the ijolite, whilst dykes of

nepheline-syenite and cancrinite-phonolite are also found.

Analysed samples have prefixed SuB numbers.

(ii) Tororo, (Williams, 1952; Davies, 1956;
Sutherland,1966; King and Sutherland, 1966).

Some 35 miles from Budeda, and a few miles from the
Kenya border, the Tororo complex consists of a pear shaped
carbonatite body, of Tertiary age, intruded into syenitic
fenite, and a smaller separate carbonatite (Limekiln Hill
carbonatite - Sutherland, 1966) intruded into syenitic fenite,
nepheline-syenite, ijolite which are brecciated.

The emplacement of carbonatite was preceeded by intense
feldspathisation of breccia fragments on Limekiln Hill.
Ijolite agglomerate dykes are found to cut agglomerate.

Analysed samples have prefixed SuTo numbers.

(iii) Napak, (King 1949; Sutherland, 1966, King and
Sutherland, 1966).

This centre lies north-west of Mount Elgon. Extrusive
lavas and pyroclastics remain around a well defined ijolite-
carbonatite complex, emplaced in basement gneisses. The
basement gneisses are fenitised around the central intrusive
rocks.

Analysed specimens have prefixed SuN numbers.

(iv) Toror, (Du Bois, 1956, 1959; Sutherland, 1965,1966;
King and Sutherland, 1966).

The Toror complex consists of intrusive rocks of
hypabyssal character, (trachyte, phonolite, and agglomerate),
associated with a ring-shaped intrusion of carbonatite emplaced
in granitic gneiss. Fenitisation is only slight, but brecciation
is extensive.

Analysed specimens have prefixed SuT numbers.

1.2 Petrography and mineralogy of the carbonatites, peralkaline
silicate rocks and fenites.

(i) Carbonatites.

Detailed study of the petrography of carbonatites from the
Western Kenya complexes, notably Homa Mountain (Flegg, 1969) and

North Ruri (Dixon, 1968) has given rise to the recognition
of a variety of carbonatite types.

Dixon (1968) subdivided the North Ruri carbonatites into
three main types; namely, sovite (coarse grained white
carbonatite), alvikite with or without rhombic calcite
Phenocrysts (fine-medium grained, generally darker coloured
rock), and ferruginous alvikite (deep brown coloured fine
grained carbonatite). Flegg proposed a similar classification
for the Homa carbonatites. In addition, dyke rocks containing
calcite pseudomorphs after melilite were recognised at Homa
(Clarke, 1969), denoted here by melilite-pseudomorph carbonatite,
and intrusive breccias, containing a variety of fragmented
silicate rocks in a carbonate matrix are referred to as
intrusive breccias (sovite breccias of Saggerson, 1952).

This classification of the carbonatitic rocks has been
used throughout this work.

The mineralogy of the carbonatitic rocks varies
considerably both between and within the carbonatite groups
mentioned above. The sovites of Homa Mountain were made up
of coarse grained platy to equant calcite crystals, which
could be orientated or non-orientated. Accessory minerals
were rarely abundant, and included apatite, biotite,
pyroxene and occasional pyrochlore, (Flegg, 1969).
At North Ruri, the sovites were similar to those at Homa,
and were found to contain apatite, sphene, pyroxene,
feldspar, magnetite, and pyrochlore as accessory minerals,
(Dixon, 1968). The sovites from Budeda showed replacement
relationships with the ijolites, and with increasing calcite
content the ijolites graded into carbonatite with schlieren
of pyroxene. Apatite, sphene and pyrite were found as
accessory minerals in these rocks, (Sutherland, 1966).
A great many xenoliths were apparent in sovite from Limekiln
Hill, Tororo, whilst less were found in the main sovite
intrusion. Magnetite, apatite, biotite, and pyrochlore
were common accessory minerals in these carbonatites, whilst
pyroxene and feldspar were common in the Limekiln Hill
carbonatites.

The alvikites were generally much finer grained rocks
than the sovites, and differed generally from thesovites in
the mode of emplacement.

At Homa Mountain, the alvikites were intruded as dykes
and cone sheets from three inches to fifteen feet thick.
Both porphyritic and non-porphyritic types are represented.
Biotite, euhedral pyrochlore, apatite, pyroxene, amphibole,
and large euhedral magnetites are more common in the
non-porphyritic types, (Flegg, 1969). Red-brown biotite,
euhedral magnetite, apatite and pyrochlore, fluorite,
barite, and pyroxene were common accessory minerals in
the rhomb-alvikites from North Ruri, (Dixon, 1968).
Alvikitic dykes from Tororo were noted to contain magnetite,
biotite and chlorite, (Sutherland, 1966).

Ferruginous alvikites intruded generally later than
the alvikites and sovites, and found as dykes, veins and
cone sheets, are well represented in the Western Kenya
complexes. These rocks were noted to contain a characteristic
mineral assemblage at Homa Mountain, including the minerals
barite, fluorite, monazite, bastnaesite, dahllite, collophane,
(Flegg, 1969). An abundance of iron ores (hematite,
magnetite, goethite) gave the rock its characteristic deep
brown colour. Ferruginous alvikites from North Ruri,
occuring as thin dykes and cone sheets up to three metres
thick, consisted of small close-packed rhombs and rounded
grains of reddish-brown carbonate, in a matrix of clear
calcite and iron ore, (Dixon, 1968). Fluorite was a common
accessory mineral with barite, monazite and biotite.

Late carbonate dykes found at Homa Mountain were
composed of lath-like pseudomorphs after melilite, with
both matrix and laths being carbonated. These dykes were
recognisably later than the other carbonatites, and were
designated melilite-pseudomorph carbonatites.

The sovite breccias of Homa Mountain (Saggerson, 1952),
were composed of breccia fragments of ijolite, Nyanzian
lava, carbonatite and fenite set in a fine grained matrix

of limonite and calcite. These rocks were named intrusive carbonatitic breccias to avoid confusion with the sovites which were intruded earlier than the breccias.

(ii) Peralkaline silicate rocks.

Included in the silicate rocks associated with carbonatites are melanocratic to leucocratic rocks of the ijolite series (pyroxenite-melteigite-ijolite-urtite-melanite ijolite), nepheline-syenite, and feldspathic ijolite. The fine grained volcanic equivalents of the plutonic series are represented by melanephelinite-nephelinite-phonolitic nephelinite-phonolite rocks. A variety of fenitic rocks are found at each complex, which generally grade from slightly fenitised country rock to syenitic fenite with nepheline.

The mineralogy of the ijolitic rocks is complicated, and varies considerably from specimen to specimen. Such rocks from Homa Mountain were shown to belong to a simplified paragenetic sequence by Clarke (1969), which is reproduced below.

Early magmatic	Late magmatic	Postmagmatic	Deuteric
Diopsidic Pyroxene	Aegirine-augite	Calcite	Phlogopite
Nepheline	Nepheline	Apatite 2	Cancrinite
Perovskite	Melanite/sphene	Feldspar	Sericite
Apatite 1	Wollastonite		Natrolite,
			Analcime,
			Pectolite

Variation in mineralogical composition of the ijolitic rocks from Napak depended principally on the relative proportions of pyroxene and nepheline. Other minerals which were invariably found in the ijolites were melanite, iron-titanium oxides, wollastonite, sphene, apatite, perovskite and biotite. Cancrinite, pectolite, calcite and zeolites were mostly found as replacement minerals. The pyroxenitic pyroxene was diopsidic in composition, whilst in the

melteigites and later ijolites the pyroxenes were more
acmitic. Magnetite was less abundant in the ijolites
than in the pyroxenites, whilst melanite was shown to
invade and ultimately replace iron oxide and perovskite
of the pyroxenite, (King and Sutherland, 1966).

Nepheline-syenitic rocks found at Tororo, are dark
fine grained rocks, containing small euhedral altered
nepheline, acicular acmitic pyroxene, zeolite and
cancrinite replacing nepheline, and K-feldspar in
clear poikilitic plates or intergrown laths, (Sutherland,
1966). Red-brown biotite and apatite are also noted from
these rocks. The nepheline-microsyenite of North Ruri
was noted to contain nepheline, aegirine-augite, K-feldspar,
and smaller amounts of sphene, apatite, magnetite, and
wollastonite. Eudialyte and gotzenite were present as
rare accessory minerals, (Dixon, 1968).

The finer grained volcanic peralkaline silicate rocks
are also variable in their mineralogy. Melanephelinites
from North Ruri were noted to contain zoned augite,
olivine, magnetite and nepheline phenocrysts in a
matrix of fine grained crystalline nepheline, augite,
magnetite, apatite and perovskite (Dixon, 1968).
Nephelinites were mineralogically similar to the
melanephelinites, except for the pyroxene which were
margined by aegirine-rich pyroxene in the nephelinites,
and the nepheline phenocrysts which were more common in
the nephelinites. The later phonolitic nephelinites were
noted to contain nepheline, aegirine and feldspar in a
matrix of the same minerals.

Phonolitic rocks from Toror, Eastern Uganda, (King
and Sutherland, 1966) contained phenocrysts of nepheline,
feldspar (which gave compositions of soda-orthoclase and
sanidine), diopsidic pyroxene zoned to aegirine rich
margins, and less abundant amphibole and sphene. The
groundmass of most of the phonolites "consists of small
laths of feldspar with interstitial nepheline, and is

often altered to zeolite or kaolin", (King and Sutherland, 1966). Sphene, zircon, granular magnetite, natrolite, cancrinite, calcite, sodalite, analcite, pectolite, and rare phlogopite were noted as being accessory to the phonolitic rocks.

The fenitic rocks at the complexes in E.Uganda have been extensively described by King and Sutherland (1966), and by Sutherland (1966). Fenitisation of granite and metabasalt at N. Ruri has also been described by Dixon (1968), and fenitisation of country rock at Homa by Clarke (1968).

All the fenitic rocks show the typical Na-fenitisation characteristic of carbonatite complexes, where initial brecciation of country rock is followed by recrystallisation of feldspar and growth of dark minerals aegirine rich pyroxene and alkali-amphibole.

This contrasts with the "feldspathisation" of country rock adjacent to carbonatite intrusions, where the growth of dark minerals is suppressed or absent, (Clarke, 1968).

More detailed descriptions of the petrography of each rock type at the various complexes, are given in the works to which previous reference has been given.

1.3 Selection of samples for analysis.

Representative unweathered samples of the main rock types were chosen from the various carbonatitic complexes in Western Kenya, and similar rock types were selected from complexes in Eastern Uganda.

Specimen number, field location, rock type and other relevant field data pertaining to the carbonatites and silicate rocks selected for analysis are shown in Appendix Table 1.

Due to this geochemical study being based on analysis of material which had originally been chosen for petrographic study, no systematic sampling of the various intrusions of

peralkaline rocks and carbonatites or fenites could be attempted. Instead, samples have been chosen for analysis according to rock type, which in turn was based on their petrographic characteristics described earlier (pp Section 1.2). Thus, for the purposes of sampling, the presence of accessory and minor minerals in the various rock types have been ignored.

1.4 **Mineralogy of the analysed samples.**

(a) A qualitative estimate of the mineralogy of the carbonatites and carbonatitic breccias, based on thin section study, is given in Appendix Table 2 (a).

(b) The mineralogy of the ijolitic rocks chosen for analysis was extremely diverse, and often varied considerably within one hand specimen. In order to obtain a semi-quantitative partial modal analysis of the analysed rock, an X-ray diffraction study was carried out on the rock powder used in the analysis. In this way a fuller classification of the ijolitic rocks was obtained. The method of analysis is described below.

Method for partial modal analysis of the intrusive peralkaline silicate rocks.

One gram of powdered rock was mixed thoroughly with 0.2 gms. quartz powder, which was used as an internal standard. Each sample was ground to an approximate grain size of minus-200-mesh under acetone. The mixtures were mounted in circular sample holders, and gently packed down to avoid preferential orientation of the grains. Two mounts were made for each rock powder in this way, and several diffractometer patterns recorded for each mount using a chart recorder set at a convenient speed.

A series of mineral standard samples were prepared from minerals separated from the peralkaline rocks under study, and were mixed with quartz, ground and mounted in the same way as the samples. Several mounts and several

X-ray diffraction patterns were recorded for each standard using the same instrument settings as for the samples.

Standards for the minerals pyroxene (diopside), nepheline, melanite garnet, K-feldspar were produced in this way.

Reflections for each mineral, free from interference from other minerals present in the peralkaline intrusive rocks, were chosen and calibration graphs of intensity of reflection (i.e. peak height of reflection on the diffraction pattern) versus the weight percentage of the mineral in the powders were constructed from the average readings for each standard for each mineral. The graphs were linear.

In the case of nepheline, interference from feldspar was unavoidable. A correction factor, based on the amount of feldspar present in the rock, was calculated from the results of runs on nepheline/feldspar mixed standards.

The peak height for each reflection (and each mineral) was then divided by the corresponding internal standard peak height for that diffraction pattern, and the average of all the patterns for each rock calculated and compared with the standard graphs to give the approximate weight percentage of each mineral in each rock powder. The correction for nepheline was applied after average values of peak height to quartz peak height had been calculated.

An internal standard was used to avoid the effects of instrument fluctuation and mass absorption between samples and standards. Quartz was employed for this purpose due to its absence in the rocks under study, its availability and good peak height to weight percentage ratio.

The analysis is only semi-quantitative due to the variation in reflection intensity and 2Θ value with variation in chemical composition of each mineral (Zussman, 1967). However, the results of X-ray diffraction techniques showed good correspondence to point counting modes of the same rocks.

Minerals generally present in amounts less than
5 wt.% in the rocks were not detectable using this method.
The presence of the minerals sphene, apatite, cancrinite,
natrolite and magnetite, were recorded from thin section
study of the rocks, and are tabulated with the partial
modal analyses in Appendix Table 2 (b) (i).

(c) The mineralogical composition of the phonolitic
rocks was difficult to determine from thin section due to
the fine grain size of the matrix to these rocks.
Qualitative analysis of the leucocratic minerals in the
matrices and phenocrysts of these tocks was carried out
using X-ray diffraction techniques described below.

Method for the partial modal analysis of phonolitic
rocks.

Samples of each analysed phonolitic rock were crushed,
and powder of grain size between 120 and 200-mesh was
separated from the powder by sieving. This fraction was
then washed with distilled water and acetone, and was then
dried.

The magnetic fraction of each rock was firstly separated
from the non-magnetic fraction with a bar magnet, and finally
using a Frantz iso-dynamic separator. The non-magnetic
fraction (leucocratic mineral fraction) was then crushed to
approximately minus-200-mesh, and mounted in a circular
sample holder for X-ray diffraction analysis. X-ray
diffraction patterns for each rock were recorded on a
chart recorder between the angles 19° and 50° 2θ.

Each diffraction pattern was then compared with "standard"
patterns on which reflections for each mineral were clearly
marked. The presence of feldspar, nepheline, analcime,
natrolite, cancrinite, and apatite was easily detected in
the rocks.

The results of the modal analyses of the phonolitic rocks
using X-ray diffraction techniques for the felsic minerals,
and thin section study of rocks for mafic minerals are given

in Appendix Table 2 (b) (ii).

(d) The fenitic rocks analysed and the mineralogy of the rocks obtained from thin section study, are shown in Appendix Table 2 (b) (iii).

1.5 Analysis of the samples and selection of trace and minor elements for analysis.

The large variation in rock type from almost pure carbonate rock to quartz-rich basement rock, and relatively large variation in concentration of different elements within the rocks affected the choice of analytical methods, and selection of elements for analysis.

Large concentrations of REE, Nb, Zr, Ba, and Sr have been reported from carbonatitic rocks, whilst relatively little is known about the concentrations of these elements in the ijolitic and nepheline-syenitic rocks, and fenites associated with carbonatites. In addition to these elements, concentrations of Cu, Zn, Pb, Ni, Mo, in sulphide minerals (Heinrich, 1966), Ti and V in magnetite and opaque oxides (Deans, 1966) and U have been noted from carbonatitic rocks, whilst Be has been found in large concentrations in fenitic rocks (Heinrich and Deane 1962; Zhabin and Mukhitdinov, 1959).

In this study, spectrometric analyses of trace elements Ba, Be, Bi, Cr, Cu, Co, Li, Mo, Ni, Pb, Sn, Sr, Ga, Ge, V, Zn, Zr were obtained from both carbonate and silicate rocks using an A.R.L. 29000B direct reading spectrometer. In addition to this data, the concentrations of major elements Si, Al, Ca, Fe, Mn, Mg and Ti were also obtained using the direct reading spectrometer.

X-ray fluorescence spectrometry was used in the analysis of these rocks for the rare-earth elements (REE) La, Ce, Nd and Dy, and Y. The various methods and techniques employed in these analyses are given in Appendix 1.

The discussion of the results which follows has been

subdivided into a series of related topics (Chapter 2 - Chapter 4). The REE data in both carbonatites and silicate rocks has been treated separately from other analyses in Chapter 2, as REE form a coherent group of elements.

In Chapter 3 the trace element analyses of carbonatites, carbonatitic breccias, and feldspathic country rock adjacent to carbonatite intrusion are dealt with, while trace element distributions in peralkaline silicate rocks, and fenites are discussed in Chapter 4. Chapter 5 contains a summary of the data, and discussion of the results as a whole.

1.6 Acknowledgements.

CHAPTER   TWO.

Rare-earth elements Lanthanum, Cerium and Neodymium, and
Yttrium in carbonatites and related rocks from carbonatitic
complexes in Western Kenya and Eastern Uganda.

2.1   Introduction.

Carbonatites and associated peralkaline rocks and fenites
characteristically contain concentrations of rare-earth and
related elements either present as rare-earth minerals
(Heinrich, 1966, Jaffe and Collins, 1969), or more usually
dispersed in the lattices of Ca minerals such as calcite,
apatite, sphene, pyrochlore and to a lesser extent pyroxene
and garnet (Heinrich, 1966; Balashov and Pozharitskaya, 1968;
Kapustin, 1966).

The rare-earth elements are generally more abundant in
carbonatites than in the ijolitic and fenitic rocks of
carbonatite complexes. Their abundance in carbonatites has
often been used as a criterion in the recognition of a body
as magmatic as opposed to sedimentary limestone, (Deans, 1968;
Bowden, 1962, 1968).

The rare-earth elements, from Lanthanum (z = 57) to
Lutetium (z = 71) are usually subdivided into a light
lanthanide series Lanthanum to Europium and a heavy lanthanide
series Gadolinium to Lutetium plus Yttrium. Yttrium (z = 39),
although not strictly a member of the lanthanide series, is
similar chemically and physically to the rare-earth elements.
The similarity of Yttrium to the heavy lanthanides designates
this series as the Yttrium-earths, whilst the light lanthanides
are often referred to as the cerium-earths, after their most
abundant member.

Aleksiyev, 1966, pointed out that the relative abundance
of Ce, Nd and Y in igneous rocks is "ten times higher than that
of the other elements of the rare-earth group", and that
determination of these elements could be made without
preliminary enrichment of the samples. He also indicated

that (Ce+Nd) showed a good linear correlation with total
Ce-earth content, whilst Y also correlated with total
Y-earth content of igneous rocks.

In this study La, Ce, Nd and Y were determined in a
series of rocks from carbonatitic centres in Western Kenya
and Eastern Uganda, in order to obtain information concerning
the concentration and fractionation of the rare-earth elements
and Y in carbonatites and related peralkaline rocks.

2.2 Choice of specimens for analysis.

Material was chosen for analysis from carbonatitic complexes
in Western Kenya (Homa Mountain, North Ruri, and Wasaki
centres), and Eastern Uganda (Tororo, Toror, Budeda and Napak).
Brief descriptions of each complex are given in Chapter 1, and
the location of each complex is shown in Figure 1.1.

Sampling of the carbonatites was based on the recognition
of a variety of carbonatite types in the W. Kenya complexes,
(Dixon, 1969; Flegg, 1969). Several samples of each carbonatite
type were selected for analysis from each complex.

Mineralogical analysis of the ijolitic rocks was carried
out using thin section and X-ray diffraction techniques
described in Chapter 1. A range of rocks from pyroxenite,
ijolite, melanite-ijolite, urtite, feldspathic-ijolite, to
nepheline-syenite were classified in this way, and several
samples of each of these rock types were selected for analysis
where possible, from all complexes under study.

2.3 Method of analysis.

Specimens chosen for analysis were cleaned of weathered
material, and brought down to approximately 5mm rock chips
with a rock slicer. The carbonatites were then crushed to
-200 mesh in a steel Tema mill, and the silicate rocks
crushed in a percussion mortar to pass through a 200 mesh
sieve.

The powders were thoroughly mixed, and then pelletised
at 15 tons pressure using cellulose backing. Master standard
powders were made up for carbonatites and silicate rocks by
spiking carbonatite and ijolite base with oxides of the

F I G U R E   2 . 1   (a) - (d).

Analyses below the detection limit for each element, and analyses which were above the upper limit of sensitivity for each element, are not shown in Fig. 2.1 (a) - (d).

The number of such analyses, for each element are shown below.

	Ce		La		Y
	<50ppm	>8000ppm	<35ppm	>6000ppm	<50ppm
Sovite	-	-	-	-	8
Alvikite	-	-	-	-	1
Ferruginous alvikite	-	4	-	2	-

fig.2.1b.

fig.2.1a.

fig.2.1d.

fig.2.1c.

KEY.

Sovite

Alvikite

Ferruginous
alvikite

PPM Lanthanum

PPM Cerium

PPM Yttrium

PPM Neodymium
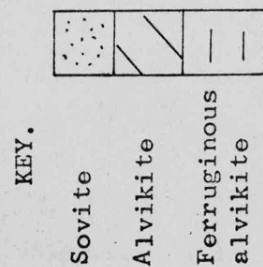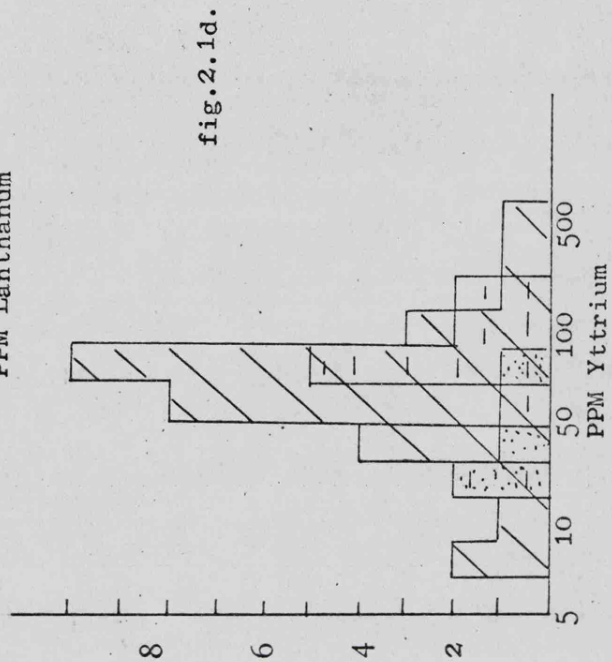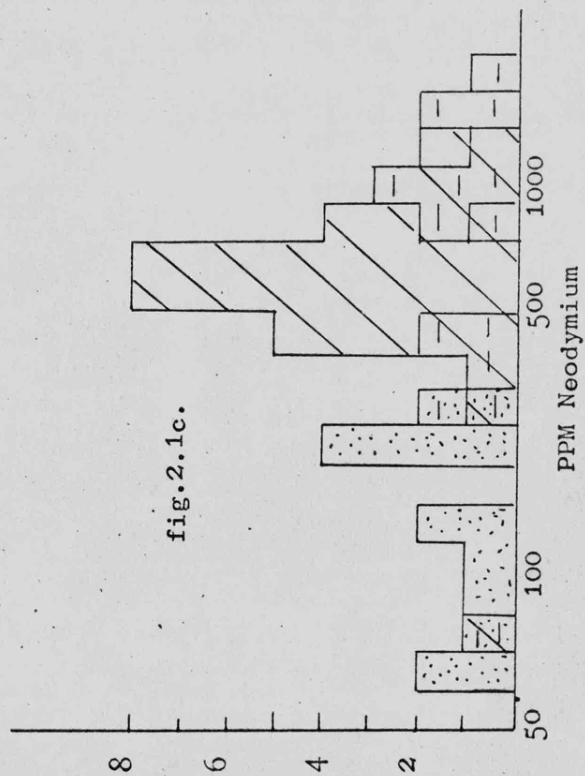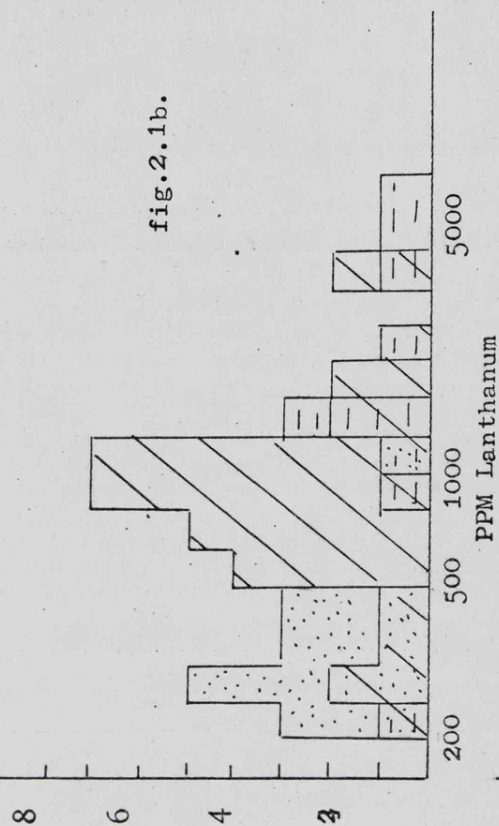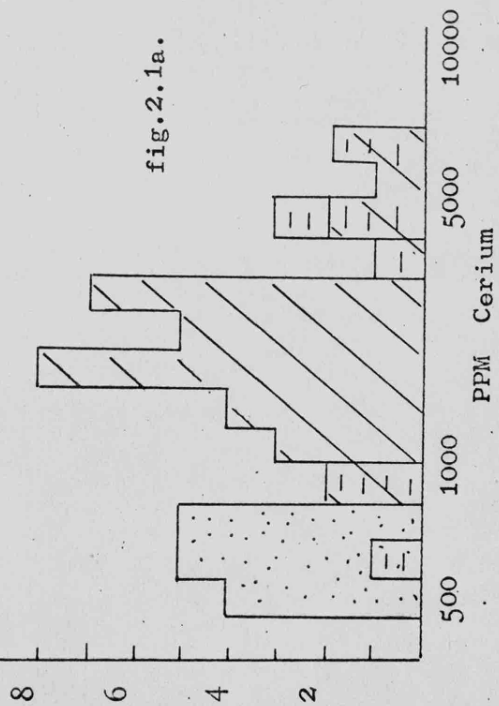
elements to be analysed, giving 10,000ppm of each added element. A series of standards were produced from the master standards by logarithmic dilution with the appropriate base. The standards were pelleted with the samples.

Analyses were carried out using a Siemens Krystalloflex 4 X-ray fluorescence spectrometer, employing Cr and W target elements, LiF 2.0.0. analysing crystal, and gas flow and scintillation counters. Pulse height analysis was used to minimise the effect of interfering radiation.

During the analysis, all standards were run each day, and the 5000ppm standard run every 3-4 samples to calibrate the instrument and to correct for instrumental drift during analysis. Calibration graphs for each element were constructed after correction for the amount of each element in the original base. The concentrations of each element in the samples were read off from the calibration graphs, and then corrected for mass absorption using major element analyses of each sample and standard obtained previously (Chapters 3 and 4, this thesis). The corrected results are given in Appendix Table 3 (a); 4 (c) to 6 (c), along with other trace and minor element data for the carbonatites, instrusive silicate rocks, phonolitic rocks, and fenites respectively.

2.4 Discussion of results.

(a) The distribution of La, Ce, Nd, and Y in the analysed carbonatites, carbonatitic breccias, and feldspathic rocks with carbonatites.

Frequency histograms, plotted on a logarithmic scale for each element and each carbonatite group are shown in Figures 2.1(a) - 2.1(d). The distribution of each element can be seen to approach lognormality. Geometric means and ranges of concentration of Ce, La, Nd and Y in the carbonatite groups are given in Table 2.1 below.

	Ce	La	Nd	Y	N
Sovite					
Mean	560ppm	330ppm	145ppm	-	14
Range	70-2500ppm	125-1000ppm	12-920ppm	<5-110ppm	14
Alvikite					
Mean	1830ppm	730ppm	470ppm	34ppm	33
Range	808-6856ppm	250-3578ppm	17-2000ppm	<15-600ppm	33
Ferruginous Alvikite					
Mean	-	-	760ppm	89ppm	14
Range	598-10000ppm	17-6000ppm	78-2450ppm	22-210ppm	14
Melilite Pseudomorph carbonatite.					
Mean	2860ppm	2530ppm	566ppm	101ppm	3
Range	1479-4595ppm	1530-3535ppm	520-590ppm	78-130ppm	3
Carbonatitic Breccias.					
Mean	198ppm			46ppm	3
Range	125-500ppm	35-590ppm	50-350ppm	25-100ppm	3

Table 2.1. Geometric means and ranges of concentration of Ce, La, Nd and Y in carbonatitic rocks. N = number of analyses.

The carbonatites and carbonatitic breccias are enriched in Ce-earth elements (La, Ce and Nd) and show a relative lack of Y-earths, (Y and Dy). A general increase in the concentration of Ce, La, Nd, and Y in sovite to alvikite to ferruginous alvikite, corresponds with the order of emplacement of the various carbonatites at the various complexes studied. This is in agreement with other geochemical data concerning carbonatitic rocks (Vainshtein et al 1961; van Wambeke, 1964), and would appear to show that in general, later intruded carbonatites are characteristically enriched in the rare-earth elements.

A 'students -t Test' carried out on the data for Ce, La, Nd, and Y in the sovites and alvikites, showed that the differences in the concentrations of these elements
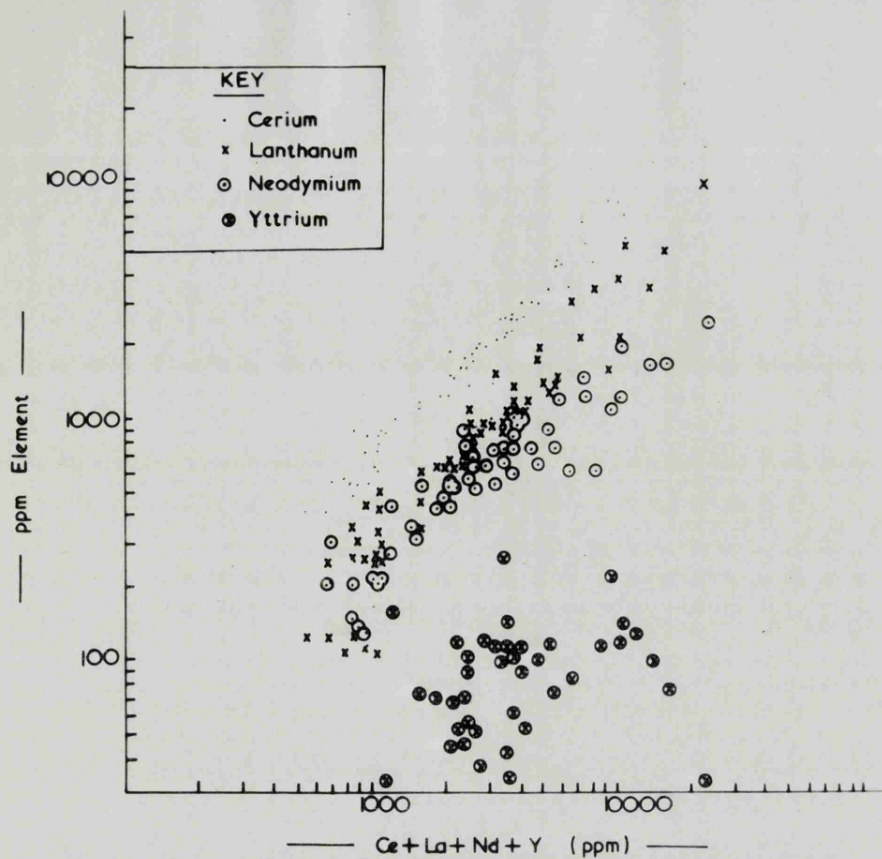
Fig. 2.2 Variation of Ce, La, Nd, and Y with Total Rare-Earth element content, expressed as Ce + La + Nd + Y, in carbonatites from W. Kenya and E. Uganda.
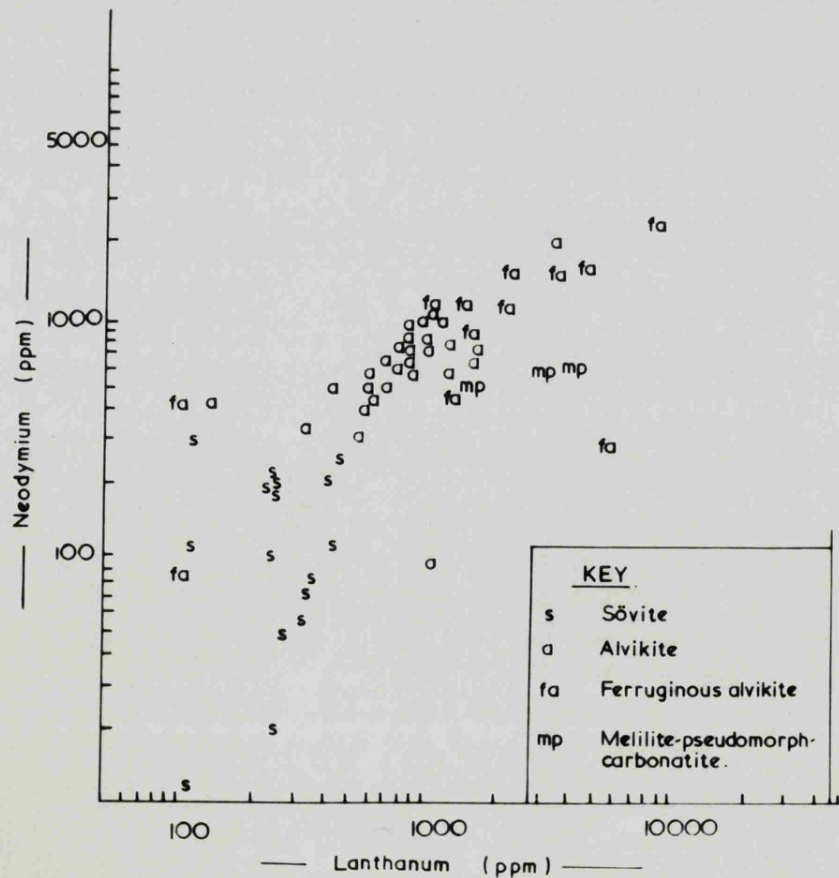
Fig. 2·3 Graph of Lanthanum and Neodymium concentrations in carbonatites from W. Kenya and E. Uganda.

in the two carbonatitic groups was statistically highly
significant. Thus the rare-earth elements are consistently
more concentrated in the alvikites than in the sovites at
all complexes considered in this study. These differences
confirm the field observations that the two types of
carbonatite occur as different types of intrusion, and are
generally distinct petrographically.

On the other hand, the alvikites, which show all
gradations from one type to another petrographically
(Flegg, 1969), also occasionally show high concentrations
of the rare-earth elements, typical of the ferruginous
alvikites. This would indicate a closer relationship
between alvikite and ferruginous alvikite, than between
sovite and either of the other two carbonatite groups.

Both the carbonatitic breccias, and the melilite-
pseudomorph carbonatites are Ce-earth enriched, which
indicates their carbonatitic affinity, whilst the latter
are enriched in La, Ce and Nd, a factor which emphasises
the late intrusion of these rocks, (Flegg, 1969).

Comparison of the distributions of the rare-earth
elements and Y in the carbonatites also reveals slight
relative variation of each indiuidual element with
increasing concentration of the rare-earth elements
(Fig. 2.2). An increase in the concentration of (total)
rare-earth elements correlates well with La, Ce and to a
lesser extent Nd, but shows little relationship with Y.
Variation in the relative concentrations ofLa, Ce, Nd
and Y are more pronounced for the samples with the greatest
concentrations of these elements. Vlasov (1966), stated
that an increase in the Ce/Nd ratio amounted to an increase
in concentration of the Ce-earth elements. Similarly, the
La/Nd ratio should also show such a trent, and a plot of
La against Nd for the carbonatitic rocks should describe
variation to Ce-earth (or conversely Y-earth) enrichment
within the carbonatites. Figure 2.3 shows such a variation
in the samples of carbonatite from W. Kenya and E.Uganda.

The sovites are seen to show a range of La and Nd
concentrations, but with an increase in the concentration
of these elements, and relatively greater increase in the
concentration of Nd, these rocks trend towards the
alvikites, which are relatively Nd-enriched (Y-earth
enriched) compared to the sovitic rocks.

The rarer melilite-pseudomorph carbonatites contrast
with the majority of the alvikites, showing a greater
concentration of La relative to Nd than the alvikites.
This La enrichment is also shown by the most ferruginous
alvikites, and those alvikites with abundant rare-earth
elements.

Thus although the carbonatitic rocks are enriched in
Ce-earth elements overall, the alvikites are relatively
enriched in Nd (Y-earths) compared to the sovites, whilst
those carbonatites containing the greatest amounts of
rare-earth elements are relatively La (Ce-earth) enriched
compared to the alvikites. This contrasts with the
overall Ce-earth enrichment of later intruded carbonatites
noted for the Kaiserstuhl complex, (van Wambeke,1964).

(b)   The relationship between rare-earth element
        distribution and mineralogy of the carbonatites.

The rare-earth elements in the sovites and alvikites are
generally found to be dispersed in the calcium minerals
calcite, apatite and pyrochlore. Several crystals of these
minerals were analysed for Ce and La using an electron
microprobe, in order to investigate the concentration of
these elements in the different minerals of carbonatites.

Method of Analysis.

Polished thin sections of several sovites, alvikites
and ferruginous alvikites were prepared, and suitable grains
of calcite, apatite, and pyrochlore were located and marked
for analysis. Each section was coated with gold and mounted
in an A.E.I. SEM2 electron microprobe. Zone refined rare-
earth fluoride crystals were used as standards. Corrections

for mass absorption, atomic number correction and
instrument drift were made. The results are given in
Appendix Table 8 (b).

Despite the relatively large errors of analysis,
significant differences in the concentration of Ce and
La in the different minerals, and in the same mineral
from different rocks can be seen.

Pyrochlore contains the most Ce and La, calcite
contains the least, whilst apatite contains intermediate
amounts of these elements. This relationship has been
noted for other carbonatitic rocks (Balashov and Pozharitskaya,
1968; Kapustin, 1966; van Wambeke, 1964).

Also in Table 8 (b) it is interesting to note that the
calcite from sovite contained less Ce than calcite from
alvikite and ferruginous alvikite, a fact which would
account for the greater concentration of the rare-earth
elements in the alvikites. Apatite contained greater
concentrations of Ce in the later alvikites. The abundant
rare-earth elements in the later ferruginous alvikites and
some late alvikites were attributed to the presence of
rare-earth minerals in these rocks. The presence of such
a mineral was suspected but not recognisable in thin
section of specimen HC258. Monazite $(CePO_4)$ was located
in the rock using the electron microprobe X-ray line scan
image. The mineral showed as small bleb-like crystals in
barite, and appeared as brownish coloured crystals in thin
section, easily mistaken for limonite. An analysis of the
monazite is given in Appendix Table 8 (b).

Thus the alvikites are enriched in rare-earth elements
relative to the sovite due to the increased concentration
of rare-earth elements in calcite and to a lesser extent
apatite of the alvikites. The ferruginous alvikites, and
some later alvikites are enriched in Ce-earth elements
predominantly due to the presence of rare-earth minerals
(containing predominantly Ce-earth elements) in these rocks.

(c) Discussion.

The abundance of the REE in all carbonatites, and the
increasing concentration of these elements coinciding with
the order of emplacement of the various carbonatites at the
complexes studied, suggests that the carbonatite types are
genetically related.

The absence of rock types with REE contents intermediate
between those of sovite and alvikite, and the Nd (Y-earth)
enrichment of the majority of the alvikites relative to the
sovites distinguishes the two rock types geochemically.

The Nd enrichment of the alvikites must represent a
Y-earth enrichment of at least some of the Ca-minerals within
the alvikites. Apatite and pyrochlore rarely exceeded 1% in
the analysed carbonatites, and it would thus appear likely that
these minerals do not contribute to any great extent to the
Y-earth enrichment. Calcite, however, is found in all the
rocks in abundance, and variation in the REE content of this
mineral would greatly affect the REE content of the whole rock.

In order to show the observed relationships in REE
composition, the alvikitic calcite would have to be enriched
in Y-earth elements compared to the sovitic calcite. Such a
situation has been shown to occur in early and late calcite
from W. and E. Siberian carbonatites (Balashov and Pozharitskaya,
1968). The later calcite, as in the samples from W.Kenya also
showed a greater enrichment in the REE compared with the
earlier calcites.

The geochemical differences in REE contents of the sovites
and alvikites would thus be due to the greater concentration
of these elements in the calcite of the alvikites and Y-earth
enrichment of this mineral in the alvikites compared to
calcite in the sovitic rocks.

It is difficult to reconcile this relationship with the
most obvious origin for the alvikites, in being fractionation
products of carbonatitic liquids which initially crystallised
sovite. It is merely apparent that liquids from which the

alvikites crystallised were more enriched in the rare-earth
elements than liquids from which sovites crystallised.

The Ce-earth enrichment of the majority of the ferruginous
alvikites, and some alvikites is undoubtedly due to the
concentration of predominantly Ce-earth elements in rare-
earth minerals monazite and bastnaesite in these rocks
(see Chapter 1). The highly selective Ce-earth composition
of such minerals has been noted elsewhere, (Khomyakov,1964).

The abnormally high concentrations of REE in these rocks
suggests that the rare-earth minerals are not derived from
earlier Ca minerals but that fluids from which these rocks
crystallised were greatly enriched in REE.

Several of the ferruginous alvikites were found to show
evidence of a "hydrothermal origin", (Flegg, 1969), in
containing banded fluorite, which led this author to the
conclusion that late hydrous alkaline fluids from carbonatitic
liquids were important in the formation of the later intruded
ferruginous alvikites. Kuellmer, Visocky and Tuttle (1966)
indicated the possibility of producing all gradations between
such solutions and carbonatitic liquids by adding alkalis to
compositions in the synthetic system calcite-barite-fluorite-
H_2O. The importance of alkali ions, and carbonate ions in the
transportation of REE in hydrous solutions has been stressed
in the literature (Sinkova and Turanskaya 1968)and has been
suggested as a means of transport of REE in carbonatitic
fluids by Kapustin (1966).

It would thus seem probable that the hydrous residual
carbonatitic liquids were enriched in the REE, and on cooling
precipitated rare-earth minerals. Such fluids would allow
these elements a certain mobility, and would account for the
veins of rare-earth mineral bearing ferruginous alvikite.
It is also conceivable that such fluids trapped in the
interstices of intruded semi-solid carbonatite, would on
cooling, produce similar mineralogy to that found in the
late veins. Heinrich (1966, p.174) noted that not

FIGURE 2 . 4.

Analyses below the detection limit for each element
are not shown in Fig. 2.4.

The number of analyses, for each element in each rock,
which were below the detection limit are shown below.

	La <35ppm	Ce <50ppm	Y <5ppm
Pyroxenite	2	3	7
Ijolite	1	-	1
Urtite	-	4	5
Nepheline- syenite	-	2	1
Phonolite	3	2	1
Fenite	-	2	2

KEY

- ijolite, feldspathic ijolite, melanite ijolite
- pyroxenite
- urtite
- nepheline-syenite
- "phonolite"
- fenite
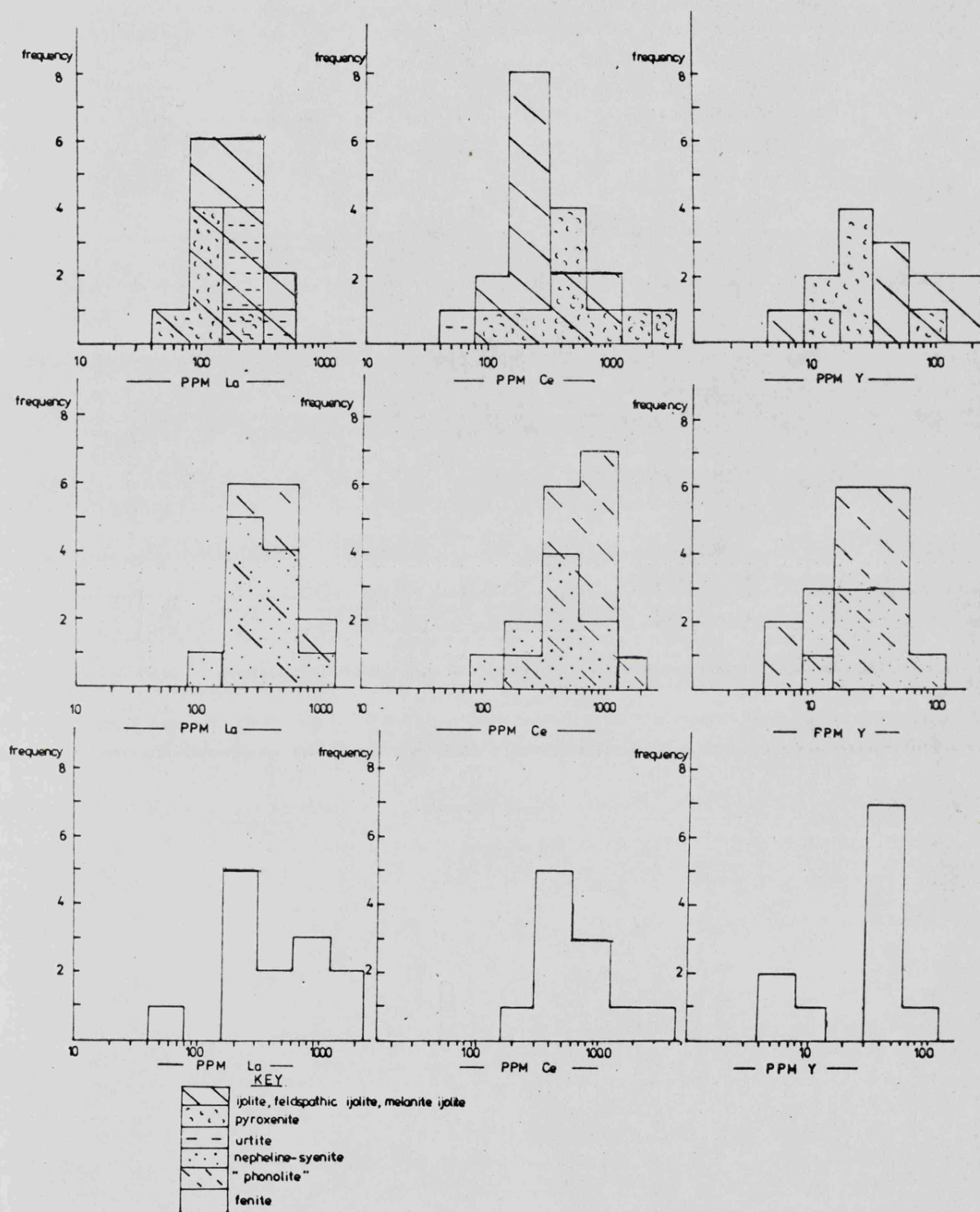
Fig. 2.4. Frequency histograms for Ce, La, and Y in peralkaline silicate rocks and fenites from carbonatitic complexes in W. Kenya and E. Uganda.

uncommonly rare-earth carbonates appear in vuggy carbonatite, in part as minute platelets attached to the vug cavity walls. Similar drusy cavities containing rare earth minerals were recorded from Tundulu and Chilwa carbonatites (Campbell Smith, 1953).

2.5   (a)   The distribution of Ce, La and Nd and Y in the silicate rocks of carbonatite complexes of Western Kenya and Eastern Uganda.

The concentrations of Ce, La and Y in the ijolitic rocks, nepheline-syenites, phonolites and fenites from carbonatitic complexes in Western Kenya and Eastern Uganda are shown in Figure 2.4, as frequency histograms plotted on a logarithmic scale.

Comparing the distribution of each element in the three major rock groups it is apparent that the ijolitic rocks contain generally lower concentrations of these elements than the nepheline-syenites and phonolitic rocks. The fenites, however, contain generally greater concentrations of Ce, La and Y than the magmatic rocks. All the silicate rocks, as in the carbonatites, are Ce-earth enriched.

Large variations in concentration of all three elements, however, are apparent within each petrographic group, (Table 2.2 and Figure 2.4).

In order to analyse the variation within each rock group it became necessary to further subdivide the silicate rocks. The ijolitic rocks were subdivided using semi-quantitative X-ray diffraction techniques, into pyroxenite, urtite, ijolite, melanite ijolite, feldspathic ijolite, and feldspathic microijolite. The phonolitic rocks were analysed mineralogically using thin section and X-ray diffraction techniques and subdivided into melanephelinite, nephelinite, phonolitic nephelinite, and analcime - and cancrinite-phonolite groups. The ranges of concentration of La, Ce and Y in these rock types, nepheline syenites and fenites are shown in Table 2.2 below.

Rock Type	Lanthanum Range	Cerium Range	Yttrium Range	N
Pyroxenite	<35-800ppm	130-3500ppm	<5-77ppm	6
Ijolite	135-250ppm	< 50-370ppm	<5-14ppm	3
Melanite ijolite	<30-200ppm	< 50-900ppm	<5-147ppm	7
Feldspathic ijolite	45-110ppm	500-580ppm	<5-32ppm	3
Urtite	180-330ppm	< 50-80ppm	< 5ppm	5
Nepheline syenite	80-1000ppm	< 50-1100ppm	<5-80ppm	11
Melanephelinite	<35ppm	350-580ppm	<3-25ppm	3
Nephelinite	240-500ppm	300-1100ppm	7-45ppm	3
Phonolitic nephelinite	155-500ppm	600-1100ppm	9-38ppm	4
Analcime-phonolite	300-700ppm	< 50-1300ppm	7-270ppm	7
Cancrinite-phonolite	300ppm	< 50ppm	19ppm	1
Syenitic fenite with nepheline	350-450ppm	< 50ppm	< 5-40ppm	2
Syenitic fenite	50-1350ppm	<50-930ppm	< 5-57ppm	7
Regional fenite	170-1600ppm	880-2700ppm	< 5-65ppm	5

Table 2.2. Ranges of concentration of La, Ce, and Y in peralkaline silicate rocks and fenites of W. Kenya and E.Uganda.
N = number of analyses.

In the peralkaline intrusive rocks, Ce, La, and Y are more abundant generally in the nepheline-syenites, whilst La is consistently more abundant in urtite than Ce and Y. The melanite ijolites are notably enriched in Yttrium relative to the other rocks. In general, Ce > La >> Y
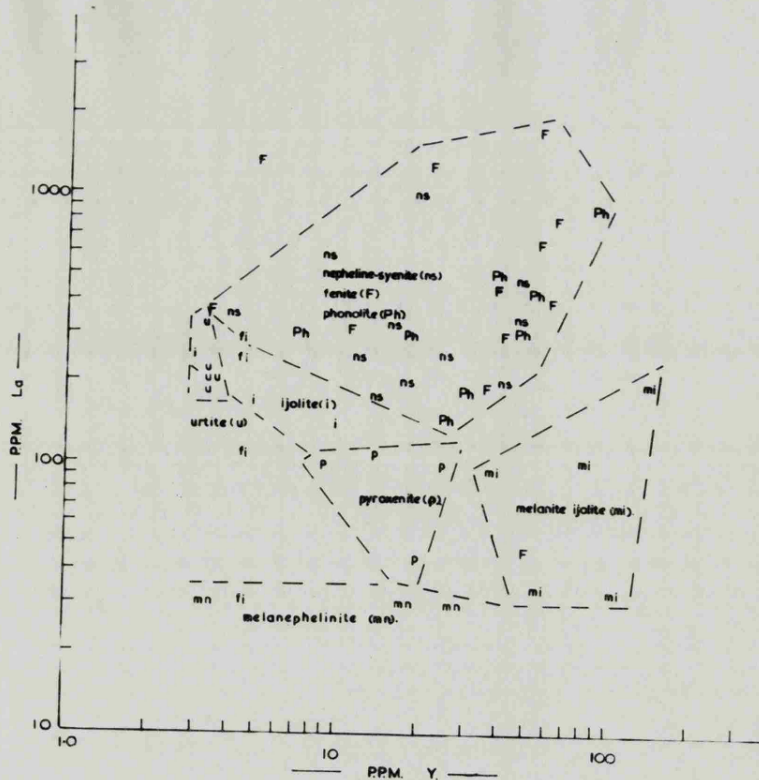
Fig. 2.5. Variation of La and Y in peralkaline silicate rocks and fenites from carbonatitic complexes in W. Kenya and E. Uganda.

Key

a	alvikite.
s	sövite.
fa	ferruginous alvikite.
mp	melilite-pseudomorph carbonatite.
i	ijolite.
mi	melanite ijolite.
fi	feldspathic ijolite.
ns	nepheline syenite.
ph	phonolitic rocks.
mn	melanephelinite.
u	urtite.
p	pyroxenite.
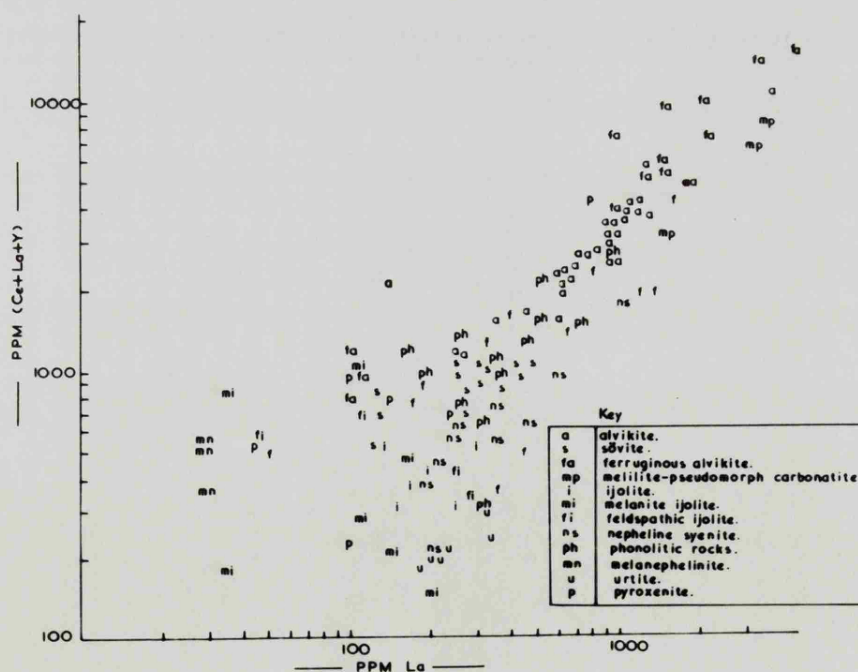
Fig. 2.6. Plot of approximate total rare-earth concentration expressed as (Ce+La+Y) against La for carbonatites and associated silicate rocks from W. Kenya and E. Uganda.

except in the nepheline-syenites where La tends to exceed the concentration of ^{C}e, with again Y being subordinate.

Amongst the fine grained peralkaline rocks, the melanephelinites contain the least Ce, La and Y, and the analcime phonolites contain the greatest concentrations of these elements.

The fenites contain greater concentrations of these elements in the regional fenites, although all fenites contain greater concentrations of La, Ce and Y than unfenitised basement.

Variation in concentration of the rare-earth elements is shown graphically in Figure 2.5, where La and Y have been plotted for all silicate rocks. These two elements, generally found to be detectable in the silicate rocks of the carbonatite complexes, were taken as being representative of relative enrichment in cerium - or yttrium-earth elements, (Aleksiyev, 1966).

Three general observations can be made from Figure 2.5, namely the cerium-earth enrichment (in La especially) of the urtites, the pronounced Y-earth enrichment of the melanite ijolites, and the increase in concentration of both La and Y in the fenites, phonolites and nepheline-syenites.

(b) The relationship between the mineralogy of the silicate rocks and the concentration of Ce, La and Y.

A survey of the literature reveals that rare-earth minerals are seldom found in peralkaline silicate rocks and fenites. Heinrich and Deane, (1962) however, noted a rare case of bastnaesite from fenite at Seal Lake whilst Parsons, (1957), noted the presence of rare-earth minerals in fenite associated with carbonatisation at Nemegosenda Lake. No such minerals have been reported from the silicate rocks of carbonatite centres in Western Kenya and Eastern Uganda. More commonly the rare-earth elements are found as isomorphous impurities in Ca-rich minerals of the silicate rocks (Vlasov,1966 p.240; van Wambeke, 1964; Erikson and Blade, 1963). Quantitative

and semiquantative estimates of the mineralogy of the ijolitic rocks, phonolitic rocks and fenitic rocks (Appendix Table 2 (b) (i) - (iii)),showed that the Ca-rich minerals sphene, melanite, and pyroxene are abundant in some ijolites, whilst apatite is a ubiquitous accessory mineral in these rocks.

Several crystals of apatite from ijolite and nepheline-syenite and fenite were analysed for Ce and La using an A.E.I. SEM2 electron microprobe, in order to investigate the concentration of these elements in the intrusive silicate rocks and fenites. The same techniques were used in this case, as were used for apatites from carbonatites. The results, corrected for mass absorption and atomic number are given in Appendix Table 8 (b).

Despite the relatively large errors involved in the analysis, the concentration of Ce, and to a lesser extent La, are significantly higher in the apatite from nepheline-syenite than in apatite from ijolite. Fenitic apatite contained similar concentration of Ce and La to that of the nepheline-syenite, except for the slightly fenitised granite which contained relatively low concentrations of both elements.

Thus, the increased concentrations of rare-earth elements in nepheline-syenite and syenitic fenite are reflected in increased concentrations of Ce and La in the apatite of these rocks.

Khomyakov (1963) stated that both garnet and sphene had a greater capacity for the uptake of Y-earth elements than Ce-earth elements. Analyses of garnet and sphene from Magnet Cove, Arkansas,(Erikson and Blade, 1963) would support this statement.

The melanite ijolites and sphene rich rocks from W.Kenya and E. Uganda are more enriched in Y relative to La than any other ijolitic rock (Figure 2.5), although the concentration of Y does not exceed that of Ce, in these rocks. This would suggest that Y is concentrated to a

large extent in garnet and sphene, although the Y-earth
enrichment of these minerals is limited by the Ce-earth
enriched environment in which the minerals formed.

The presence of Ca-rich minerals sphene, perovskite
and apatite in the phonolitic rocks was also noted,
(Appendix Table 2 (b) (iii)). Analyses of sphene and
perovskite from peralkaline lavas from East Africa (Smith,
1970), showed both sphene and perovskite to contain abundant
rare-earth elements, perovskite more so than sphene.

(c)   Evidence for the derivation of the peralkaline rocks
      and fenites.

The analyses for Ce, La and Y in the peralkaline silicate
rocks and fenites show three divergent trends, all of which
are found in the intrusive rocks (plutonic series), whilst
only one such trend is shown by the volcanic (phonolitic rock)
series, (Figure 2.5).

Two opposing trends are found in the intrusive series, namely
the Y-earth enrichment of the melanite ijolites, and the La
enrichment of the urtites and ijolites relative to the
pyroxenites. The concentration of Y in the melanite ijolites
is undoubtedly related to the concentration of this element
in the abundant melanite garnet in these rocks.

The La enrichment of the more leucocratic urtites and
ijolites compared to the melanocratic pyroxenites in relation
to the mineralogy of these rocks is not immediately apparent.
However, the position of the ijolitic rocks intermediate between
the La-rich urtites and more Y enriched pyroxenites suggests a
relationship between La enrichment and increasing leococratic
mineral content in the ijolitic rocks, (Figure 2.5).

The plutonic nepheline-syenites display a third trend,
that of increasing concentration of both La and Y relative
to concentration of these elements in ijolite. This increase
in concentration compares well with the rare-earth distribution
in the syenitic fenites. The similarity of the rare-earth

distribution between these two rock types emphasises the relationship between nepheline-syenite and syenitic fenite noted from field and petrographic study, (King and Sutherland, 1966).

The greater concentration of rare-earth elements in fenitic rocks compared to unfenitised basement rocks indicates that these elements are introduced into country rock by fenitising solutions. The abundant alkali and carbonate ions in the peralkaline liquids would undoubtedly aid migration of the rare-earths as complex ions in fenitising solutions emanating from peralkaline liquids, (Kapustin,1967; Sinkova and Turanskaya, 1968).

The Phonolitic rocks, particularly the analcime-phonolites, contain greater concentrations of both La and Y compared to the melanephelinitic rocks. King and Sutherland (1966) considered the phonolitic rocks to have formed by crystallisation differentiation of nephelinitic magma in E. Uganda. The low concentration of rare-earth elements in the minerals pyroxene, nepheline, feldspar, olivine and iron ore minerals (Erikson and Blade, 1963) which crystallised from nephelinitic liquids, would concentrate the rare-earths in later residual liquids. The concentration of these elements in the later analcime phonolites would support the derivation of these rocks by fractionational crystallisation of nephelinitic liquids.

2.6   The relationship between rare-earth distribution in
        carbonatites and in their associated silicate rocks.

The relationship between the carbonatites and their associated silicate rocks has been discussed at length in the literature, and remains controversial.

From the distribution of the rare-earth elements in the peralkaline rocks and carbonatites, shown graphically in Figure 2.6, several points emerge.

1. The cerium-earth enrichment of the ijolite rocks, phonolitic rocks and fenite rocks, emphasises a genetic

relationship between these rocks and carbonatites.

2. These elements are on the whole more concentrated in the carbonatites than in the associated silicate rocks at most complexes, (Vainshtein et al., 1961; van Wambeke, 1966; Balashov and Pozharitskaya, 1968). This to a large extent reflects the greater scope for isomorphic replacement of Ca by the rare-earth elements in carbonatites (see Figure 2.6).

3. The concentration of the rare-earth elements in the later carbonatites greatly exceeds that in any of the silicate rocks analysed (Figure 2.6), and represents the termination ~~culmination~~ of igneous activity at the various complexes.

4. The distribution of the rare-earth elements in peralkaline silicate rocks and carbonatites is in part a function of the chemical properties of these elements, in that they are retained in the liquid throughout much of the sequence of crystallisation of silicate and carbonate liquids.

Migration of the rare-earth elements is thought to be due to the ability of these elements to form complex ions in hyrous alkali-carbonate rich fluids. The presence of such complexes in solution is thought to have been important in the migration of the elements in fenitising solutions, and in the final "hydrothermal" carbonatitic stage.

5. The rare-earth elements are present in Ca-bearing minerals as isomorphic impurities. The nature of the Ca lattice site in the mineral has a definite effect on the composition of the rare-earth elements incorporated in the mineral. Garnet, sphene, and calcite were shown to have a preference for Y-earth elements, whilst pyrochlore, apatite and the rare earth minerals preferred the Ce-earth elements, giving rise to variation in the concentration of individual rare-earth elements in the rocks with variation in mineralogy.

C H A P T E R   T H R E E.

The Distribution of some trace and minor elements in carbonatites and carbonatitic breccias from Western Kenya and Eastern Uganda.

3.1. Introduction.

This work is part of a geochemical investigation of carbonatites and related silicate rocks and involves the analysis of carbonatites from W. Kenya and E. Uganda for trace and minor elements.

Carbonatites and their associated rocks contain a characteristic assemblage of trace elements, which are often found in exceptional concentration, (Heinrich, 1966). The presence of large concentration of particularly Ba, Sr, Nb and Ce-earth elements is a characteristic of carbonatitic rocks in general. Pecora (1956) showed the concentration of these elements in carbonatites to be greater than in other igneous rocks. In addition to these "characteristic" elements of carbonatites, large concentration of copper, lead, zinc and other base metals are occasionally found as sulphides such as at Phalaborwa (Forster, 1958), S. Africa.

In this chapter, the distributions of Ba, Be, Bi, Cr, Cu, Co, Li, Mo, Ni, Pb,Sn, Sr, Ga, Ge, V, Zn, Zr, Mn (as MnO), Ti (as TiO_2) and Fe (as Fe_2O_3) were investigated in a number of carbonatites, carbonatitic breccias, and feldspathised country rocks.

The dsitributions of the rare-earth elements La, Ce and Nd, and Y in these rocks and related silicate rocks were discussed in Chapter 2.

3.2. Choice of specimens for analysis.

Samples were selected for analysis from existing

collections of peralkaline rocks and carbonatites at
Leicester University and Bedford College, London.
Specimens were chosen from the following carbonatitic
centres, (see Figure 1 (i), which are described briefly
in Chapter 1.

Western Kenya.

(i) Homa Mountain.

(ii) North Ruri.

(iii) Wasaki centres including Usaki and Sokolo.

Eastern Uganda.

(i) Budeda.

(ii) Tororo.

(iii) Toror.

(iv) Napak.

Representative samples of the main carbonatite types
exposed at each complex, were selected for analysis giving
a total range of carbonatitic rocks from early sovitic
carbonatite to late rare-earth bearing ferruginous carbonatite
from the varied complexes.

The carbonatites have been subdivided petrographically
into five main groups, namely, sovite, alvikite, ferruginous
alvikite, melilite-pseudomorph carbonatite and intrusive
carbonatitic breccia. A brief description of each petrographic
carbonatite group is given in Chapter 1, with particular
emphasis on the assemblage of accessory minerals in each group.
The mineralogy of each analysed rock sample, as determined
from thin section study, is given in Appendix Table 2 (a).

3.3 Method of analysis.

Rock powders used in this study were prepared by crushing
unweathered rock samples to minus-200-mesh, in a steel Tema
mill. Mineral samples were separated from a 60 to 150-mesh
fraction of crushed carbonatite rock by magnetic separation
techniques, and were finally purified by hand picking under
a binocular microscope.

The mineral extracts were crushed to minus-200 mesh in

an agate mortar.

All powders were dried at $110^{\circ}C$ before analysis.

Rock samples were analysed spectrometrically using an
A.R.L. 29000 Direct Reading Spectrometer. Lines were set
on this instrument for the determination of Ba, Be, Cr,
Ni, Pb, Nb, Sn, Sr, Bi, Ga,V, Ge, Zn, Zr in concentrations
up to 1000ppm approximately. In addition, lines set for
major elements Mn, Ti, Mg, Fe, Si, Al, and K allowed a
semiquantitative estimate of the concentration of these
elements in the carbonatites. Results of replicate analyses
on a carbonatite sample gave a relative error for determination
of trace and minor elements of generally better than 10%,
(see Appendix 1). In the case of major element analyses
for five elements (Fe, Mg, Mn, Ti, Al), the relative error
was generally better than 25%.

Calibration of the instrument during analysis was
obtained by analysing a series of synthetic standards,
which were prepared and run in the same way as the samples.
Due to the high carbonate content of the samples, each
sample and standard was diluted with specpure silica, to
avoid ejection of material from the electrode during arcing.
Sodium fluoride buffer, and carbon powder were added to the
sample/silica mixes in the ratio 1:2:2, and the whole was
thoroughly mixed before being packed into graphite electrodes
ready for analysis.

Details of the analytical procedures are given in
Appendix 1.

The samples of calcite were analysed in the same way as
the carbonatite using the same standards for calibration.

During the analysis of magnetite, pyroxene and mica,
instrument calibration was obtained using synthetic bases
corresponding approximately to the composition of each of
these minerals.

3.4 Results of analyses.

The results of the analyses for major elements, trace

F I G U R E   3 . 1   (a) to (m).

Analyses below the detection limit for each element, and those concentrations which were above the upper limit of sensitivity for each analysis, are not shown in Fig. 3.1 (a) to (m).

The number of analyses less than detection limit, and greater than the upper limit of sensitivity for each element in the various carbonatites are shown below.

| | Sovite | | Alvikite | | Ferruginous Alvikite | | Detection Limit | Upper Limit of sensitivity |
	<	>	<	>	<	>		
Nb	4	-	4	5	7	-	50 ppm	1000 ppm
MnO	-	-	-	4	-	9	0.1 %	3 %
Fe_2O_3	1	-	-	1	-	5	0.1 %	30 %
TiO_2	12	-	13	-	10	-	0.1 %	5 %
Zn	4	-	1	-	-	2	10 ppm	2000 ppm
Zr	4	-	7	-	6	-	10 ppm	1000 ppm
Li	-	-	7	-	5	-	10 ppm	1000 ppm
MgO	13	-	7	-	7	-	0.1 %	10 %
Mo	-	-	9	-	2	-	10 ppm	1000 ppm
Ba	-	-	-	1	-	10	10 ppm	40000 ppm

fig. 3.1a — frequency vs PPM Sr
fig. 3.1h. — frequency vs PPM Zn
fig. 3.1b. — frequency vs PPM Ba
fig. 3.1j. — frequency vs PPM Zr
fig. 3.1c. — frequency vs PPM Nb
fig. 3.1g. — frequency vs PPM V
fig. 3.1d. — frequency vs % MnO
fig. 3.1k. — frequency vs PPM Li
fig. 3.1e. — frequency vs wt. per cent Fe_2O_3
fig. 3.1m. — frequency vs wt. per cent MgO
fig. 3.1f. — frequency vs wt. per cent TiO_2
fig. 3.1l. — frequency vs PPM Mo
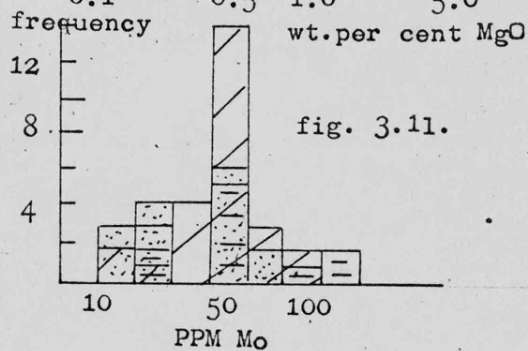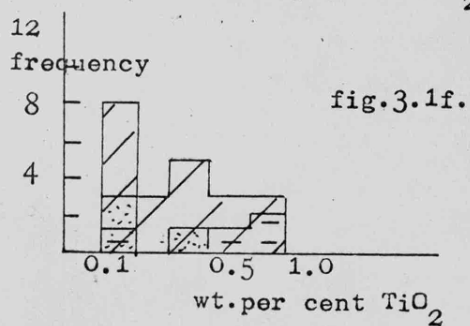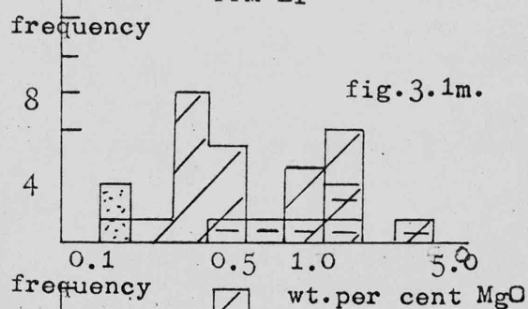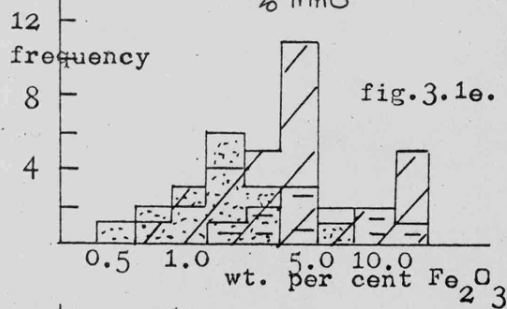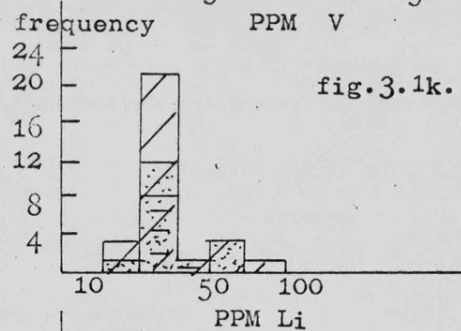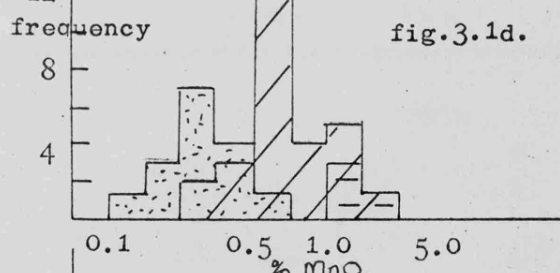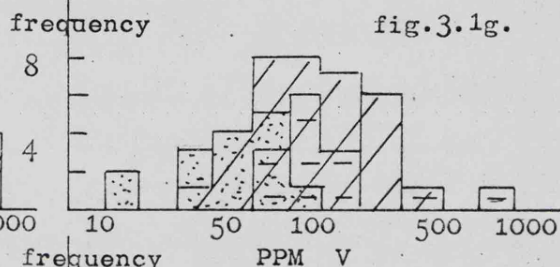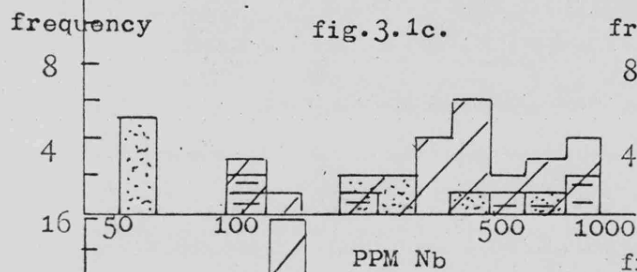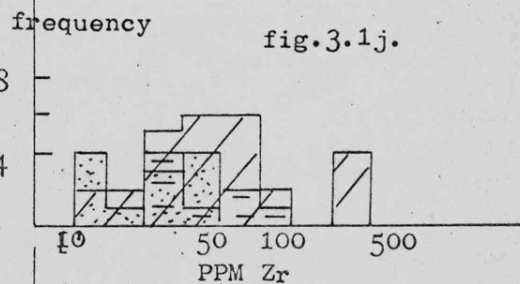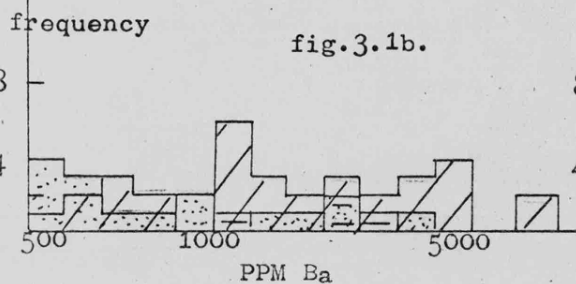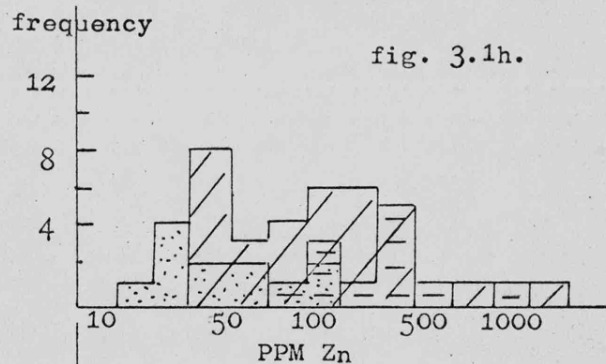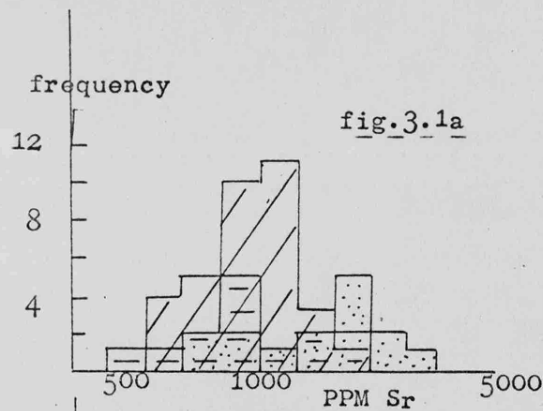
KEY.   Sovite   Alvikite   Ferruginous alvikite

and minor elements,and qualitative analysis of the
mineralogy of the carbonatites are given in Appendix Table
3 (a) and 2 (a) respectively.

The analyses of the minerals calcite, magnetite, and
pyroxene and mica are given in Appendix Tables 3 (b) (i) -
(iii) respectively.

3.5 Discussion.

(i) Strontium and Barium.

Both Sr and Ba are characteristic minor elements of
carbonatites and related rocks, (Heinrich, 1966, p.222).
The distribution of these elements in the sovites, alvikites,
and ferruginous alvikites from W. Kenya and E. Uganda are
shown in Figures 3.1 (a) and 3.1 (b). Geometric means and
ranges of concentration of Sr and Ba in the various
carbonatite groups are given in Table 3.1 below.

Rock Type	Strontium Mean	Strontium Range	Barium Mean	Barium Range
Sovite	1200ppm	70-2550ppm	620ppm	260-3280ppm
Alvikite	930ppm	545-1820ppm	+1850ppm	355->40000ppm
Ferruginous Alvikite	810ppm	230-1880ppm	-	1220->40000ppm
Melilite-pseudomorph carbonatite	661ppm	380-1175ppm	4510ppm	2480-7600ppm
Carbonatitic Breccia	297ppm	65-1015ppm	2130ppm	660-5360ppm

Table 3.1. Geometric means and ranges of concentration
of Sr and Ba in carbonatites and carbonatitic
breccias.

+ signifies that the mean is approximate due
to some analyses being above the upper limit
of sensitivity.

The sovites contain the lowest concentrations of Ba and

the highest concentrations of Sr in relation to all the
later carbonatites. The ratio Sr/Ba is thus highest
(generally greater than 1) in the sovites, and is least
in the Ba-enriched ferruginous alvikites. The trend of
increasing concentration of Ba and decreasing concentration
of Sr coincides with the order of emplacement of the various
carbonatites at most complexes.

Similar results were obtained for the Kaiserstuhl
carbonatites, which were notably enriched in Ba in the
later instrusive brown carbonatites (les carbonatite brunes),
whilst Sr was impoverished in these rocks. The Sr/Ba ratio
decreased from a maximum in sovite to a minimum in the late
dolomitic carbonatites, (van Wambeke, 1964). The Sr and Ba
content of the Alno carbonatites however showed the presence
of a Sr and Ba enriched sovite, and a sovite enriched in Ba
and impoverished in Sr, (von Eckermann, 1966).

The distributions of Sr and Ba in the carbonatites are
related in the main to the concentration of these elements
in the mineral calcite, and to a lesser extent apatite and
pyrochlore.

As shown in Appendix Table 3 (b) (i), Sr was found to be
more abundant in sovitic calcite than in the alvikitic
calcite, whilst Ba varied antipathetically to Sr and was
more abundant in the later alvikitic calcite. As in the
carbonatitic rocks the Sr/Ba ratio decreased from a
maximum in sovite and was least in the Ba-enriched
alvikitic calcite.

Small amounts of Ba and Sr were found in acmitic
pyroxene (Appendix Table 3 (b) (iii), whilst mica and
feldspar from carbonatite were notably enriched in Ba,
presumably substituting for K^+ in the lattices of the
potassium-rich feldspar and mica.

The large concentrations of Ba in the later
ferruginous alvikites were due to the presence of barite
in these rocks.

(ii) Niobium.

Although the distribution of Nb was found to be sporadic throughout the carbonatites, generally greater concentrations of this element were found in the alvikites, (Figure 3.1(c)). The variation in concentration of this element in the various carbonatite groups is shown in Table 3.2 below. The sovites are seen to contain the least Nb generally.

The variability in the Nb concentration is undoubtedly related to the sporadic occurence of pyrochlore $(CaNaNb_2O_6F)$ in the carbonatites. Pyrochlore was noted as being more abundant in the alvikites than in the other carbonatite groups, (Flegg, 1969), and was the only niobate reported from the carbonatites in W.Kenya and E.Uganda. Little Nb was found in the analysed minerals from the carbonatites, (See Appendix Table 3 (b)). Heinrich (1966) noted small amounts of this element in magnetite from carbonatite, whilst minor amounts were present in sphene, garnet, and aegirine. The presence of Nb in garnet has been noted in the ijolitic rocks from carbonatitic complexes (see Chapter 4, this study), and has been noted to occur in the minerals fersmite and columbite in carbonatites, although pyrochlore is by far the most abundant Nb-bearing mineral found in carbonatites, (Heinrich, 1966).

Niobium

Rock Type	Geometric mean	Range	No.Analyses
Sovite	69ppm	<50-700ppm	16
Alvikite	* 290ppm	<50-1000ppm	35
Ferruginous Alvikite	* 87ppm	<50-1000ppm	14
Melilite-pseudomorph carbonatite	698ppm	625-840ppm	3
Carbonatitic breccia	-	<50-480ppm	6

Table 3.2. The distribution of Nb in the analysed carbonatitic rocks of W. Kenya and E. Uganda.

* signifies that the mean is only approximate due to analyses being above the upper limit of sensitivity.

(iii) <u>Manganese and Iron.</u>

The distribution of Mn (as MnO) and Fe (as total Fe expressed as Fe_2O_3) in sovite, alvikite, and ferruginous alvikite, are shown (as frequency histograms plotted on a logarithmic scale) in Figures 3.1 (d) and 3.1 (e) respectively. Geometric means and ranges of concentration of MnO and Fe_2O_3 in the various carbonatite types are given in Table 3.3 below.

Mn is generally more abundant in the ferruginous alvikites, and least abundant in the sovites at the complexes studied. Fe_2O_3 shows a similar distribution to MnO, although the ferruginous alvikites show great variability in the content of Fe_2O_3. The carbonatitic breccias, thought to have been intruded with the alvikites, also contain large concentration of Fe_2O_3 relative to the sovites and alvikites.

Rock Type	MnO Mean	Range	Fe_2O_3 Mean	Range
Sovite	0.33%	0.1 - 0.8%	1.44%	0.1 - 6.7%
Alvikite	0.92%	0.33- 3.2%	* 5.01%	0.8- 30%
Ferruginous Alvikite	* 2.5%	1.6- 3%	* 8.5%	2.0- 30%
Melilite-pseudomorph carbonatite	0.76%	0.25- 2.0%	3.43%	3.1 - 3.6%
Carbonatitic breccia	0.86%	0.56- 2.32%	8.77%	5.6- 13.9%

<u>Table 3.3.</u> Geometric means and ranges of concentration of MnO and Fe_2O_3 in carbonatitic rocks from W. Kenya and E. Uganda.

* signifies that the mean is approximate due to analyses being above the upper limit of sensitivity.

Both Mn and Fe are present to a large extent in oxide minerals (magnetite, hematite, goethite) in the carbonatites.

Spectrometric analyses of magnetite (Appendix Table 3 (b)
(ii)) showed from 0.42-1.5% MnO in this mineral whilst
electron microprobe analyses of magnetite grains in
carbonatite showed 0.7-1.4% MnO. The unusually high
concentrations of MnO in the ferruginous alvikites could
not be traced to any mineral of Mn, and probably are
present in the abundant magnetite and hematite in these
rocks.

In addition to the abundant oxide minerals, iron was
found to be a major component of pyroxene (acmite) from
carbonatite, mica, and also present in orthoclase feldspar
(greater than 1%). Both Mn and Fe were present in
generally small amounts in the carbonate (calcite) minerals
of carbonatites. The earlier sovitic calcite contained
less Mn and Fe than the later alvikitic calcites, greater
concentration of Fe corresponding generally to greater
concentrations of Mn, (see Appendix Table 3 (b) (i)).

The large amount of iron found in the intrusive
carbonatitic breccias was present in the abundant iron
ore minerals magnetite, hematite and goethite in these
rocks. The source of the iron may stem from the breakdown
of, and feldspathisation of breccia fragments within these
intrusive bodies.

(iv) Titanium, Vanadium, Chromium, Cobalt, and Copper.

In Appendix Table 3 (a), and analyses of Cr, Co and Ni
are generally below the limit of detection for these
elements (generally less than 10ppm). Nickel and Chromium
were undetected in magnetite from carbonatite (Appendix
Table 3 (b) (iii), whilst small amounts of Co (5-35ppm),
and Cu (5-25ppm) were found in this mineral.

The concentrations of Titanium and Vanadium greatly
exceed those of Cr, Ni, Cu and Co in the carbonatitic rocks.
The distributions of these elements in sovite, alvikite,
and ferruginous alvikite are shown in Figures 3.1 (f) and
3.1 (g). Geometric means and ranges of concentration of

these elements in the various carbonatite groups are given
in Table 3.4 below.

Rock Type	TiO_2 Wt.%		Vanadium ppm.	
	Mean	Range	Mean	Range
Sovite	-	< 0.1 - 0.35%	40ppm	10 - 80ppm
Alvikite	-	< 0.1 - 0.96%	87ppm	30 - 450ppm
Ferruginous alvikite	-	< 0.1 - 0.8%	140ppm	60 - 940ppm
Melilite-pseudomorph carbonatites	-	-	82ppm	50-140ppm
Carbonatitic breccia	1.02%	0.4 - 1.9%	127ppm	70 - 180ppm

Table 3.4. Geometric means and ranges of concentration of
TiO_2 and Vanadium in carbonatites from W.Kenya
and E.Uganda.

Titanium was more consistently found in the alvikites than
in the other carbonatites proper. The intrusive carbonatitic
breccias, however, contained much greater concentrations of
TiO_2 than any of the carbonatites, which suggests that the
concentration of Ti in these rocks may, as with the iron, be
related to the breakdown of breccia fragments within the
intrusion. Vanadium is less concentrated in the carbonatitic
breccias, and shows a general increase in concentration from
sovite to alvikite to ferruginous alvikite, (Table 3.4 and
Figure 3.1 (g)).

Both these elements were found to be notably concentrated
in magnetite (Appendix Table 3 (b) (ii)), and (Appendix Table
8 (c)), whilst small blebs of ilmenite were found in magnetite
grains in some alvikites, using an electron microprobe. The
grains were unfortunately too small for analysis. Little
relationship between carbonatite group and concentration of
Ti and V in carbonatite rocks and minerals was found in the
data.

Titanium was found to be present as a major constituent of Pyrochlore (Appendix Table 8 (c)), varying from 3.99% to 6.53% TiO_2, and was also found in pyroxene (0.7 - 1.35% TiO_2) and mica (1.5 - 2.4% TiO_2), from carbonatites, (Appendix Table 3 (b) (iii)). Vanadium follows Titanium to a large extent in the carbonatitic minerals. Pyroxene was notably enriched in V (greater than 2000ppm), whilst mica from carbonatite contained from 480-1200ppm V.

(v) Zinc and Lead.

Zinc and Lead were found in greater concentration in the ferruginous alvikites than in the other carbonatites and carbonatitic breccias. The ranges of concentration of Lead, and ranges of concentration of Zinc in the carbonatites and breccias are given in Table 3.5 below. The distribution of Zn in the sovites, alvikites and ferruginous alvikites is shown in Figure 3.1 (h). Zinc is seen to increase in concentration from the sovites to the alvikites to the ferruginous alvikites, whilst Pb is more sporadically found in alvikites, rarely detectable in sovite, and shows greatest concentration in the ferruginous alvikites.

Rock Type	Zinc Range	Lead Range
Sovite	< 10-180ppm	<10-45ppm
Alvikite	< 10-2000ppm	<10-170ppm
Ferruginous Alvikite	110-2000ppm	20-460ppm
Melilite-pseudomorph carbonatite	115-240ppm	15-90ppm
Carbonatitic breccia	,110-255ppm	< 10-40ppm

Table 3.5. The distributions of Zinc and Lead in the carbonatitic rocks and carbonatitic intrusive breccias of W. Kenya and E. Uganda.

The concentration of Zn in the carbonatites is related predominantly to the presence of magnetite in the rocks. Analyses of magnetite from carbonatite showed from 780-1940ppm Zn, (Appendix Table 3 (b) (ii)). Small amounts of Zn were also found in calcite (Appendix Table 3 (b) (i)). Unusually high concentrations of both Zn and Pb in other carbonatites were associated with the occurence of sphalerite and galena, as late stage replacement veins and carbonatitic phases, (Heinrich, 1966, p.241). Few sulphide minerals have been reported from the carbonatites of W.Kenya and E. Uganda.

(vi) Zirconium.

Zirconium rarely exceeds 100ppm in the analysed carbonatites and carbonatitic breccias. The greatest concentrations of Zr are found in the alvikites, (Figure 3.1 (j)),whilst the sovites contain the least concentrations. The distribution of Zr in the various carbonatites and intrusive carbonatitic breccias are given in Table 3.6 below, as ranges of concentration within the petrographic groups.

Rock Type	Zirconium Range
Sovite	<10-50ppm
Alvikite	<10-240ppm
Ferruginous alvikite	<10-90ppm
Melilite-pseudomorph carbonatite	30-60ppm
Carbonatitic breccia	40-100ppm

Table 3.6. Ranges of concentration of Zr in carbonatites and carbonatitic breccias of W. Kenya and E. Uganda.

Analyses of carbonatitic pyrochlore presented in the literature show Zr to be present in this mineral in amounts

up to 4.6% ZrO_2, (van der Veen, 1963; van Wambeke, 1966).
The variability of the concentration of Zr in the
carbonatites will thus, like Nb, be related to the
sporadic occurence of pyrochlore. In addition, Zr was
found in minor concentration in pyroxene from carbonatite
(1450-2300ppm), and in much smaller concentration in
magnetite, (10-70ppm). Zr enriched pyroxene was noted
from carbonatite at Magnet Cove, Arkansas, (Erikson and
Blade, 1963).

No minerals containing Zr as a major element have been
reported in the carbonatites from W. Kenya or E. Uganda
complexes studied here. Baldock (1968), however, noted
calzirtite ($CaZr_3TiO_9$) from the Bukusu complex, E. Uganda,
and Zr has also been found in large amounts in zircon,
Zr-garnet (kimzeyite), baddeleyite and zirkelite from
carbonatite, (Heinrich, 1966, p.235).

(vii) Lithium and Molybdenum.

The distributions of Li and Mo are shown in Figures
3.1(k) and 3.1(l), in sovite, alvikite, and ferruginous
alvikite. Little variation is apparent between the
distributions of both elements between the carbonatite
types. However, unusual concentrations of Mo were found
in three ferruginous alvikites (100-680ppm). The tendency
for Mo to concentrate to late stages in carbonatitic rocks,
and to occur as molybdenite was noted by Heinrich, (1966,
p.241). Neither Mo or Li were found in appreciable
concentration in the analysed minerals from carbonatite.

(viii) Magnesium.

Magnesium is surprisingly low in all analysed
carbonatites, (Appendix, Table 3 (a)). The absence of
dolomitic carbonatites reflecting the pressure/temperature
conditions under which the carbonatites were formed.

Relatively small amounts of Mg were found in ankeritic
calcite (Appendix Table 3 (b) (i)), and also magnetite

(Appendix Table 3 (b) (ii)). Pyroxene and mica contained varying amounts of Mg.

(ix) Aluminium.

Alumina was undetected in most analysed carbonatites, which reflects the paucity of alumino-silicate minerals in the analysed carbonatites, (compare carbonatite mineralogy, Appendix Table 2 (a)). In the carbonatitic breccias, where breccia fragments and matrix have been feldspathised, the concentration of alumina is considerably more than in the carbonatites.

The ranges of concentration of alumina in the various carbonatites and carbonatitic breccias are given in Table 3.7 below.

Rock Type	Al_2O_3 Range
Sovite	0.1-0.95%
Alvikite	0.1-1.25%
Ferruginous Alvikite	0.1-0.7%
Melilite-pseudomorph carbonatite	0.1-0.15%
Carbonatitic breccia	5.35-10.2%

Table 3.7. Ranges of concentration of Al_2O_3 in carbonatites and carbonatitic breccias, from W. Kenya and E. Uganda.

3.6 **The distribution trace elements in feldspathised country rock adjacent to carbonatite instrusions.**

Analyses of several samples of feldspathised country rock from Homa Mountain and Toror and Napak are shown in Appendix Table 3 (c). All the rocks are enriched in Ba especially, and contain generally greater amounts of Zr, Nb, V, Zn, Pb, Ga, and Be compared with the sovitic rocks with which these are associated.

The rocks into which the carbonatites were intruded were varied, (Chapter 1), and must have varied in minor element content from place to place. The abundance of such elements as Ba, Zr, Nb, Ga, etc., in all feldspathised rocks would thus suggest that these minor elements have been introduced into the country rock by feldspathising solutions and/or carbonatitic fluids. The source of the feldspathising solutions must lie in the carbonatitic intrusions, and are probably derived from vapour phases, enriched in minor elements, emanating from crystallising carbonatite.

Analyses of feldspar from these rocks (Appendix Table 3 (c)),showed considerable concentrations of Ba, Ga, present in this metasomatic mineral, whilst Sr and Pb were also detected in this mineral.

The presence of pyrochlore and magnetite in these rocks emphasises the relationship with carbonatites, and account for the concentrations of Nb, and Zr (in pyrochlore), and Fe, Mn, Ti, V, and Zn (in magnetite). The small amounts of calcite introduced with these minerals would contain probably Sr, and some Ba.

3.7 Multivariate Statistical Analysis of trace and major element data in carbonatites and carbonatitic breccias.

General geochemical trends concerning series of intruded carbonatites have been described in the literature from a number of complexes, (e.g. Kaiserstuhl complex, (van Wambeke, 1964); Magnet Cove complex, Arkansas (Erikson and Blade,1963)). Similar trends have been noted for the complexes investigated in this study. In order to aid explanation of the variation in trace, minor and major element concentrations in the carbonatitic rocks, the data has been treated statistically, using product-moment correlation analysis, and principal factor analysis techniques. Data for the concentration of the rare-earth elements La, Ce, and Nd and Y (Chapter 2) in carbonatites have been included with the spectrometric

analyses of the carbonatites for the multivariate
statistical analysis, in order to represent the chemical
variation within the carbonatites more fully.

(i) Correlation analysis of carbonatitic data.

A Pearson product-moment correlation coefficient (r_{xy})
was computed for all possible pairs of elements represented
in the data, (see Harbaugh and Merriam, 1968, p.160).

The value of a correlation coefficient, r_{xy}, for two
variables (elements) x and y with mean values $\bar{x}$ and $\bar{y}$ for
a series of samples (total number N) is given by

$$r_{xy} = \frac{\sum_{i}^{N}(x - \bar{x})(y - \bar{y})}{(\sum_{i}^{N}(x - \bar{x})^2 \sum_{i}^{N}(y - \bar{y})^2 / N - 1)^{\frac{1}{2}}}$$

and will vary between 1 and -1.

This effectively gives a measure of linear variation
between two variables or elements. Values of r_{xy} close to
1 indicate a positive linear correlation between two
variables (the two elements vary sympathetically). Values
of r_{xy} close to -1 indicate negative linear correlation
(antipathetic behaviour between the two variables). A
correlation matrix is made up of values of r_{xy} for each
variable correlated with all other variables in the data.

The product moment correlation coefficient is used
ideally for data which is normally distributed. Ahrens
(1954, 1963a, b, c, 1964, 1966) has shown that geochemical
data is often distributed lognormally, although criticism
of this assumption has been noted (Butler, 1964). The
data for element concentrations in carbonatites would
seem to fit lognormal rather than normal distributions
(Figures 3.1a-1). In order to represent correlations
between the elements more ideally, the data was transformed
to logarithmic values before computation of the correlation
coeffients. The product moment correlation coeffient matrix
is reproduced in Appendix Table 9 (a).

The correlations between major elements, (as oxides) and

minor elements are summarised below in Table 3.8.

Variable	Correlated variables in order of significance.
Fe_2O_3	V, Zn, MnO, MgO, TiO_2.
MnO	Ce, Ba, Zn, Nd, La, Fe_2O_3
MgO	Fe_2O_3
TiO_2	Fe_2O_3
Ba	MnO, Ce, Zn.
Ce	La, Nd, MnO, Ba, Zn.
Li	Mo.
Mo.	Li.
Nb	Zr.
Nd	Ce, La, MnO.
Sr	-
V	Zn, Fe_2O_3
Zn	Fe_2O_3, MnO, V, Ba, Ce.
Y	-
Zr	Nb.

Table 3.8. Summary of Pearson product-moment correlation
coefficient matrix.

The lack of correlation between Ba and Sr in the
carbonatites, noted in the Alno carbonatite, Sweden (von
Eckermann 1952, 1966), is also a feature of the rocks from
W. Kenya and E. Uganda. Correlations between Nb and Zr;
Fe_2O_3 and V, Zn, MnO, MgO, TiO_2; and Ce, La and Nd are
related to the concentration of these elements and oxides
in pyrochlore, magnetite, and Ca and Ce-earth minerals
respectively.

The information expressed in a correlation matrix can
be made more understandable by further manipulation of the
co-efficients in procedures such as factor analysis, (Harbaugh
and Merriam, 1968, p.162), in which the contributions of
different coefficients are merged.

Principal components analysis is similar to factor
analysis, being a simpler procedure not based on an elaborate
set of assumptions involved in factor analysis (Wahlstedt
and Davis), 1968).

(ii) Principal Components analysis.

The mathematical background to principal components
analysis is treated fully in Morrison, 1967; Harman, 1960;
and Wahlstedt and Davis, 1968, and will not be dealt with
here.

The procedure consists of a series of operations on a
data matrix, in this case a product-moment correlation
matrix, shown in Appendix Table 9a.

From the correlation matrix, which represents
correlations between elements and oxides present in the
analytical data, a series of new variables or principal
components are computed, which account successively for
the most possible correlation in the matrix. Associated
with each principal component is an eigenvalue and a series
of eigenvectors. Each of the eigenvectors for each
principal component refers to one element or oxide in the
original data. The value of each principal component for
each sample is given by summing the product of the
eigenvectors and values of the elements or oxides to
which they refer, for each sample.

The contribution of each element to a given principal
component may be readily obtained by squaring the values
of the terms of each eigenvector for that component, and
dividing the individual terms by the total (Wahlstedt and
Davis, 1968). If only a few of the original elements or
oxides account for most of a principal component, that

component may be regarded as a combination of these (related) elements and oxides, ignoring the contribution of the other original variables.

The approximate percentage of the correlation accounted for by each principal component is given by dividing the eigenvalue for each component by the sum of all the eigenvalues. If the first few principal components account for an acceptable amount of the correlation, the remaining components may be discarded, thus reducing the problem in dimensionality.

The principal components thus give an indication of the variation of an association of related elements or oxides in the analysed carbonatite rocks.

The eigenvalues, eigenvectors, and percentage contribution of each eigenvalue to the total correlation are shown in Appendix Table 10 (a).

The distribution of eight principal components in the carbonatites, accounting for 90% of the correlation are shown graphically in Figures 3.2 as frequency histograms for sovite, alvikite and ferruginous alvikite carbonatites. The eigenvectors referring to each of the sixteen elements and oxides are shown in Table 3.9 for each of the eight principal components.

The first principal component, accounting for the most correlation, is a "general component", and is not related to any distinct group of elements. The carbonatite groups in Figure 3.2(a) are not distinguished by this component.

Components 2 and 3, however, show a gradual variation from sovite through alvikite to ferruginous alvikite, (Figure 3.2(b)). From Table 3.9, component 2 represents an association of Fe_2O_3, MnO, Ba and Zn (positive values) which are seen to increase from sovite to late ferruginous alvikite. Component 3 represents a bipolar association of Ce, La, Zn and V, (negative values of eigenvectors) and Sr (positive eigenvector values), which decreases in value from sovite to alvikite to

Figure 3.2 Eight principal components, obtained from Principal Components Analysis of carbonatite data for carbonatites from W Kenya and E Uganda.

	Fe$_2$O$_3$	MnO	TiO$_2$	MgO	Ba	Ce	Li	Mo	Nb	Nd	Sr	V	Y	Zn	Zr
1	-0.1236	-0.2207	-0.3145	-0.3450	-0.0864	-0.0507	-0.3054	-0.3690	-0.3263	-0.2641	-0.3023	-0.0289	-0.3160	-0.1709	-0.2758
2	0.4672	0.3322	0.1988	-0.2646	0.3940	-0.0512	-0.1731	-0.2015	0.0303	0.0666	0.1885	-0.1486	-0.1515	0.3059	0.2931
3	0.1096	-0.0525	0.2089	0.0593	-0.1703	-0.4785	-0.2176	-0.1276	0.1903	0.0033	0.2684	-0.3793	-0.1610	-0.3620	-0.0387
4	0.0903	0.0006	-0.2787	-0.1438	-0.0268	-0.4664	0.3828	0.1961	-0.2742	-0.0353	0.0575	0.0902	0.2742	0.2781	-0.3969
5	-0.2839	-0.3259	0.0578	-0.0188	0.5813	0.1078	0.0626	-0.0185	0.0733	-0.3759	0.3781	0.1588	-0.1919	0.1333	0.0404
6	-0.2000	-0.1847	-0.2995	-0.0359	0.2644	0.0757	0.0865	0.0801	0.0373	0.1799	-0.1546	-0.8126	0.0764	0.1274	0.0412
7	-0.1126	0.0666	-0.0926	-0.0538	0.3362	-0.1266	0.0263	-0.1285	-0.1811	0.7461	-0.1026	0.2618	-0.2431	-0.1284	0.1683
8	-0.5437	0.7513	-0.0222	-0.1168	0.0524	-0.1936	-0.0175	0.0037	0.0339	-0.2410	-0.0642	-0.0632	-0.0330	0.0092	0.1259

TABLE 3.9   Eigenvectors for eight principal components obtained from principal components analysis of carbonatite data , using a correlation matrix.

48.

ferruginous alvikite. This would indicate that the
association of elements Ce, La, Zn, and V increased in
concentration from sovite to ferruginous alvikite, whilst
that of Sr decreases. These would support the view that
the series sovite-alvikite-ferruginous alvikite is
characterised by increasing concentration of Ce, La,
Zn and V (component 3), and Fe, Mn and Ba (component 2),
in the later intrusive rocks. Of the remaining components,
accounting for significantly less correlation than the first
three components, component 4 (a bipolar association of Ce,
TiO_2, Zr, and Nb (negative values), and Li, Y, and Zn
(positive values in Table 3.19); component 7 (Nd and Ba
association); and component 8 (bipolar association of Mn
(positive) and iron(negative); all show markedly different
values in the alvikites than in the other carbonatite
groups. Components 5 and 6 show little relationship to
carbonatite groups.

The associations represented by components 4 and 6 can
be related to the mineralogy of the carbonatites. For
example, the sporadic occurrence of pyrochlore, but
generally greater abundance in alvikites is reflected in
the appearance of Ce, Nb, Zr and TiO_2 in component 4.
Similarly the association of V, TiO_2, and to a lesser extent
Fe_2O_3 in component 6 is related to the distribution of
magnetite in the carbonatites which is more abundant in
the alvikites and ferruginous alvikites.

3.8. Discussion.

The distribution of major, minor and trace elements in
the carbonatitic rocks and minerals from W. Kenya and E.
Uganda show several recognisable geochemical trends, which
are discussed below.

The elements Nb, Ti, Ba and Ce-earths are generally
present as isomorphous elements in the lattices of minerals
in sovite and alvikite rocks (Nb and Ti in magnetite;

Ce-earths and Ba in calcite and apatite). Concentration of these elements in sufficient quantity to form their own independent minerals occurred during crystallisation of the carbonatites which were studied. Nb and Ti crystallised in the mineral pyrochlore, (gen. formula $CaNa(NbTi)_2O_6F$), a partial analysis of this mineral is given in Appendix Table 8 (c)),whilst Ti also is found in the minerals Ti-magnetite and ilmenite (Appendix Table 8 (c)).Both pyrochlore and magnetite are more abundant in the alvikites. Ba is found in barite, and the Ce-earths in monazite, which are more abundant in the ferruginous alvikites but are also found in some alvikites.

Of the elements which have not been observed to form their own independent minerals in these carbonatitic rocks, Mn, Mo, Y, Zn, and Pb are generally concentrated in the ferruginous alvikites; Sr is more abundant in the sovites; and Zr, following Nb, is generally more abundant in the alvikites.

The occurrence of small amounts of pyrolusite, molybdenite, galena, sphalerite, strontianite, and baddeleyite at other carbonatitic complexes (Heinrich, 1966), all associated with late stage carbonatite activity indicates that these elements also can form their own minerals when present in sufficient concentration. The relatively high concentration of the elements Mn, Zn, Pb, Mo in some ferruginous alvikites suggests that small amounts of these minerals may be present in the ferruginous alvikites.

Elements not characteristically concentrated in the carbonatites, namely Ag, Be, Ga, Li, Ge, Sn, Cr, Ni, W, Bi, and Cu are rarely reported in large amounts from other carbonatites. However, native gold, pentlandite, and various copper sulphides, have been reported from Phalaborwa, and Cu mineralisation was noted from carbonatitic bodies at Akjoujit, Maritania (Heinrich, 1966, p.550).

The geochemical similarity of each carbonatite group

from the different complexes in W. Kenya and E. Uganda is
noteworthy. This would indicate a common process in the
formation of each carbonatite group, not only in the
spatially related complexes of W. Kenya, but also in the
varied complexes of E. Uganda. The data also supports
the field and petrographic distinction of the carbonatite
groups.

The association of characteristic minor elements
(Sr, Nb, Ba, Ce-earths) in all the analysed carbonatites
emphasises the relationship between the carbonatites,
sovite, alvikite and ferruginous alvikite and the
carbonatitic breccias and rarer melilite-pseudomorph
carbonatites. These carbonatites and carbonatitic rocks
can be characterised by the association of minor elements
in unusually high concentrations relative to other igneous
rocks and carbonate rocks.

The sovites, recognised from field evidence as the
earliest intruded carbonatites at most complexes (Flegg,
1969; Dixon, 1968; Sutherland, 1966), contain generally
higher concentrations of Sr, and variable concentrations
of Ba, Nb, Ce-earth elements, Fe, Mn, Zn, and V which are
significantly less concentrated in sovite than in the
later carbonatites.

The alvikites are much finer grained rocks compared
to the sovites, and were generally intruded later than the
sovites as dykes and cone sheets, (Dixon, 1968; Flegg,
1969). Ce-earth elements (see Chapter 2, this thesis),
barium, Nb, Ti, Fe, Mn, Zn, and V are more concentrated
in the alvikites than in the sovites, whilst Sr is less
abundant. The youngest intrusive phase, the ferruginous
alvikites, contain the greatest concentration of Ba,
Ce-earth elements, and Mn and Fe, whilst Zn and V are
also abundant in these rocks.

The variation in concentration of the various elements
in sovite, alvikites, ferruginous alvikites, melilite-
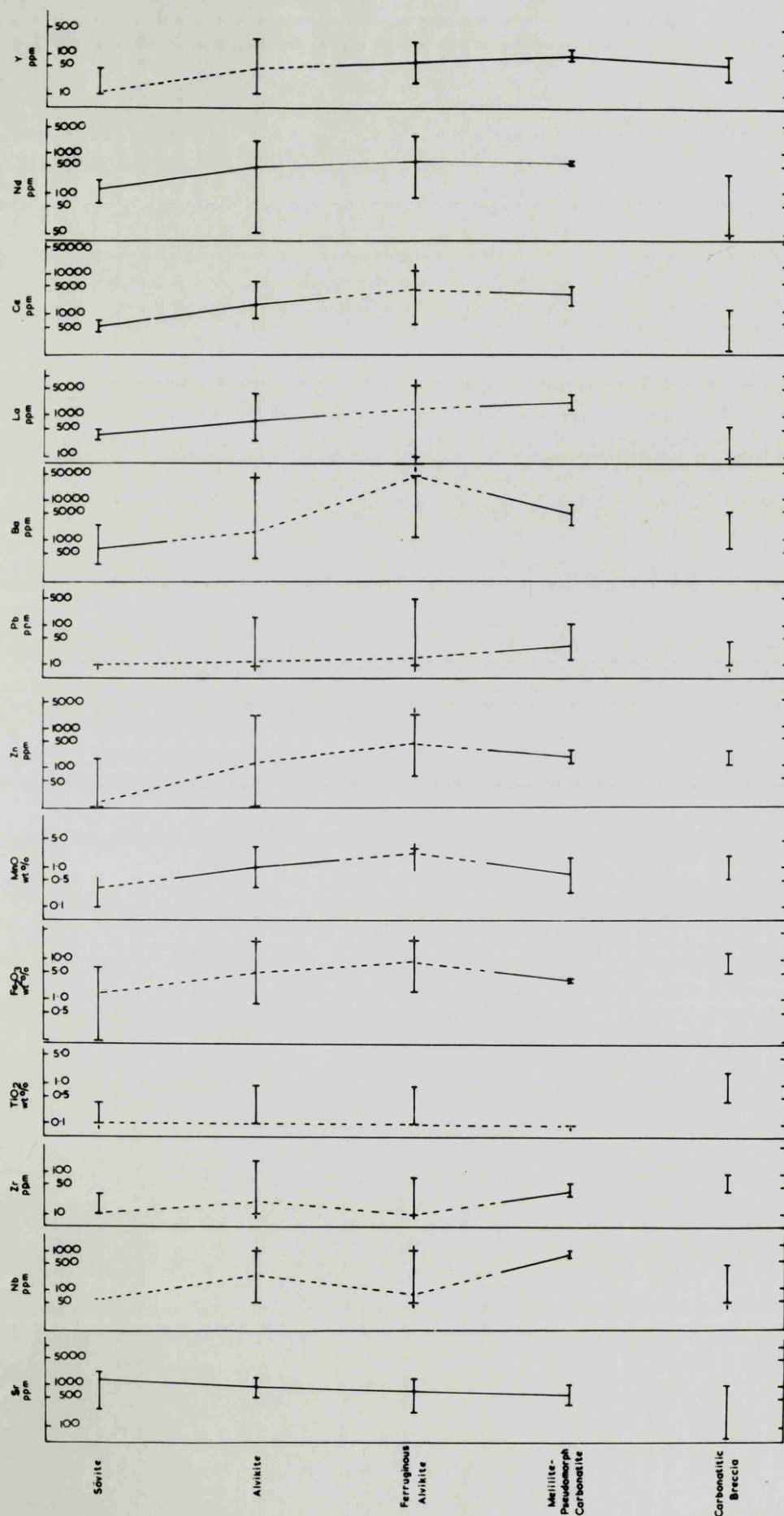
Fig. 3.3. Geometric means and ranges of concentration of Sr, Nb, Zr, Ti (as TiO_2), Fe (as Fe_2O_3),

Mn (as MnO), Zn, Pb, Ba, La, Ce, Nd and Y in carbonatitic rocks from W. Kenya and E. Uganda.

Dashed lines indicate an approximate mean due to some analyses being below the limit of

pseudomorph carbonatite, and carbonatitic breccia are summarised in Figure 3.3.

The distinction, geochemical and petrographic, between the carbonatite groups, suggests that at least the sovites and the later carbonatites, (comprising alvikite, ferruginous alvikite, and melilite-pseudomorph carbonatites), may differ in their origin. However, the characteristic trace and minor elements (Sr, Ba, Ce-earths, etc.) are present in all carbonatite groups. Also consistent geochemical trends between the carbonatite groups, coinciding with the order of emplacement of the different groups at each complex, would suggest that the carbonatites are related to a crystallisation series of a carbonatitic liquid, at each complex.

In order to account for the accumulation of minor elements in the carbonatitic rocks, and for concentration in the later intruded carbonatites, assimilation and reaction of country rock adjacent to carbonatite intrusions must be considered.

It has been demonstrated that in the carbonatitic rocks of Homa Mountain, magnetite, pyroxene and feldspar could be attributed to be of xenolithic origin in at least some carbonatites (Flegg, 1969). Dixon, (1968) considered some crystals of magnetite, apatite, pyroxene and feldspar and pyrochlore to be of xenolithic origin at North Ruri, whilst pyroxene was a notable xenolithic mineral at Budeda, (Sutherland 1966).

Analyses of feldspathised country rock, however, from Homa Mountain (Appendix Table 3 (c)), showed that the elements Ba, Ce-earths, Nb, Zr, Zn, V, Pb and Ga had been introduced into the country rock by feldspathising solutions emanating from crystallising carbonatite. This, and the generally lower concentration of the minor elements studied, in the country rock, show that the concentration of such minor elements in the carbonatites

by assimilation and reaction of country rock adjacent to carbonatite intrusions, is untenable.

The most likely mechanism for the concentration of the trace and minor elements in the later carbonatites is by fractional crystallisation of mainly carbonates from a carbonatitic liquid, which was initially enriched in the minor and trace elements which are characteristically concentrated in the carbonatitic rocks.

Wyllie (1966, p.324), stated that the intrusive sequences recorded at some carbonatite complexes could be explained on the basis of differentiation processes occurring during crystallisation of carbonate magma. Crystallisation of mainly calcite from such liquids could conceivably produce residual liquids enriched in those elements not incorporated to any great extent in the crystallising minerals.

The geochemical evidence presented here suggests that the alvikites represent crystallisation products of carbonatitic liquids which had undergone extreme fractionation before intrusion of alvikite, and after intrusion of sovite.

The ferruginous alvikites, intruded as dykes and veins, represent the culmination of carbonatitic activity at the complexes in W. Kenya. These rocks showed evidence of a hydrothermal origin, (Flegg, 1969). Kuellmer, Visocky and Tuttle (1966), showed that with addition of alkalis to compositions in the system calcite-barite-fluorite-H_2O, all gradations between carbonatitic liquids and hydrothermal solutions might be expected. Thus crystallisation of later alvikitic liquids would be expected to yield residual fluids which were hydrothermal (and alkali-carbonate rich) in character, and contained an abundance of rare elements, due to fractionation. Crystallisation of calcite, barite, fluorite, iron ores (magnetite, hematite and goethite) mica, feldspar, and rarer monazite and bastnaesite (Flegg, 1969; Dixon, 1968) from such liquids gave rise to the typical geochemical character of these rocks.

The rarer melilite pseudomorph carbonatites, intruded late in the history of the Homa Mountain complex, are characteristically enriched in Ba and REE, and depleted in Sr.

Such characteristics indicate not only an affinity with the carbonatitic rocks but support the view that the later stages of carbonatitic activity at Homa Mountain (and by comparison, the other complexes studied in this thesis) are typically enriched in Ba, REE, and depleted in Sr, whilst the elements Mn, Fe, Zn, Pb and more rarely Mo also are enriched in most later alvikites and ferruginous alvikites.

3.9. Conclusions.

The carbonatites analysed in this study represent only a small proportion of those carbonatites intruded at the various complexes in W. Kenya and E. Uganda. The very heterogenuity of the rocks, in the content of accessory minerals, advises caution in the interpretation of the distributions of the various elements in these rocks.

However, despite this variability, characteristic assemblages of trace and minor elements, associated with the carbonatites as a whole, and within each carbonatite group have been recognised. The data may be summarised thus:-

1.   All carbonatites and carbonatitic breccias are notably enriched in Sr, Ba, Ce-earth elements, and contained variable concentrations of Nb, Zr, Fe, Mn, Zn, V, Ti, and Pb.

2.   The sovites differ from the other carbonatites in containing generally less Ba, Ce-earths, Nb, Zn, V, Fe, Mn, Ti and more Sr. The alvikites are enriched in Nb, REE, Fe, Ti, Zn, V, and Mn and Ba relative to the sovites, whilst the greatest concentrations of Fe, Mn, Ce-earths, Ba (and F) are characteristic of the ferruginous alvikites.

3.   The increasing concentration of Ba, Fe, Mn, Ce-earths,

Zn and V in the series sovite-alvikite-ferruginous alvikite, and the decreasing concentration of Sr, coincides with the order of emplacement of the various carbonatite types at most complexes.

4. The trace and minor elements are generally present as isomorphous substituted elements in minerals of the earlier carbonatites; Sr, Ba, REE, Fe, Mn in calcite; Sr, Ba, REE in apatite and pyrochlore; Zr and Ti in pyrochlore; Zn, V, Ti in magnetite; V, Zr, Ti in mica and pyroxene (aegirine).

The later carbonatites (especially the ferruginous alvikites) characteristically contain minerals in which rare elements are present as major components (e.g. Nb in pyrochlore, Ba in barite, Ce-earths in monazite, in the ferruginous alvikites).

5. The most likely mechanism for concentration of trace and minor elements to the later stages of carbonatitic activity, is by fractionation of mainly carbonates from carbonatitic liquids, which were enriched in these elements.

C H A P T E R   F O U R.

The Distribution of minor and trace elements in peralkaline silicate rocks, phonolitic rocks, and fenites, associated with carbonatites from W. Kenya and E. Uganda.

4.1. Introduction.

The aim of the study is to obtain detailed information on the distribution of minor and trace elements in the peralkaline intrusive rocks (pyroxenite-ijolite-urtite-nepheline syenite), phonolitic rocks (including analcime-phonolite, phonolitic nephelinite, and melanephelinite), and fenite rocks from carbonatite complexes in W. Kenya and E. Uganda. Analyses of carbonatites for minor and trace elements at the various complexes have already been determined (Chapter 3), whilst Chapter 2 investigated the distribution of the rare earth elements La, Ce, Nd, and Y in carbonatites and related silicate intrusive rocks and fenites.

4.2. Choice of specimens.

Samples were selected for analysis from existing collections of peralkaline rocks and fenites at Leicester University and Bedford College, London, in addition to rocks previously analysed for the rare earth elements.

Representative rocks were selected from Homa Mountain, North Ruri, and Wasaki in W. Kenya, and from Tororo, Toror, Napak, and Budeda in E. Uganda. More detailed accounts of each centre are given in ~~Appendix~~ Chapter 1.

4.3 <u>Analytical method.</u>

The samples were crushed to -150 mesh and analysed
quantitatively for trace elements Ag, Ba, Be, Co, Cr,
Cu, Ga, Ge, Li, Nb, Ni, Pb, Sn, Sr, V, Zn, Zr, and semi-
quantitatively for major elements Si, Al, Ca, Fe, Mn, Mg,
Ti and K using an A.R.L. 29000B direct reading spectrometer.

In addition Na and K were determined in the rocks using
an EEL flame photometer, and Fe, as ferrous ion, determined
by titration with potassium dichromate after fusion with
conc. $H_2SO_4/$ HF acid mixture. Details of analytical methods
are given in Appendix 1.

In addition to rock analyses, several minerals were
separated from the intrusive rocks and fenites, and analysed
for minor and trace elements using the direct reading
spectrometer. In this way the minerals pyroxene, nepheline
feldspar, garnet and wollastonite were separated and
analysed. The minerals apatite and sphene, generally
present in amounts too small for separation were analysed
for Sr (apatite from ijolite, nepheline-syenite, and fenite),
and Ti, Al, Fe, Si, Mn, Mg, K (sphene from ijolite) using an
AEI SEM2 electron microprobe. Zoned and unzoned crystals of
garnet were also analysed using the electron microprobe.
Details of the method employed are given in Appendix 1.

4.4 <u>Results of Analyses.</u>

The results of spectrometric analyses of major and trace
elements in the intrusive silicate rocks, Phonolitic rocks
and fenite rocks are given in Appendix Tables 4 (c), 5 (c)
and 6 (c) respectively.

Semi-quantitative major element analyses of these rocks
are given in Appendix Tables 4 (b), 5 (b), and 6 (b)
respectively. Corresponding chemical analyses of these
rocks, from other sources, where available, are given in Appendix Tables 4 (a),
5 (a) and 6 (a) respectively.

In Appendix Tables 4 (a) to 4 (c) the ijolitic and
nepheline-syenite rocks have been subdivided into petrographic

F I G U R E   4 . 1.   (a) - (g).

Analyses below the detection limit for the various elements have been omitted from Fig. 4.1 (a) - (g).

The number of such analyses for each rock type, which were below the detection limits are shown below.

	Zr	Zn	V
Pyroxenite	-	-	-
Ijolite	-	-	-
Urtite	3	-	2
Nepheline- syenite	-	-	-
Phonolite	-	-	-
Fenite	-	-	2
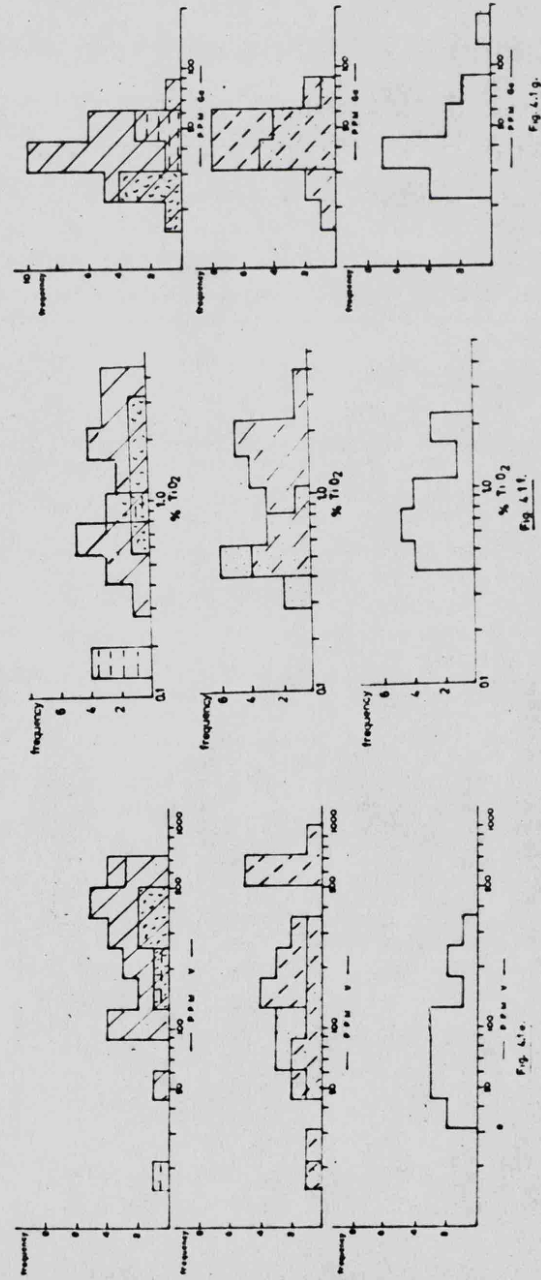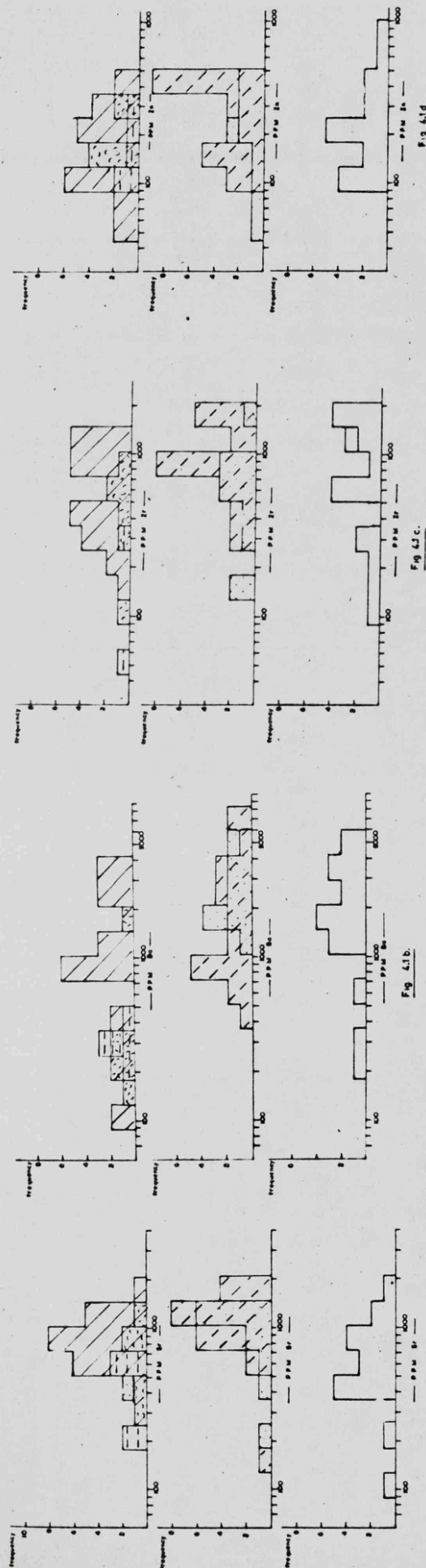
KEY

pyroxenite
'ijolite'
urtite
nepheline-syenite
'phonolite'
fenite

Fig. 4.1a-g. The distributions of Sr, Ba, Zr, Zn, V, Ti (as TiO₂), and Ga in peralkaline silicate rocks and fenites from carbonatitic complexes in W Kenya and E Uganda. 'ijolite' includes melanite ijolite and feldspathic ijolite. 'phonolite' includes melanepheline, nepheline, phonolitic nephelinite and analcime phonolite

Fig. 4.1a.
Fig. 4.1b.
Fig. 4.1c.
Fig. 4.1d.
Fig. 4.1e.
Fig. 4.1f.
Fig. 4.1g.

type. The major mineralogy of each analysed rock powder was determined semi-quantitatively using X-ray diffraction techniques. This was carried out rather than thin section determination of mineralogy, due to the large variation in proportions of major minerals in these rocks, even within one specimen. The methods employed in the determination of weight percentage of the minerals nepheline, pyroxene (diopsidic and aegirine pyroxene), feldspar, and garnet are given in Chapter 1.

In a similar manner, the phonolitic rocks have been subdivided into analcime and cancrinite phonolite, phonolitic nephelinite, nephelinite, and melanephelinite. The presence of analcime and cancrinite, nepheline and feldspar in the analysed rock powders was determined using qualitative X-ray diffraction techniques. The composition of the feldspar was also determined using X-ray diffraction procedures (Orville, 1967). Subdivision into melanephelinite was based on thin section studies. These X-ray diffraction techniques are described in Chapter 1.

The results of the spectrometric analyses of pyroxene, nepheline, feldspar, and garnet and wollastonite are given in Appendix Tables 7 (a), 7 (b) and 7 (c) respectively.

Electron microprobe analyses of garnet, and sphene, are given in Table 8 (a).

4.5. Discussion of results.

(i) Strontium and Barium.

The distributions of Sr and Ba in pyroxenite, ijolite, and urtite; phonolite and nepheline-syenite; and fenite are shown graphically in Figures 4.1 (a) and 4.1 (b) respectively, as frequency histograms plotted on a logarithmic scale.

(a) Variation of Sr and Ba in the intrusive peralkaline rocks.

The geometric means, and ranges of concentration

of Sr and Ba are given in Table 4.1 below, for these elements
in pyroxenite, ijolite, melanite ijolite, feldspathic ijolite,
urtite, nepheline-syenite and micro-ijolite.

Rock Type	Strontium		Barium	
	Mean	Range	Mean	Range
Pyroxenite	615	300-1550	330	150-1600
Ijolite	850	630-1680	1350	960-1500
Melanite Ijolite	550	300-1100	195	100-3080
Feldspathic Ijolite	890	730-1090	720	410-1510
Urtite	415	210-690	280	180-380
Nepheline Syenite	825	215-1420	2450	1100-4600
Micro Ijolite	690	530-1040	2100	960-3200

Table 4.1. Geometric means and ranges of concentration of
Sr and Ba in peralkaline intrusive rocks from
W. Kenya and E. Uganda.

Strontium is seen to vary considerably in all rock types,
but is generally higher in feldspathic ijolite, ijolite and
nepheline-syenite, and is least concentrated in the melanite
ijolites and urtites.

Barium shows less variation than Sr, being concentrated in
nepheline-syenite and micro-ijolite, and least concentrated
in pyroxenite, urtite and melanite ijolite.

The ratio of Sr/Ba is greatest in the pyroxenites,
melanite ijolites, and urtite samples, and is least in the
nepheline-syenites and (feldspathic) microijolites. As a
general rule, the lower ratios are thus found in the feldspar
enriched rocks.

Both Sr and Ba were present in varying concentrations in

the major rock forming minerals of the peralkaline rocks, pyroxene, nepheline, garnet and feldspar.

The data concerning the concentrations of these two elements in the minerals of the peralkaline rocks is summarised in Table 4.2 below.

Mineral	Rock Type	Strontium ppm Range	Barium ppm Range	Number of Analyses
Pyroxene	Pyroxenite	320ppm	70ppm	1
	Ijolite	420-1160ppm	110-500ppm	4
	Microijolite	370-750ppm	50-260ppm	4
	Nepheline-syenite	860-950ppm	300-330ppm	2
Nepheline	Ijolite	670-3000ppm	300-4000ppm	7
	Urtite	250-580ppm	50-150ppm	3
Feldspar	Microijolite	380-1250ppm	6000ppm	4
	Nepheline-syenite	190-1025ppm	6000ppm	9
Melanite garnet	Melanite ijolite	320-540ppm	100-380ppm	4
Wollastonite	Urtite	1360ppm	280ppm	1

Table 4.2. Ranges of concentration of Sr and Ba minerals of the peralkaline silicate rocks.

It is apparent from Table 4.2 that significantly more Ba is concentrated in feldspar than in any other minerals, whilst nepheline, pyroxene and garnet generally contain more Sr than Ba (Appendix Table 7(a)-(d)). Melanite garnet contains the least Sr and Ba of these minerals.

Rankama and Sahama (1964, p.471) found that although Sr and Ba resemble each other chemically, their manner of occurrence in nature showed considerable differences.

Sr was found to accompany Ca in minerals and rocks of
igneous origin, whilst both elements were found to
substitute for K in igneous minerals.

The results in Table 4.2 would indicate rather that
both elements substitute for Ca and K in the various
minerals. However, the Ca sites available showed greater
preference for the smaller Sr^{2+} ion, whilst the larger
K^+ sites of feldspar favoured the greater incorporation
of the larger Ba^{2+} ion. Substitution of both Sr and Ba
in nepheline, with the concentration of Sr exceeding that
of Ba, also shows a preference for the smaller ion for a
relatively smaller lattice position than is available in
feldspar.

Variation of the elements Sr and Ba in the peralkaline
intrusive rocks are best seen by using the ratio of Ba/K_2O
and Sr/CaO, as in Figure 4.2, where the plutonic rocks
have been compared with similar parameters for phonolitic
rocks and fenitic rocks.

In Figure 4.2, there is a general increase in Ba/K_2O
and particularly Sr/CaO in the series pyroxenite-ijolite
(compare the Sr contents of pyroxene from pyroxenite and
ijolite), whilst the Ca-rich melanite-ijolites and urtites
have low values for both ratios. This shows good agreement
with the data concerning the Sr and Ba concentrations of
minerals from the plutonic rocks, and indicates that there
is greater substitution for Ca by Sr in the minerals of
the ijolites (particularly pyroxene) relative to pyroxenite.
On the other hand, the Ca-enriched melanite-ijolites and
urtites show less substitution for Ca by Sr in the lattices
of Ca-rich melanite and wollastonite in these rocks.

The nepheline-syenites show the highest values of both
ratios, due to the large concentrations of Ba in feldspar,
and also of Sr in this Ca-poor mineral.

Thus, although the variation in concentrations of both
Sr and Ba in the intrusive rocks is complicated by the

$Ba/K_2O \cdot 10^2$

KEY
p   pyroxenite
u   urtite
i   ijolite
mi melanite ijolite
fi feldspathic ijolite
ns nepheline-syenite
f   fenite

nepheline-syenite

fenite

ijolite

melanite ijolite

pyroxenite

urtite

$Sr/CaO \cdot 10^2$

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 12 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0

12 11 10 9 8 7 6 5 4 3 2 1
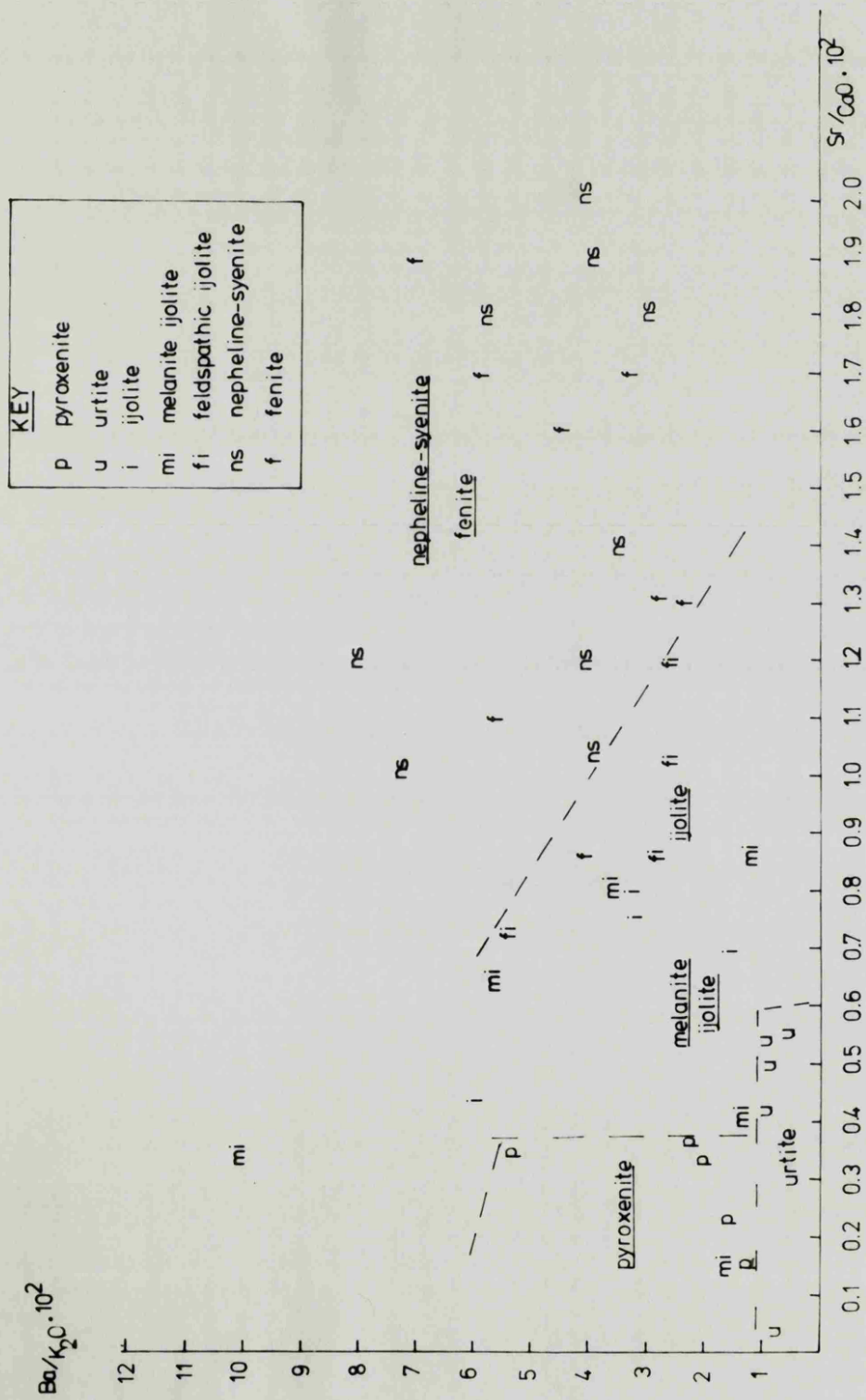
Fig 4.2.   Variation of Ba/K$_2$O and Sr/CaO in peralkaline intrusive silicate rocks and
fenites from W. Kenya and E. Uganda.

variety of minerals in which these elements are found, several factors suggest that both elements are concentrated to varying extents in later formed minerals relative to early magmatic minerals, Sr in later Ca poor pyroxene of the ijolites, and Ba in later feldspar. In contrast to this, the Ca rich late-stage minerals melanite and wollastonite are relatively depleted in Sr relative to Ca. The generally low concentration of Sr in Ca rich garnets (Rankama and Sahama, 1964, p.473) would suggest that the crystallochemical peculiarities of this mineral discriminates against the uptake of Sr in to the crystal lattice.

(b) Variation of Sr and Ba in the phonolitic rocks.
The ranges of concentration of Sr and Ba in the various nephelinites and phonolites are shown in Table 4.3 below.

Rock Type	Strontium Range	Barium Range
Melanephelinite	720-1700ppm	950-6000ppm
Nephelinite	1000-1230ppm	1000-7280ppm
Phonolitic nephelinite	880-1820ppm	870- 4000ppm
Analcime-phonolite	150-1650ppm	480-3400ppm
Cancrinite-phonolite	970ppm	1150ppm

Table 4.3. Concentration of Sr and Ba in the phonolitic rocks.

All the phonolites, as in the plutonic rocks contain large concentrations of both Sr and Ba. However, the greater concentrations of both Ba and Sr in the melanephelinites distinguish these rocks from the intrusive equivalents (pyroxenites), whilst the phonolites contain greater amounts

of Sr than their plutonic equivalents (nepheline-syenites).

The analcime-and cancrinite-phonolites show generally higher values of Sr/Ba compared to the melanephelinites, nephelinites, and phonolitic nephelinites (Appendix Table 5 (c).

Analyses of cancrinite and analcime from peralkaline complexes outside East Africa (Alno, von Eckermann 1952; Magnet Cove complex, Arkansas, Erikson and Blade, 1963) have shown that the concentration of Sr exceeds that of Ba in both these minerals, which would account for the data on these rocks.

The abundance of K-feldspar in both the phonolitic nephelinites and in the analcime phonolites, however, suggest that to a large extent, the earlier feldspar of the phonolitic nephelinites is more enriched in Ba than the later feldspar of the analcime phonolites.

Previous studies have shown that the Sr and Ba concentrations of K-feldspar depend on the temperature of formation of the feldspar (Noll, 1934; von Engelhardt, 1936). The K-feldspar first to crystallise contains greater concentrations of Ba and Sr, than crystals of later generation (Rankama and Sahama 1964, p.472).

The distributions of Ba and Sr in the phonolitic rocks would suggest that these elements are removed from the liquid with crystallisation of feldspar. Also due to the lower temperature of formation of the analcime phonolites (or possibly due to the lower concentration of Ba and Sr in the later liquids, due to removal of these elements, particularly Ba in feldspar), the concentrations of Ba and Sr are relatively depleted in later formed feldspar in these rocks. Consequently, these elements tend to be less concentrated in the later formed analcime phonolites. Also relatively greater amounts of Sr than Ba would be found in these rocks compared to the earlier phonolites, due to the high Sr/Ba ratio of cancrinite and analcime,

and the lower concentrations of particularly Ba in the feldspars of these rocks.

The incorporation of large concentrations of Ba in the melanephelinites and nephelinites, rocks which are lacking in feldspar, requires further investigation.

(c) Variation of Sr and Ba in the fenitic rocks.

In general the higher grade fenites contain more Sr and Ba than the less strongly fenitised rocks at each complex (Appendix Table 6 (b)). Sr/Ba is less than 1 in all but one fenite. This may be explained by the greater concentration of Ba than Sr in the abundant feldspar in the fenitic rocks, whilst pyroxene and feldspar from fenite contain relatively smaller amounts of Sr (Appendix Tables 7 (a) and (c)).

The concentration of these elements in the fenitic rocks relative to country rock at Homa Mountain indicates that Sr and Ba are introduced into the country rocks by fenitising solutions.

(ii) Niobium and Zirconium.

The distribution of Zr in the silicate rocks of the carbonatite complexes of W. Kenya and E. Uganda is shown in Figure 4.1(c). Zirconium is more abundant in the fenites and phonolites than in the intrusive nepheline-syenites ijolitic rocks, pyroxenite and urtite.

(a) Niobium and Zirconium in the intrusive rocks.

Geometric means and ranges of concentration of Nb and Zr in the various intrusive rocks are given in Table 4.4 below.

Rock Type	Niobium Mean	Range	Zirconium Mean	Range
Pyroxenite	400ppm	185-860ppm	400ppm	100-1000ppm
Ijolite	330ppm	<50-1350ppm	680ppm	170-840ppm
Melanite Ijolite	290ppm	220-670ppm	670ppm	320-1350ppm
Feldspathic Ijolite	135 ppm	< 50-830ppm	870ppm	500-1280ppm
Ijolite Urtite	<50ppm	< 50ppm	< 10ppm	<10-350ppm
Nepheline Syenite	<50ppm	<50-330ppm	510ppm	110-1900ppm
Microijolite	<50ppm	< 50ppm	390ppm	200-510ppm

Table 4.4. Geometric means and ranges of Nb and Zr in

peralkaline silicate rocks of W. Kenya and E. Uganda.

Niobium is present in higher concentration in pyroxenite, ijolite and melanite ijolite, and to be least concentrated in urtite and microijolite. Zirconium, like Nb, is concentrated in pyroxenite ijolite and melanite ijolite, and shows much smaller concentration in the urtite, but differs from Nb in being concentrated in feldspathised ijolite, nepheline-syenite, and microijolite.

Forms of occurrence of Nb and Zr in the peralkaline intrusive rocks.

The mineral analyses in Appendix Tables 7(a) to 7(d) showed that pyroxene, feldspar and nepheline contained generally no detectable Nb. Garnet, however, contained Nb in amount greater than 1000ppm. Both sphene, and garnet were found to contain Nb in minor amounts at Magnet Cove (Erikson and Blade, 1963). The distribution of Nb in the peralkaline intrusive rocks would thus be related to the content of accessory sphene and

garnet in the rocks. From textural and mineralogical
studies both garnet and sphene were considered to be late
stage ijolitic minerals (Clarke, 1969). Thus Nb is
concentrated to later stages of crystallisation of ijolitic
liquids.

Zirconium was present in minor amounts in garnet, and
in pyroxene from nepheline syenite, microijolite and to a
lesser extent ijolitic pyroxenes, more acmitic pyroxene
from nepheline-syenite generally containing more Zr (Table
4.5). Trace amounts of Zr were found in feldspar and
nepheline (Appendix Tables 7(a) to 7(d)). Erikson and
Blade (1963) noted Zr rich sphene garnet and acmitic
pyroxene from Magnet Cove, Arkansas, Qualitative analysis
of sphene and garnet from ijolitic rocks by electron
microprobe showed the presence of Zr in these minerals
from peralkaline rocks of W. Kenya.

Rock Type	Zr Range	No. of Analyses.
Pyroxenite	470ppm	1
Ijolite	650-2060ppm	4
Microijolite	280-1150ppm	4
Nepheline Syenite	1000-1150ppm	2
Melanephelinite	140-1140	3
Phonolite	960-1460	2

Table 4.5. Ranges of concentration of Zr in pyroxenes
from ijolitic, nepheline-syenite and
phonolitic rocks from W. Kenya and E. Uganda

The concentration of Zr in the later stage minerals
garnet and sphene, and in acmitic pyroxene of the nepheline-
syenites and microijolite, suggests that Zr, like Nb, is
concentrated to later stages of ijolitic liquids with
crystallisation. The presence of Zr in the major rock-forming

aegirine-rich pyroxenes of the nepheline-syenites would
indicate a concentration of Zr in the liquid from which
nepheline syenitic crystallised, and suggests a trend
towards Zr enriched 'agpaitic' crystallisation (e.g. Lovozero
Alkaline massif, Gerasimovsky et al, 1966). The presence of
eudialyte in the nepheline-syenite at North Ruri (Dixon,
1968) encourages this view.

(b) Nb and Zr in the phonolitic rocks and
melanephelinites.

Concentration of Nb and Zr in these rocks varies
considerably, ranges of concentration of these elements in
the phonolitic rocks is shown in Table 4.6 below.

Rock Type	Niobium Range	Zirconium Range
Melanephelinite	< 50-400ppm	300-790ppm
Nephelinite	300-560ppm	590-1500ppm
Phonolitic nephelinite	< 50-950ppm	550-1500ppm
Analcime-phonolite	< 50-200ppm	800-1740ppm
Cancrinite phonolite	< 50ppm	1680ppm

Table 4.6. Niobium and Zr in phonolitic rocks.

In Table 4.6, the concentration of Nb is seen to vary to
a greater extent than Zr, which reflects the uneven distribution
of Nb bearing minerals in the phonolitic rocks. Zr tends to
increase in concentration from melanephelinite to analcime
and cancrinite phonolite.

Form of occurrence of Nb and Zr in the phonolitic rocks.

Niobium was not detected in the phonolitic pyroxenes
(Appendix Table 7(a)),however, Smith (1970), noted the presence
of Nb in sphene and peroskite from peralkaline lavas from
East Africa.

Zirconium was noted in the sphene and perovskite of these lavas, and was also found in the pyroxenes in the phonolites (Table 4.5). The melanephelinitic pyroxenes contained less Zr than the more acmitic phonolitic pyroxenes, as in the intrusive rocks.

Thus both Nb and Zr are related to the sporadic occurrence of sphene and perovskite in the phonolites, whereas Zr is also related to the presence or absence of acmitic pyroxene.

(c) Nb and Zr in the Fenitic rocks.

Both Nb and Zr are more abundant in the fenites analysed from Homa and N. Ruri than at Budeda and Tororo. The low grade fenite at Homa (HC54) contains much less Nb and Zr than the more highly fenitised rocks at this complex, which indicates that both Nb and Zr are introduced into the country rock with fenitising solutions. As in the intrusive rocks, Nb shows much greater variation in the fenites than Zr. In general, greater concentrations of Zr are found in the higher grade syenitic fenites.

Form of occurrence of Nb and Zr in the fenitic rocks.

Sphene is noted as a ubiquitous accessory in the fenites from Budeda (Sutherland, 1966) and Homa (Clarke, 1968) and N.Ruri (Dixon, 1968). The distribution of Nb would depend to a large extent on the presence of sphene in the fenites. Zirconium, found to vary between 260 and 2500ppm in fenitic pyroxenes (Appendix Table 7(a)),would also be related to the mineral sphene.

In conclusion, the general paucity of Nb and Zr in the country rocks around the carbonatitic complexes, and the enrichment of fenitic rocks in these elements indicate that Nb and Zr were present in fenitising solutions, being concentrated locally in sphene, whilst Zr is more evenly distributed in the fenites in pyroxene and locally in sphene.

Summary.

Nb varies considerably in concentration in the silicate rocks and fenites of carbonatitic complexes, being locally concentrated in Ti rich minerals (e.g. sphene), and more consistently present in melanite garnet rich ijolites.

Zirconium is more evenly distributed in the peralkaline rocks and fenites, occurring locally in accessory Ti-rich minerals, generally in amounts greater than 1000ppm, and also in pyroxenes of intrusive ijolitic rocks, phonolitic rocks and fenites. Generally the more acmitic pyroxenes contain the most Zr, although considerable variation in Zr content of pyroxene was apparent (Table 4.5).

Concentration of Nb and Zr in sphene and garnet, generally regarded as late stage minerals of ijolitic rocks, shows that both elements are concentrated in residual fluids with crystallisation of ijolitic liquids. The presence of Zr in acmitic pyroxene of nepheline-syenite and fenite, and the sporadic occurrence of Nb in fenite indicate a possible relationship between late stage ijolitic liquids or fluids and fenitising solutions.

(iii) Lead and Zinc.

In all the intrusive rocks, the concentration of Zn exceeds that of Lead. The distribution of Zn in the peralkaline silicate rocks and fenites is given in Figure 4.1(d).

Zinc is generally more concentrated in the nepheline syenite, phonolite and fenites than in the ijolitic rocks, urtites and pyroxenites

(a) Zn and Pb in the intrusive silicate rocks.

The ranges of concentration of Zn and Pb are given in Table 4.7 below. Zn is more concentrated in the nepheline-syenite and feldspathised ijolite than in pyroxenite, ijolite, melanite ijolite and urtite.

Rock Type	Zinc		Lead
	Mean	Range	Range
Pyroxenite	190ppm	140-330ppm	< 10-50ppm
Ijolite	175ppm	100-355ppm	< 5-18ppm
Melanite Ijolite	120ppm	65-200ppm	< 5-25ppm
Feldspathic Ijolite	220ppm	60-300ppm	< 5-35ppm
Urtite	165ppm	100-260ppm	< 5-30ppm
Microijolite	350ppm	60-450ppm	< 5-10ppm
Nepheline Syenite	240ppm	60-460ppm	< 5-200ppm

Table 4.7.   Zn and Pb in peralkaline intrusive rocks
(Zn - geometric means and ranges,
Pb - ranges of concentration).

Pb is sporadically present in all rock types, rarely exceeding 50ppm.

Form of occurrence of Zn and Pb.

Trace amounts of both elements are present in the rock forming minerals of the intrusive peralkaline rocks, (Appendix Tables 7(a) to 7(d).

In feldspar, 10-60ppm Zn and 5-20ppm Pb were found, whilst in nepheline, 25-60ppm Zn and 5-20ppm Pb were found by spectrometric analysis. Zn is more concentrated in the mafic minerals. 100-1300ppm Zn were found in pyroxene, and 170-360ppm in melanite garnet. The pyroxenes from microijolite and nepheline syenite showed slightly higher Zn contents than the ijolitic pyroxenes, with the exception of U351 which is anomalously rich in Zn.

Pb was rarely detected in the analysed mafic minerals.

(b) Zn and Pb in the Phonolitic rocks and melanephelinites.

The ranges of concentration of analysed phonolites and melanephelinites are given in Table 4.8 below.

Rock Type	Zinc Range	Lead Range
Melanephelinite	100-360ppm	< 5-50ppm
Nephelinite	140-360ppm	< 5-50ppm
Phonolitic nephelinite	120-400ppm	25-80ppm
Analcime phonolite	250-470ppm	15-100ppm
Cancrinite phonolite	160ppm	10ppm

Table 4.8. Zn and Pb ranges of concentration in phonolitic and melanephelinitic rocks.

Both Zn and Pb are concentrated in the analcime phonolites and to a lesser extent the phonolitic nephelinites, relative to the melanephelinites and nephelinites.

Analyses of pyroxene from phonolitic rocks showed that Zn was more concentrated in phonolitic pyroxene than in melanephelinitic pyroxene, whilst Pb was undetected in these minerals. The increase in concentration of Pb in the analcime and nepheline-rich phonolites may be due to substitution of Pb in the feldspar lattice.

(c) Zn and Pb in Fenitic rocks.

Zinc in analysed fenites varies widely from 90-1000ppm, and Pb from 5-440ppm. The fenites from N.Ruri are anomalously rich in both Zn and Pb, and several of the analysed fenites show anomalously high concentrations of either Zn or Pb, or both as in the case of N.Ruri. The anomalies are probably due to small amounts of sulphide minerals in the analysed rocks. Heinrich (1966,p.88) noted sphalerite from fenite at Nemegosenda Lake, Ontario, and both sphalerite and

galena from fenites near Seal Lake, central Labrador.

Neither Pb nor Zn were detected in fenitic feldspar,
however, Zn was found in fenitic pyroxene (Appendix Tables
7(a) and 7(c)).

(iv) Chromium, Nickel, Copper Cobalt, Vanadium, and Titanium.

Cr, Ni, Cu and Co are not characteristically concentrated
in the peralkaline intrusive rocks. The highest concentrations
of these elements are found in the pyroxenites, whilst the
ijolites contain generally much smaller concentrations. All
four elements are generally below the limit of detection in
the microijolites, nepheline-syenites, and urtites. The ranges
of concentration of these elements in the various rock types
are given in Table 4.9 below.

Rock Type	Cr Range ppm	Ni Range ppm	Cu Range ppm	Co Range ppm
Pyroxenite	< 5-354	< 5-184	10-100	20-79
Ijolite	< 5-26	10-130	< 5-75	22-33
Melanite Ijolite	< 5	10-40	< 5-44	10-30
Feldspathic Ijolite	<5-30	< 5-62	< 5-70	<5-30
Urtite	< 5	< 5	< 5	<5-5
Microijolite	< 5	< 5	<5-20	<5-10
Nepheline Syenite	< 5-12	<5-10	< 5-5	<5-12

Table 4.9. Ranges of concentration of Cr, Ni, Cu and Co
in peralkaline intrusive rocks.

Vanadium and Titanium are considerably more concentrated
than Cr, Ni, Cu and Co in the peralkaline silicate rocks.

The distributions of these elements are shown in Figures
4.1 (e) and 4.1 (f) respectively, for all peralkaline
silicate rocks and fenites.

(a) V and Ti in peralkaline intrusive rocks.

Concentrations of V and Ti as TiO_2 are shown in Table
4.10 below for the various rock types from the carbonatitic
complexes.

Rock Type	Vanadium			TiO_2	
		ppm			wt.%
	Mean		Range	Mean	Range
Pyroxenite	250		130-380	1.11	0.64 - 2.3
Ijolite	175		100-325	0.93	0.41 - 1.98
Melanite- Ijolite	320		240-660	2.0	0.75 - 4.2
Feldspathic- Ijolite	165		120-475	1.0	0.4 - 3.8
Urtite	20		10-250	0.17	< 0.1 - 0.82
Microijolite	250		125-700	0.81	0.42 - 1.5
Nepheline- Syenite	87		20-275	0.5	0.3 - 0.74

Table 4.10. V and TiO_2 in intrusive peralkaline rocks,

geometric means and ranges.

Both V and Ti are concentrated in melanite ijolite and
to a lesser extent in pyroxenite, and are least concentrated
in the urtite and nepheline syenites, (Table 4.10).

Form of occurrence of V and Ti.

As expected, V and Ti were found to be present in the mafic
minerals of the intrusive rocks. Melanite garnet was found by
electron microprobe analysis to contain from 2.73 wt.% TiO_2 in

light coloured areas of zoned garnet, to 7.49 wt.% TiO_2 in dark coloured zone of the same crystal (HC741, Appendix Table 8 (a)). Results of analyses of other garnets for TiO_2 were found to vary within these limits. Spectrometric analyses of garnet showed that V was also concentrated to a large extent in this mineral, (Appendix Table 7 (d)), varying from 980-1980ppm. Electron microprobe analyses of sphene for TiO_2 showed 38.15 - 40.03 wt.% TiO_2 to be present in this mineral. V was noted by Heinrich (1966, p.240) to accompany Ti in sphene.

Pyroxene was found to contain from 250-1550ppm V in the intrusive rocks, whilst TiO_2 varied from 0.2 - 3.3 wt.%. Little correlation between high Ti and V in the pyroxenes is apparent from Appendix Table 7 (a), however, V is consistently more concentrated in the more aegirine rich pyroxenes of nepheline syenite and microijolite, than in the pyroxenitic and some ijolitic pyroxenes. Heinrich (1966, p.240) similarly noted aegirine pyroxene enriched in Vanadium.

Relatively small amounts of both V and Ti were found in analysed feldspar, however, these may be due to contamination by Ti and V rich minerals (e.g. sphene).

Thus, in the intrusive rocks as a whole, both Ti and V are concentrated in Ti rich garnet and sphene, whilst V is generally more abundant in the aegirine-rich pyroxenes, the content of Ti in pyroxene being more variable.

(b) Cr, Ni, Cu, Co, V and Ti in phonolitic rocks
       and melanephelinites.

The ranges of concentration of Cr, Ni, Cu, and Co in the phonolites and melanephelinites are shown in Table 4.11 overleaf.

Rock Type	Cr Range	Ni Range	Cu Range	Co Range
Melaneph- elinite	50-410ppm	30-120ppm	110-215ppm	50-60ppm
Nephelinite	<5-236ppm	< 5-54ppm	<5-110ppm	< 5-30ppm
Phonolitic nephelinite	< 5-40ppm	< 5-38ppm	<5-102ppm	< 5-22ppm
Analcime Phonolite	< 5ppm	< 5ppm	<5-20ppm	< 5ppm
Cancrinite Phonolite	12ppm	< 5ppm	<5ppm	< 5ppm

Table 4.11. Concentration ranges for Cr, Ni, Cu and Co in phonolitic rocks and melanephelinites.

The melanephelinites are seen in Table 4.11 to contain the greatest concentrations of Cr, Ni, Cu and Co, which compares with their intrusive equivalents, the pyroxenites. The analcime phonolites contain the least concentration of these elements.

As in the intrusive rocks, V and Ti are considerably more concentrated in the peralkaline phonolites and melanephelinites. The ranges of concentration of V and Ti as TiO_2 are given in Table 4.12 below.

Rock Type	Vanadium Range ppm	Titanium Range wt.% TiO_2
Melanephelinite	220-750	0.84 - 3.5
Nephelinite	80-600	0.55 - 1.55
Phonolitic nephelinite	125-675	0.65 - 1.6
Analcime phonolite	20-260	0.39 - 1.89
Cancrinite phonolite	60	0.54

Table 4.12. Ranges of concentration of V and TiO_2 in phonolites and melanephelinites.

In Table 4.12, both Ti and V are more concentrated in melanephelinite than in the more leucocratic rocks. The analcime phonolites contain the least V, whilst Ti shows a large spread of values of concentration in the leucocratic phonolites.

The analysed pyroxenes from phonolite and melanephelinite (Appendix 7(a)), showed a greater concentration of Ti in the melanephelinitic pyroxene than in the phonolitic pyroxene, however V shows little relationship to rock type.

(c) Cr, Ni, Cu, Co, V and Ti in fenite.

Cr, Cu, Ni and Co rarely exceed 20ppm in the analysed fenites, excepting Cu in the fenites from Budeda which varies between 5 and 25ppm. Consequently these elements are not concentrated during the fenitisation process at the complexes studied.

V and Ti are less concentrated in the fenites than in the peralkaline intrusive rocks (See Figures 4.1(f) and 4.1(g)). Both elements were found in fenitic pyroxene, being generally in greater concentration than in ijolitic pyroxene, and more comparable with V and Ti contents of the nepheline syenites and microijolites. A decrease in both V and Ti was noted for the elements in the pyroxenes of low grade fenites RR16 and RR6 from Rangwa, with respect to the higher grade fenite RR201.

Accessory sphene of the fenites would concentrate mainly Ti, and also V locally.

(v) (a) Gallium in the peralkaline silicate rocks and fenites.

Geometric means and ranges of concentration of Ga in the intrusive rocks are shown in Table 4.13 overleaf.

Gallium is less abundant in the pyroxenite, ijolite and melanite ijolite, and generally present in greater amount in the urtites, feldspathic ijolite, microijolites and nepheline syenites.

Rock Type	Gallium	
	Mean	Range
Pyroxenite	20ppm	10-30ppm
Ijolite	26ppm	25-50ppm
Melanite Ijolite	30ppm	20-35ppm
Feldspathic Ijolite	41ppm	35-58ppm
Urtite	49ppm	35-60ppm
Microijolite	50ppm	35-58ppm
Nepheline-syenite	45ppm	10-80ppm

Table 4.13. Geometric means and ranges of concentration of Ga in the intrusive silicate rocks.

Form of occurrence of Ga in the intrusive rocks.

In Appendix Tables 7(a) to 7(d), Ga was found to be more concentrated in nepheline and feldspar rather than pyroxene, although traces of Ga were found in all three minerals. Nepheline generally contained the most Ga.

(b) Gallium in the phonolitic rocks and melanephelinites.

Table 4.14 shows the ranges of concentration of Ga in the phonolitic rocks and melanephelinites.

Rock Type	Gallium Range ppm
Melanephelinite	10-40
Nephelinite	35-50
Phonolitic Nephelinite	33-50
Analcime Phonolite	35-80
Cancrinite Phonolite	58

Table 4.14. Ranges of concentration of Ga in phonolitic rocks and melanephelinites.

As in the intrusive rocks, the melanocratic melanephelinites
contain the least Ga, whilst the analcime phonolites contain
the most Ga.

(c) <u>Ga in the fenites.</u>

Ga varies from 25-150ppm in the analysed fenites, being
generally more concentrated in the higher grade fenites at
most complexes. Analyses of fenitic feldspar showed that
considerably more Ga enters this feldspar than the same
mineral from the intrusive rock series, which would account
for the generally higher concentration of this element in
the fenites. Ga therefore becomes a mobile element in
fenitising solutions, and selectively concentrates in the
fenitising solutions associated with the peralkaline rocks.

(vi) <u>Beryllium, Lithium and Tin.</u>

These elements were found not to be concentrated in the
peralkaline rocks. In Appendix Tables 4 (c), 5 (c) and 6 (c),
Li is noted to be more consistently present in the melanite
ijolite, whilst Sn and Be showed little systematic variation.
The phonolitic rocks and melanephelinites contain little
Be, Li or Sn, however the fenites contained the highest
concentrations (although only in few samples) of Be and Li.

Li was found to be notably concentrated in two amphiboles
from fenite (290 and 900ppm Li), (Appendix Table 7 (d)).

Be has been reported as the mineral baryllite
($Be_2BaSi_2O_7$) from fenite at Seal Lake, Labrador, (Heinrich
and Deane, 1962), and from Vishnevogorsk-Ilmen Mountains
massif, S. Urals (Zhabin and Mukhitdinov, 1959).

4.6 Multivariate Statistical Analysis of Geochemical Data for the
peralkaline Silicate rocks and fenites.

The peralkaline silicate rocks, often called the mixed rocks,
are typically varied in mineralogy and consequently in their
geochemistry.

In order to detect any underlying trends in the geochemical
data, correlation analysis was applied to the data, using a
computer program written by the author.

Correlation analysis.

The Pearson product moment correlation coefficient (r_{xy})
was computed using logarithm transformed trace and major
element data collected in the above study. Data pertaining
to ijolitic rocks, nepheline-syenitic rocks, phonolitic rocks,
and fenites from carbonatitic centres in W. Kenya and E. Uganda
were treated in this way.

The computed correlation matrix, containing all possible
correlation pairs is shown in Appendix Table 9(b). Elements
omitted from these calculations were Cr, Cu, Ni, Sn, and Bi,
which proved to be invariably below the analytical detection
limit for each element. The significance of each correlation
was arbitrarily taken as 0.5.

From Appendix Table 9(b), significant positive correlations,
signifying sympathetic behaviour of two elements in the
analysed rocks, were found for:-

$$FeO \quad - \quad MgO$$
$$Fe_2O_3 \quad - \quad MnO, \ TiO_2, \ Nb, \ V, \ Zr$$
$$MnO \quad - \quad Li, \ Nb$$
$$MgO \quad - \quad CaO, \ Co, \ V$$
$$K_2O \quad - \quad Ga, \ Ba$$
$$TiO_2 \quad - \quad MgO, \ Fe_2O_3, \ Co, \ Nb, \ V, \ Zr$$
$$Ba \quad - \quad Sr, \ K_2O$$
$$V \quad - \quad Fe_2O_3, \ Nb, \ TiO_2$$
$$Zr \quad - \quad Fe_2O_3, \ TiO_2$$

Negative correlations, indicating antipathetic variation
of two elements (or oxides in the case of major elements) in
the analysed rocks were indicated for:-

Na_2O	-	Co
FeO	-	Fe_2O_3
K_2O	-	FeO, MgO, Co
Ga	-	Mg, Co
TiO_2	-	La
La	-	CaO, Nb, TiO_2

Ce, Y and Zn showed no significant correlation with other
analysed elements.

The inter-relationships between the elements expressed in
the correlation matrix are related to the rock mineralogy.
The occurrence of Fe^{3+}, Ti, Nb, V, Zr in garnet and sphene
(or related to the occurrence of titanosilicate minerals in
the rocks), (see Appendix Tables 7 (d) and 8 (a)), are
represented as positive correlations, as are K_2O, Ga, and Ba
which are found in relatively large amounts for each element
in potassium feldspar, (Appendix Table 7 (c)). The presence
of MgO, Ca, Co and V in pyroxene are also reflected as
positive correlations. The negative correlations essentially
represent the antipathetic behaviour of elements concentrated
in melanocratic rocks with those elements concentrated in
leucocratic minerals and rocks. The association of FeO, MgO,
and Co (amongst others which are not represented in the matrix)
in melanocratic rocks , are negatively related to Na and Ga
which are generally present in greater concentration in the
leucocratic rocks.

4.7 Discussion.

As in the carbonatitic rocks (Chapter 3, this thesis), all
the peralkaline silicate rocks contain a characteristic
assemblage of trace elements, which, with the exception of Zr
which is much more abundant in the silicate rocks, are also
characteristic of the carbonatitic rocks.

The trace elements are mainly dispersed as isomorphous
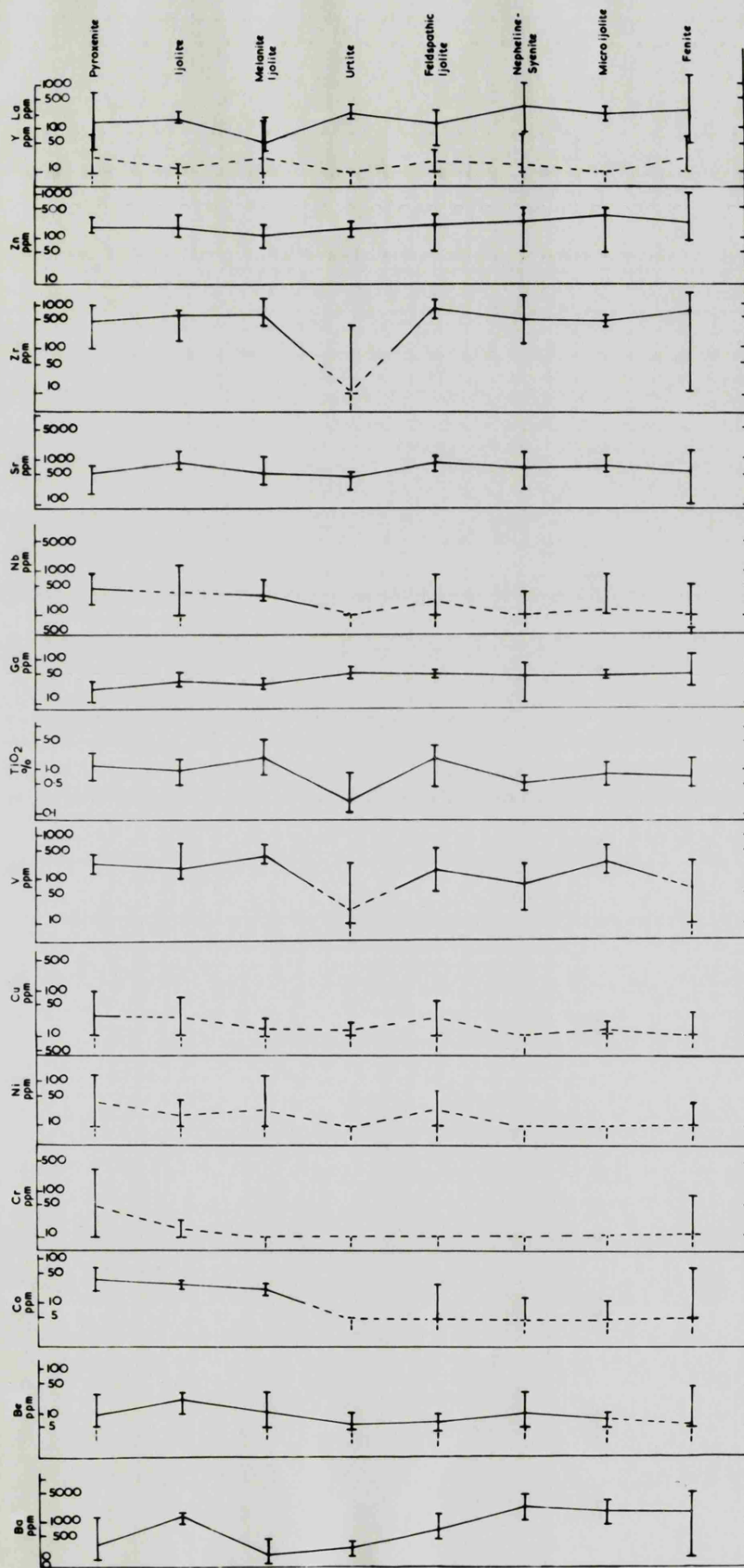
FIG 4.3   Geometric means and ranges of concentration of Ba,Be,Co,Cr,Ni,Cu,V, TiO₂, Ga,Nb,Sr,Zr,Zn,Y, La and Mn, in pyroxenite , ijolite,
melanite ijolite, urtite, feldspathic ijolite, nepheline syenite , micro ijolite   and   fenite, associated with carbonatites in
W. Kenya   and   E. Uganda

Dashed lines indicate that some analyses are below the detection limit for that element
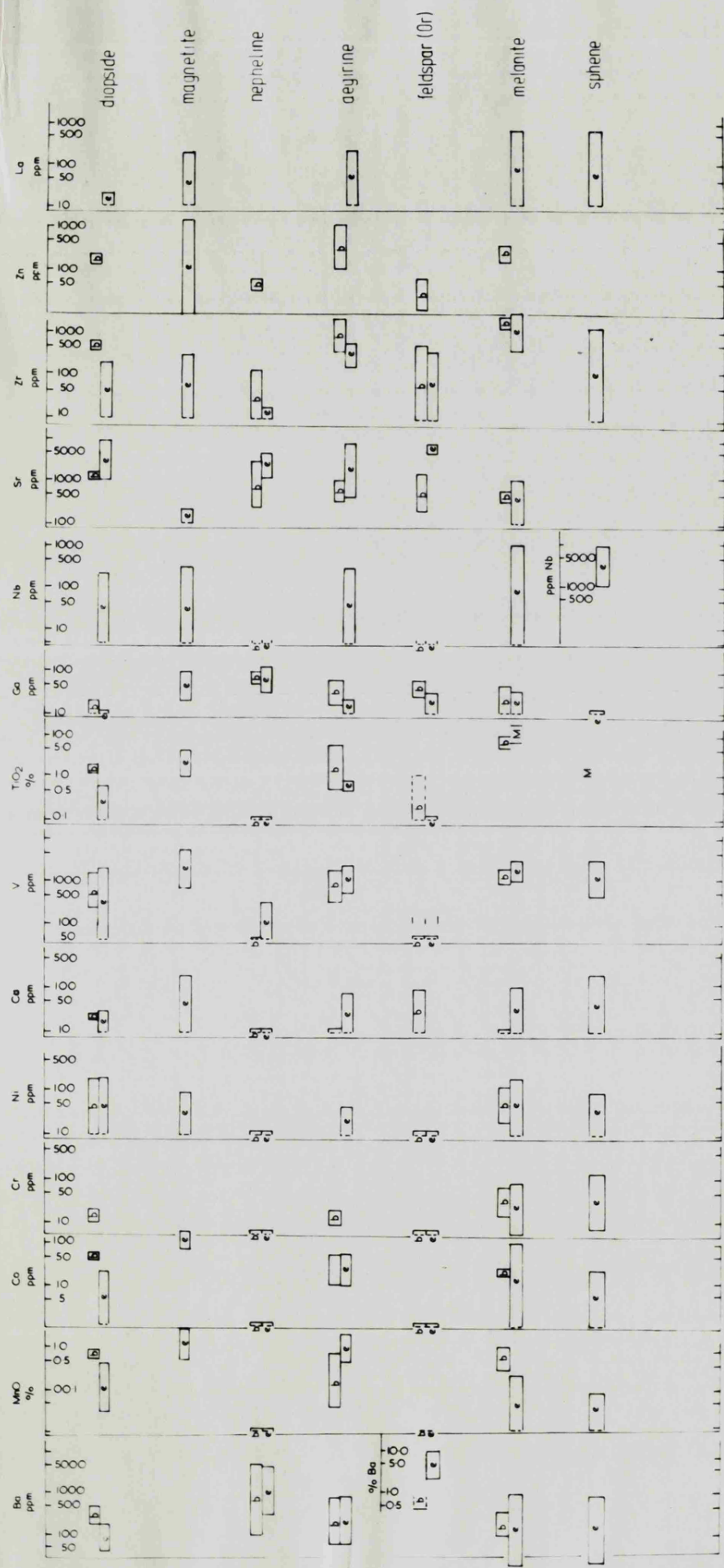
Fig. 4.4. The distribution of trace elements in minerals from peralkaline silicate rocks from carbonatitic complexes in W Kenya and E Uganda. Comparison is made with similar data given by Erikson and Blade (1953) for the Magnet Cove peralkaline complex, Arkansas.

b - data from this study, e - data from Erikson and Blade (1953), M - major element.

substituted elements in the crystal lattices of the major
and accessory minerals of the peralkaline rocks. Rare-
element minerals are typically absent from these rocks,
unlike the carbonatitic rocks. The distribution of the
various trace elements between the various minerals of
the ijolitic rocks are summarised in the Figure 4.4,
and compared with data from Erikson and Blade (1963).

Significant variation in the concentrations of
individual elements between the various rock types are
apparent from previous discussions in this chapter.
This variation is summarised below for the plutonic
peralkaline rocks and fenites, into a number of related
associations which may have genetic significance. The
data is summarised graphically in Figure 4.3.

All the plutonic peralkaline rocks show a lack of
the elements Cr, Ni, Cu and Co. These elements, however,
are more abundant in the pyroxenitic rocks than in other
ijolitic rocks. Also V and Ti greatly exceed the
concentrations of the former elements.

The Ca-enrichment of the melanite ijolites is
noteworthy, and the variability of the elements Ti, Zr,
Nb, and V in the ijolitic rocks was found to be related to
the occurrence of melanite garnet.

The nepheline-syenites characteristically are enriched
in Ba, Ga, Zr and to a lesser extent Zn and V. These
elements were found in the major rock forming minerals
of this rock, Ba in large concentrations in feldspar,
Zr, V, Zn in the acmitic pyroxene of this rock type.

The fenites show a similar distribution of these
elements to the nepheline-syenites, containing Ba and
Ga enriched feldspar, and Pyroxene containing relatively
large concentrations of Zr, V, and Zn. The paucity of
these elements in the country rock around the peralkaline
rocks leads to the conclusion that these elements are
introduced into the country rocks by fenitising
solutions, along with other trace elements typical of

this volcanic activity such as Sr, and the rare-earth elements.

In the volcanic rocks there is also a general lack of the elements Cr, Ni, Co and Cu, whilst V and Ti are also present in much greater quantity. The volcanic equivalents of the pyroxenites, the melanephelinites, were found to contain the greatest concentrations of Cr, Ni and Cu in comparison with the other volcanic rocks.

The phonolitic nephelinites and the analcime phonolites show a marked silica enrichment over the melanephelinites and nephelinites. This behaviour is coupled with a decrease in the concentrations of Ba, Cr, Ni, Co and Cu, whilst Sr, rare-earth elements, (Ce, La and Y), Zr and Ga tend to increase in concentration.

The divergence in behaviour of Sr and Ba in the volcanic rocks from that observed in the plutonic series is note-worthy. Similarly, the Zr, V and Zn enrichment of the more acmitic pyroxenes of the later phonolites compares well with relationships noted in the plutonic rocks.

Petrographic study of the plutonic rocks showed that the minerals melanite, and sphene were developed at a late stage in the ijolitic rocks, (Clarke, 1968; Sutherland, 1966). The incorporation of large concentrations of Ti, V, Zr, Nb, and Zn in the garnet and sphene, and lack of these elements in other major minerals suggests that these elements are concentrated in residual liquids with crystallisation of ijolitic liquids under plutonic conditions.

Similarly, the greater concentration of Zr, V, Zn and to a lesser extent Sr in the later developed acmitic pyroxene of the ijolites, and the incorporation of large concentrations of Ba, and Ga into the feldspar, also a late stage mineral of the ijolitic rocks (Clarke, 1969), would indicate that these elements are also concentrated to a large extent in residual liquids. These elements

are   only removed from the liquid in appreciable amounts
with the crystallisation of these late minerals.

The fenitic rocks, which characteristically contain
large concentrations of Ba, Zr, Ga, Zn and to a lesser
extent V and Ti, and Nb, thus contain an assemblage of
trace elements which are characteristic of the later stages
of ijolitic liquids.

The volcanic rocks are typically enriched in Zr, Zn,
Ga, and the rare-earth elements in the phonolitic rocks
relative to the melanephelinites. Sr and Ba, however,
show distinctly different behaviour to that in the plutonic
rocks, tending to be more concentrated in the early
melanephelinites. Also, unlike the plutonic nepheline-
syenites, the later feldspar rich phonolites are not
greatly enriched in Ba compared to the earlier rocks.

4.8. Evidence for the origin of the peralkaline rocks and fenites.

Bailey and Schairer (1966) noted that none of the
usually invoked schemes of fractional crystallisation of
basalt would yield strongly undersaturated peralkaline
(ijolitic) residual liquids. The absence of rocks of
basaltic composition from most of the peralkaline igneous
centres in W. Kenya and E. Uganda would support this.

No other rocks in the earth's crust consistently
contain such an assemblage of trace elements as the
peralkaline silicate rocks. Thus derivation of such rocks
from partial melting of the crust, or by assimilation of
crustal rocks by (basic) magma would appear untenable,
(see also Higazy, 1952).

The plutonic and volcanic rocks from E. Uganda were
considered to have been derived from a common parent liquid,
(King and Sutherland, 1966). The near coincidence of the
composition of melanephelinite and pyroxenite led these
authors to state that it is in this compositional range

that the immediately parental magma is to be sought.

The greater concentration of Cr and Ni in the pyroxenites
and melanephelinites compared to the other peralkaline
rocks is consistent with the removal of these elements
from a peralkaline liquid in early crystallised mafic
minerals. The selective concentration of Cr and Ni in
early crystallised olivine, pyroxene and iron ore in more
basic igneous rocks has been demonstrated (Wager and
Mitchell, 1951). This data would thus support the field
and petrographic evidence, that the earliest formed rock
type was pyroxenite, with its volcanic equivalent
melanephelinite. It would thus appear probable that the
parental liquid to the peralkaline silicate rocks was
melanephelinitic in composition.

The trace element characteristics of the igneous
peralkaline rocks as a whole from W. Kenya and E. Uganda
(abundance of Sr, Ba, Ga, REE, Zr and Nb and the Ce-earth
enrichment of all the rocks) suggests a genetic relation-
ship between the volcanic and plutonic rocks. Also the
similar concentration of the trace elements in the fenitic
rocks from these complexes indicate that fenitising
solutions associated with peralkaline volcanism are also
enriched in such trace elements.

Considering the plutonic rock series, King and
Sutherland (1966) noted two main associations of rock
types. These were the pyroxenite-melteijite-ijolite-
urtite (ijolitic) series, and the nepheline-syenite
series including syenitic fenite.

The former ijolitic series characteristically became
depleted in the trace elements Cr, Ni, Cu and Co from
pyroxenite to urtite, whilst later rocks were enriched
in Zr, Ti and Nb, and possibly Sr and Ba.

This contrasts with the trace element geochemistry
of the nepheline syenites at these complexes, which are
enriched in REE (Chapter 2, Figure 2), Zr, Ba, Ga and
Zn relative to the ijolitic rocks (Figure 4.3). The

similar trace element distribution between the syenitic
fenites and the nepheline-syenites suggest that fenitising
solutions have played an important part in the formation
of the nepheline-syenites.

Comparison of the major element geochemistry of the
ijolitic rocks and phonolitic rocks showed the plutonic
and volcanic rocks to display markedly divergent trends,
(King and Sutherland, 1966). The ijolitic rocks alone
showed a marked enrichment in Ca, whilst the phonolitic
rocks were enriched in Si in later phonolites, and were
characterised by a crystallisation sequence in which the
crystallisation of nepheline was ultimately joined by
alkali feldspar. The phonolitic rocks from E. Uganda
were regarded as crystallisation-differentiation products
of a nephelinitic magma. Confirmation of the possibility
of producing such liquids from initial nephelinitic
compositions by fractional crystallisation, was obtained
by Bailey and Schairer (1966) in the synthetic system
$Na_2O-Al_2O_3-Fe_2O_3-SiO_2$.

The general decrease in concentration of Cr, Ni, Cu,
Co, Sr and Ba and increase in the concentrations of REE,
Ga, Zr, Zn and Pb in the series melanephelinite-phonolitic
nephelinite-analcime phonolite, indicates that these rocks
are related to a scheme of fractional crystallisation
which contrasts with that observed in the plutonic rock
series.

Also the contrasting trace element distributions between
the phonolitic rocks and their plutonic counterparts, the
nepheline-syenites, suggests that these rock types are of
different origin.

4.9. Conclusions.

The peralkaline silicate rocks and fenites, typically
the plutonic rocks, are heterogeneous in mineralogy, and
hence in their trace element geochemistry. Despite the

inherent variation in trace element distribution, several
geochemical factors common to all rocks, and also common
to individual petrographic groups have become apparent.
These may be summarised as follows:-

(1)   All the plutonic and volcanic peralkaline igneous
rocks are characteristically enriched in Sr, Ba, REE, Nb,
Ti, and V, and depleted in the elements Cr, Ni, Cu and Co.
These elements are present for the most part as isomorphous
substituted elements in the crystal lattices of the major
and accessory minerals of these rocks.   The greater
concentration of the latter elements in the pyroxenites
and melanephelinites, would indicate that these rocks were
formed early in the crystallisation history of the
peralkaline liquids.

(2)   Differences in the distributions of trace elements
in the volcanic and plutonic series, particularly in the Sr
and Ba concentration would indicate that the two series have
followed different courses of crystallisation, giving
residual fluids of differing composition.

(3)   The fenitic rocks contain large concentrations of
Ba, Sr, REE and Zr, and less abundant Ti, Nb and V.   The
absence of such concentrations of these elements from
unfenitised basement leads to the conclusion that these
elements are introduced into country rock by fenitising
solutions.

(4)   The similarities of the trace element distribution
within the nepheline-syenites and the syenitic fenites
from W. Kenya and E. Uganda show that fenitising
solutions have played an important part in the origin
of both these rocks.

C H A P T E R   F I V E.

Comparative geochemistry of Carbonatite and
Silicate Rocks from W. Kenya and E. Uganda,
and discussion on the origins of these rocks.

5.1. Introduction.

This final chapter is intended to express the conclusions
reached by the author in the preceding study, and is based on
the geochemical data as a whole, presented in this thesis.

Comparisons are drawn between similar data from complexes
outside East Africa, and the relationships between the various
rock types within the complexes of W. Kenya and E. Uganda are
discussed.

The aim throughout this study has been to sample the
carbonatites and related peralkaline silicate rocks and
fenites (and minerals within these rocks), in order to
geochemically characterise each major petrographic rock type.
This has inevitably led to seemingly heterogeneous
distributions of trace elements within the single petrographic
groups, due essentially to the sporadic occurrence of
accessory and rare minerals within the rocks. Two examples
of such behaviour are shown by pyrochlore in the
carbonatites, and sphene in the silicate rocks.

Such sampling of broad petrographic groups, based on
a relatively small number of samples of often heterogeneous
rocks could, and often does lead to erroneous conclusions
regarding the distributions of trace elements within the
rock series. The author is thus aware that analyses of
carbonatites and peralkaline rocks in the future may well
refine this data and lead to better and wider characterisation
of the distributions of trace elements within these rocks.

Variations in concentration of individual elements within

the petrographic groups has been expressed in the text as geometric means and ranges of concentration of each element for each rock type. This was done in order to show the variation in concentration of a particular element in a number of samples, as well as the most prevalent level of concentration, expressed as the geometric mean.

From these parameters, generalised relative features of depletion and concentration of each element in the various rocks became apparent.

5.2.   (a) The carbonatitic rocks.

In Chapters 2 and 3, the distributions of 21 trace elements and 5 major elements (Fe, Mg, Mn, Ti and Al) in carbonatitic rocks from W. Kenya and E. Uganda were investigated. These studies showed that the carbonatites were enriched in the elements Ba, Sr, REE, Nb, Mn, Fe and to a lesser extent Zn, Ti, Zr and V. The rare-earth elements were typically Ce-earth enriched with Ce/Y in some cases being greater than 100.

The elements Cr, Ni, Cu, Pb, Sn, Li, Mo, Ga, Ce, and Ag were rarely present in concentration greater than 10ppm in the carbonatites. However, Ga, and Pb were found in much greater concentrations in feldspathised country rock adjacent to the carbonatitic intrusions.

The carbonatitic rocks also showed an enrichment in the elements Ba, Fe, Mn, REE, and Zn in the alvikites relative to sovite, whilst Sr was relatively depleted in the alvikites. The ferruginous alvikites contained the greatest concentration of Fe, Mn, Ba, Ce-earth elements and Zn, whilst V and Mo were locally concentrated in these rocks.

The carbonatitic breccias and melilite-pseudomorph carbonatites also contained a characteristic assemblage of trace elements, which were characteristic of the carbonatites proper (sovite, alvikite and ferruginous alvikite). Similarly, the melilite-pseudomorph carbonatites, intruded at a late

stage in the development of the Homa Mountain complex,
showed marked similarity in trace element distributions
to the late-stage carbonatites, the ferruginous alvikites.

(b) The peralkaline silicate rocks and fenites.

The silicate rocks associated with carbonatites show
a very similar assemblage of trace elements to the
carbonatites.

The elements Cr, Ni, Cu, and Co are not present in
concentrations greater than 100ppm in most silicate rocks,
however these elements were most concentrated in the
melanephelinites and pyroxenites relative to other rocks
analysed in this study. In all the rocks Ti and V always
exceeded the concentrations of Cr, Ni, Cu and Co.

As in the carbonatites there is an abundance of Ba, Sr
and rare-earth elements. The rare-earths are always
Ce-earth enriched. Nb, Ti and to a lesser extent V are
enriched in those rocks which contain melanite garnet and
sphene, whilst Zr and Ga are present in much greater
concentration in the silicate rocks than in the carbonatitic
rocks.

Considering the relationships between the various rock
types, it is apparent that:-

(1) The rocks of pyroxenitic (melanephelinitic)
composition contain and greatest concentration of those
elements usually removed from more basic magmas in early
crystallised mafic minerals, and thus represent the earliest
formed rocks.

(2) The melanite ijolites, containing melanite and sphene
which were demonstrably later than the nepheline and pyroxene
in the ijolites, are enriched in Ti, Zr, Nb and Y, which
suggests that these elements are concentrated in later
residual ijolitic liquids.

(3) The nepheline-syenites are enriched in the elements
Ba, Zr, REE and Ga. The latter elements are also concentrated

to similar extent in the syenitic fenites, which indicates
a genetic relationship between nepheline-syenite and
fenitising solutions.

(4) The later phonolitic rocks are enriched in Sr and
relatively depleted in Ba in comparison with their plutonic
counterparts, the nepheline-syenites.

(c) The relationship between the trace element distributions
of the carbonatites and related peralkaline silicate
rocks from W. Kenya and E. Uganda.

The carbonatites and related silicate rocks show a number
of factors in common, as regards trace element distributions,
it is these factors which are characteristic of alkaline
volcanism as a whole (Heinrich, 1966; vanWambeke, 1964; Temple
and Grogan, (1965); Erikson and Blade, 1963).

These factors may be summarised thus:-

All the rocks lack the elements Cr, Ni, Co and Cu and
contain much greater concentrations of V and Ti.

Both the carbonatites and related silicate rocks contain
an assemblage of characteristic trace elements, (Sr, Ba, REE,
Nb, Zr) although considerable variation in concentrations of
these elements is apparent in these rocks.

All the rocks are Ce-earth enriched, despite great
variation in mineralogy in the rocks as a whole.

As stated above, great variation in concentrations of
individual elements between the various petrographic rock
types are apparent.

The generally greater concentration of the rare-earth
elements (REE) in the carbonatites was noted in Chapter 2,
whilst the extreme concentrations of these elements were also
found in the late stage carbonatites.

Similarly, the greatest concentrations of Sr were noted
in the early sovitic carbonatites, the greatest concentrations
of Nb were found consistently in the alvikites, and Ba was
most concentrated with REE, Fe and Mn in the later ferruginous
alvikites.
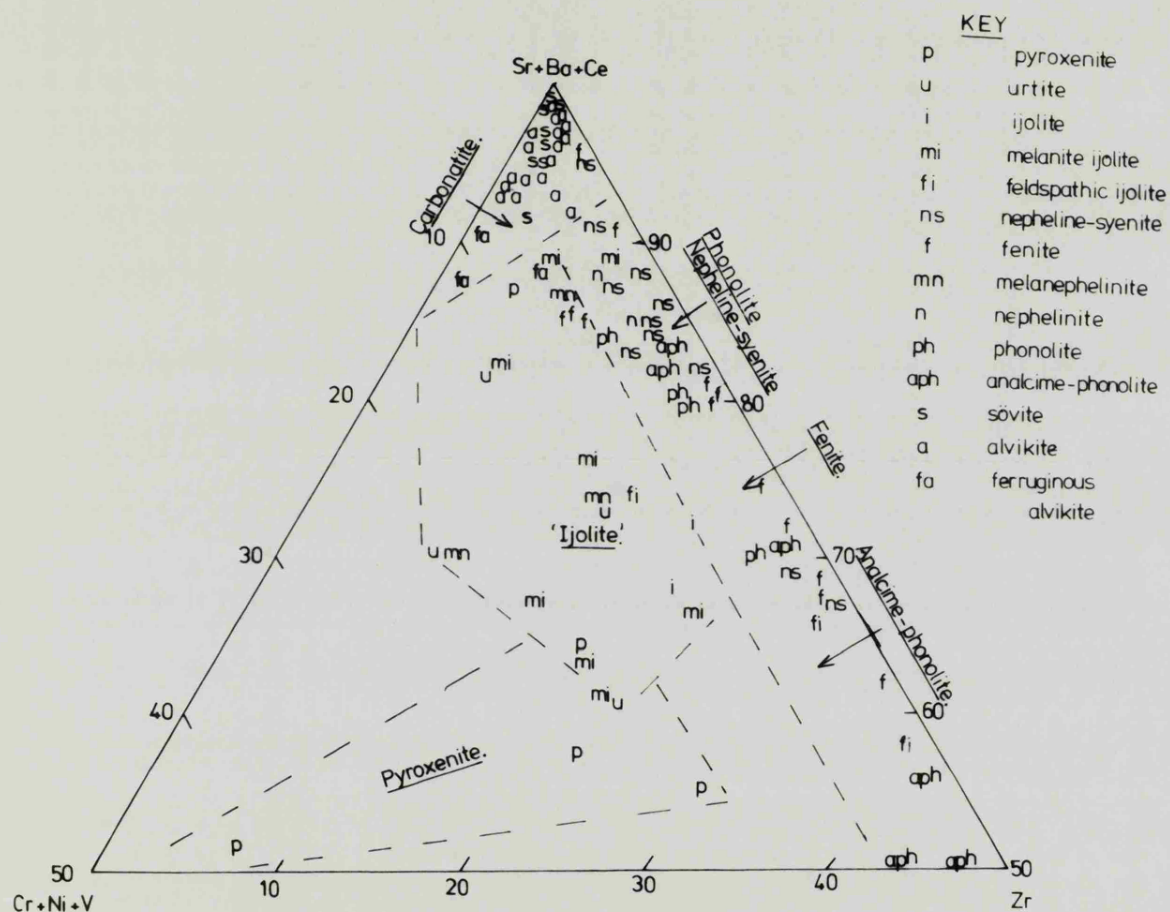
Fig. 5.1. Relative proportions of Sr+Ba+Ce, Cr+Ni+V and Zr in carbonatites and related silicate rocks from W. Kenya and E. Uganda. The fields of pyroxenite, ijolite (including melanite ijolite, feldspathic ijolite and urtite), nepheline-syenite, fenite, analcime-phonolite, phonolite and carbonatite (sovite, alvikite and ferruginous alvikite) are shown.

In contrast to these observations, Zr and to a lesser extent V and Ti, are present in greater concentrations in the peralkaline silicate rocks and fenites.

The distribution of trace elements between the various rock types found at the carbonatitic complexes in W. Kenya and E. Uganda is summarised in Figure 5.1, where Sr+Ba+Ce, V+Cr+Ni, and Zr have been calculated and plotted for all analysed rocks, on a triangular diagram.

The carbonatites are distinguished from the silicate rocks in containing the greatest relative amounts of Ce+Sr+Ba, and negligible concentrations of Cr, Ni, V and Zr. The ijolitic rocks, especially the pyroxenites, contain much greater concentrations of Cr+Ni+V, whilst the nepheline-syenites, and fenites are more enriched in Sr+Ba+Ce than the ijolitic rocks, and show a wide range of relative concentrations of Zr, and little Cr+Ni+V. The analcime phonolites are most enriched in Zr compared to other trace elements.

5.3. Origin of the peralkaline silicate rocks and carbonatites.

The relationships between the peralkaline silicate rocks and the carbonatites has been discussed at length in the literature, and remains controversial, (e.g. King, 1965; King and Sutherland, 1966; Heinrich, 1966; Tuttle and Gittins, 1966).

Two main theories concerning the origins of the peralkaline silicate rocks and carbonatites have been summarised by Heinrich, (1966, p.289). Briefly these require that -

(a) Carbonatite is a primary magma, and the peralkaline silicate rocks are produced by reaction of this magma with country rock to give fenite, ultrafenite, which are remobilised to produce intrusive peralkaline silicate rocks.

(b) The initial magma was mafic or ultramafic in composition, and carbonatite is a differentiate of this

magma. The composition of the parent magma has been variously suggested to be alkali-peridotite, pyroxenite, kimberlite, ijolite, nephelinite, peridotite.

The concentration of Cr, Ni, and Co in the early intruded silicate rocks (pyroxenite and melanephelinite), and absence of these elements in fenites and nepheline-syenites and carbonatites provides evidence for the origin of these rocks by crystallisation-differentiation of an undersaturated peralkaline liquid, rather than by partial melting of fenite or ultrafenite. It has thus been suggested (see Chapter 4) that the ijolitic rocks, and possibly the volcanic equivalents of these rocks, the melanephelinite-nephelinite rocks, originated by crystallisation differentiation of an undersaturated liquid, at the complexes in W. Kenya and E. Uganda.

The similarity of the trace element distributions in the fenites, and those found in the nepheline-syenites, however, has led to the conclusion that these rocks represent remobilised fenites, or ultrafenites. The source of the fenitising solutions must lie within the peralkaline liquid or the carbonatitic liquid, due to the abundance of trace elements which were transported along with fenitising solutions.

The feldspathisation around carbonatite intrusions and apparent absence of aegirine in these rocks, would suggest that most Na-fenitising solutions are evolved from ijolitic liquids.

The complete contrast between the mineralogy of the carbonate and silicate rocks makes comparison of trace element distributions between the two rock types difficult.

King, however, (1965), noted that calcite was often primary late-stage mineral in the ijolitic rocks and that the accessory minerals of the carbonatitic rocks were often "those which characterise the late silicate rocks".

On the other hand, the absence of carbonatitic
minerals such as pyrochlore from the ijolitic rocks
lends support to an argument that carbonatitic liquids
were separate from the peralkaline silicate melts during
the formation of these complexes. Similarly, the trace
element geochemistry would indicate no rocks transitional
between ijolite and carbonatite.

It is also difficult to envisage a carbonatitic 'fluid',
composed of predominantly carbonates, being a residual
liquid after crystallisation of ijolite, unless the
carbonatites are of hydrothermal origin. Watkinson,
(1970), however, noted that fractionation of liquids in
the synthetic system $NaAlSiO_4$-$CaCO_3$-H_sO at 1 k bar could
lead from liquids precipitating nepheline, and melilite
plus nepheline to liquids precipitating predominantly
calcite.

It has been demonstrated previously that the carbonatites
from W. Kenya and E. Uganda are of magmatic origin, (Dixon,
1969); Flegg, (1969).

A mechanism for such conditions to occur, would be
for carbonate and peralkaline silicate liquids to coexist
as immiscible liquids, one carbonate, the other silicate
melt. Synthetic melts in the system $NaAlSi_3O_8$- Na_2CO_3-
H_2O (van Groos and Wyllie, 1968) were shown to contain
immiscible carbonate and silicate liquids coexisting with
vapour, under conditions of high p_{CO_2}.

The relatively large concentrations of Sr, Ba, REE, and
Nb in the carbonatites compared to the ijolitic rocks suggest
that the carbonatites are residual. The constant association
of characteristic trace elements in both silicate and
carbonate rocks and the generally greater concentration of
these elements in carbonatites, could be explained on the
basis of crystallisation-differentiation of carbonate rich
peralkaline liquid, leading in the later stages of

differentiation to liquid immiscibility of the silicate
and carbonate magmas.

The carbonatites were shown to belong to a fractionation
series characterised by increasing concentration of REE, Ba,
Fe, Mn, and Zn and decreasing Sr which coincided with the
order of intrusion of the carbonatites. Nb and Ti were
generally more abundant in the "intermediate" carbonatites,
the alvikites.

The alvikites and ferruginous alvikites thus represent
the final products of igneous activity at these complexes,
marked by the appearance of Nb-rich pyrochlore, and rare-
earth minerals in these rocks.

5.4 Comparison of the trace element distributions of carbonatites
and peralkaline rocks, with the distribution of trace elements
in other igneous rocks.

In Table 5.1 the geometric means of trace and minor
elements in ijolite, nepheline-syenite and carbonatite
(alvikite) from complexes in W. Kenya and E. Uganda are
compared with "average" abundances for those elements in
ultrabasic rocks (Vinogradov, 1961; Turekian and Wedepohl,
1961); basic rocks (Vinogradov, 1961; Turekian and Wedepohl,
1961), and Ca-poor and Ca-rich acid rocks (Turekian and
Wedepohl, 1961). These rocks are also compared with the
"average" nepheline-syenite given by Gerasimovsky et al,
(1966) for the Lovozero Alkali massif, Kola peninsular
U.S.S.R.

It is apparent from Table 5.1 that the ijolitic and
nepheline-syenite rocks are more enriched in the elements
Ba, Be, Ga, Li, Nb, Sr, Zn, Zr and Pb and REE relative to
both basaltic and acid igneous rocks. The Lovozero
nepheline-syenite is, however, more enriched in Zr and
Nb and Ree, and depleted in Ba and Sr compared to the
ijolitic and nepheline-syenites from W. Kenya and E. Uganda.

1. Average ultrabasic rock, Vinogradov 1961.

2. Average ultrabasic rock, Turekian and Wedepohl , 1961.

3. Average basic rock. Vinogradov 1961

4. Average basic rock. Turekian and Wedepohl 1961.

5. Average Ca-poor acid rock. Turekian and Wedepohl 1961.

6. Average Ca-rich acid rock. Turekian and Wedepohl 1961.

7. Lovozero nepheline-syenite. Gerasimovsky et al 1966.

8. Ijolite geometric means, this study.

9. Nepheline-syenite geometric means, this study.

Table 5.1. Average concentrations of selected trace elements in various igneous rocks, compared to trace element concentrations in rocks analysed in this study.

	1	2	3	4	5	6	7	8	9
Ba	1	0.4	300	330	840	420	680	1350	2450
Be	0.2	-	0.4	1	3	2	8.7	23	<40
Cr	2000	1600	200	170	4.1	22	27.8	<10	<10
Co	200	150	45	48	1	7	-	-	-
Ni	2000	2000	160	130	4.5	15	12	<10	<10
Cu	20	10	100	87	10	30	11	-	-
Ga	2	1.5	18	17	17	17	60	26	45
Li	0.5	-	15	17	40	24	55	10	-
Nb	1	16	20	19	21	20	696	330	-
Sr	10	1	440	465	100	440	610	850	825
V	40	40	200	250	44	88	108	175	87
Zn	30	50	130	105	39	60	210	175	240
Zr	30	45	100	140	175	140	3480	680	510
REE	-	-	117	131	275	239	2050	-	-
Mo	0.2	0.3	1.4	1.5	1.3	1.0	1.7	<10	<10
Pb	0.1	1	8	6	19	15	14.6	<10	<10

This   is possibly due to the fact that the Zr and Nb
enriched melanite-ijolites have not been included with
the ijolites from East Africa.

Comparison of the geochemical characteristics of the
silica-undersaturated rocks association with rocks of basaltic
composition from oceanic islands (nephelinites, melilitites,
etc.) (Green and Ringwood, 1967), and the peralkaline rocks
analysed in this study show similarities in both trace and
major element distributions. Both rock series are enriched
in alkali elements, Sr, Ba, Nb, REE, Zr, and Zn, and are
depleted in Cr, Ni, Co and Cu relative to tholeitic basalt.
Similarly both rock types are Ce-earth enriched.

Green and Ringwood (1967), regarded the concentration of
rare elements and overall enrichment in Ce-earths in the
alkaline lavas as being too extreme for these rocks to have
been derived from fractionation of basalt. They suggested
that magma generated in the mantle cooled by wall rock
reaction in the mantle, where the temperature of the
surrounding rock was only a little less than that of the
magma. Wall rock reaction was responsible for solution
of low melting components from the wall rock, and for the
incorporation of these into the magma, a process related
to zone refining (Harris, 1957). The low temperature
melting components, containing 'incompatible' elements
were considered by Green and Ringwood to be present in
such phases as apatite and Mg-ilmenite and phlogopite
in the mantle. The presence of greater concentrations
of incompatible elements in the alkaline rocks was
attributed to such processes affecting magma, which was
generated in the mantle, and which gave undersaturated
lavas on extrusion.

From experimental considerations in the synthetic
system $Na_2O-Al_2O_3-SiO_2-Fe_2O_3$ at 1 k bar pressure, and
from field relationships, Bailey and Schairer, (1966),

showed that none of the usually invoked scheme of
fractionation of basalt would yield strongly under-
saturated (peralkaline) ijolitic residual liquids.
This statement is supported by the almost complete
absence of rocks of basaltic composition from the
complexes of W. Kenya and E. Uganda. It was suggested
by these authors that ijolite and carbonatite originated
in the mantle as low-temperature partial melts of mantle
material. More recently Le Bas, (1971), and Bailey,
(1969), concluded that 'degassing' of the mantle beneath
the continent of Africa had given rise to the peralkaline
volcanic rocks typically found in W. Kenya and E. Uganda.

The assemblage of trace elements present in the
peralkaline plutonic and volcanic rocks show that these
rocks contain concentrations of those elements normally
considered to be present in incompatible elements in the
mantle minerals. These would be concentrated in low
temperature partial fusion products of mantle material.
The concentration of trace and major elements, and
fractionation of rare-earth elements to Ce-earth enriched
compositions, could thus be accounted for by means other
than that of sialic contamination.

The problem of the restriction of carbonatitic igneous
activity to stable continental blocks, and absence of
these rocks from oceanic areas remains problematic.
Likewise, it would be difficult to obtain concentration
of small volumes of silica undersaturated liquid derived
by partial melting of mantle material, into large localised
magma bodies.

A P P E N D I X   O N E.

A.   Preparation of samples for analysis.

Samples chosen for analysis were firstly cleaned of weathered material, and then brought down to approximately 0.5cm rock fragments using a rock slicer.

The carbonatitic rocks and breccias were then crushed to minus 200 mesh in a steel Tema mill for approximately two minutes. Little contamination of the samples was found using this method on the relatively soft carbonate rocks.

The harder silicate rocks were found to be contaminated with Cr and Ni using the steel Tema mill. These rocks were crushed to minus 200 mesh in a percussion mortar, which gave no detectable contamination of the samples.

Powdered samples were stored in stoppered glass bottles, and were dried at $110^{o}C$ in an oven before analysis.

Rocks from which minerals were to be separated for analysis were prepared in a similar manner to the rocks above. However, various size fractions were taken from the crushed powders (generally 60-100 and 100-150 mesh fractions depending on the rock grain size) using nylon bolting cloth. Each size fraction was washed in distilled water to separate adhering fine dust from the coarser grains, and then washed in acetone, dried, and stored in a stoppered glass tube. Separations were achieved using bar-magnet, Frantz isodynamic magnetic separators, and finally purified by hand picking under a binocular microscope. Each rock usually required different settings for the magnetic separator, depending on grain size and quantity of minerals present in the fractions.

The purified mineral separates were crushed to minus 200 mesh in an agate mortar, and were stored as above.

B. **X-ray Fluorescence analysis for Ce, La, Nd, Dy and Y.**

The rock powders were pelletised using a backing of cellulose at a pressure of 15 tons. Care was taken to avoid contamination during pelletisation, and the powder surface was kept clean and not handled.

The analyses were carried out using a Siemens Krystalloflex 4 X-ray fluorescence spectrometer, employing Cr and W target X-ray tubes. The analytical lines, type of X-ray tube used, and type of counter used are shown in Table 1 for each element. Standard powders for each element in the carbonatites were made up using routine 'spiking' techniques, which involved the mixing of the element oxides with a carbonatite base to give a 10000ppm standard. This standard, and subsequent standards were then diluted with the carbonatite base to give a range of standards for these elements. All standards were thoroughly mixed before dilution to give the next highest standard, and all were pelletised in the same manner as the samples.

The standards for the silicate rocks were produced in the same manner as those for the carbonatites, using an ijolite base for dilution and mixing with the rare-earth oxides.

During the analyses, the standards were run each day to calibrate the instrument, and the 5000ppm standard every fourth sample in order to correct for instrument drift.

Calibration graphs were drawn for each element using standard procedures, and the approximate concentration in ppm of each element were obtained from these graphs, after corrections for instrument drift.

Corrections for mass absorption were applied to the approximate concentrations, using major element analyses obtained from spectrometric analysis (see below). These corrections, giving final figures for concentrations of each element in the rocks, did not vary greatly from unity. Repeat determinations on several samples throughout the

analyses showed that results were reproducible to generally better than 5% relative error, and always better than 10%.

Element	Peak 2θ	Background 2θ	Scintillation counter	Gas flow counter	Radia- tion	Tube
Y	23.78	23.0	X		KA1	W
La	82.72	84.0		X	LA1	Cr
Ce	71.76	71.2	X		LB1	W
Nd	72.22	73.0	X		LA1	W
Dy	50.26	51.0	X		LB1	W

Table 1. Conditions for analysis for Ce, La, Nd, Dy and Y using X-ray fluorescence spectrometry.

C. Spectrometric analyses.

Spectrometric analyses were carried out on both carbonate and silicate rocks and minerals using an A.R.L. 29000B direct reading emmission spectrometer (Quantometer). Lines were set on this instrument for major elements Al, Ca, Fe, Mg, Mn, Si, Ti, and for trace elements Ba, Be, Cr, Ni, Pb, Nb, Sn, Sr, Bi, Ga, Ge, Sr, V, Zr and Zn.

The positioning of the lines is shown in Table 2 overleaf.

The operation and description of the instrument is given by Tennant and Sewell, (1969), and the operating conditions used for routine analyses for the Leicester 29000B spectrometer are described by Davenport, (1970).

Element	Line ($\overset{o}{A}$)	Slit Width (μ)
Al	2378.4	75
Ca	3158.9	150
Fe	2739.6	150
Mg	2790.8	75
Mn	2933.0	75
Si	2435.2	75
Ti	3653.5	75
Ba	4550.0	50
Be	3130.4	50
Bi	3067.7	50
Co	3453.5	50
Cr	4254.4	50
Cu	3274.5	75
Ga	2943.6	75
Ge	3039.1	75
Li	6103.1	50
Mo	3170.3	50
Nb	3195.0	50
Ni	3424.7	50
Pb	2833.1	50
Sn	2840.0	50
Sr	4607.3	50
V	4379.2	75
Zn	4810.5	75
Zn	2183.6	50
Zr	3392.0	50

Table 2. Analytical lines and slit widths for
spectrometric analyses.

(i) Carbonate rocks and minerals.

Analyses of carbonate rich samples using emission spectrographs and spectrometers invites difficulties due to ejection of sample from the electrode during arcing.

Ignition of samples before analysis proved ineffective in avoiding ejection due to the absorption of moisture by the ignited sample even when stored in a desiccator. Fusion of the samples with Lithium tetraborate has been used extensively for carbonate rich samples, but proved too expensive and time consuming for this study. Dilution of the sample with specpure silica gave little ejection during arcing, and due to the relatively inexpensive method and simple procedure, was adopted for this study.

Samples of the rock powders were dried at $110^{\circ}C$ before weighing. 50mg of rock powder were weighed into a polythene vial using a Torsion balance, and 50mg of specpure silica dried at $110^{\circ}C$ were added. 150mg of a mixture of NaF buffer (Hopkin and Williams A.R. grade), and carbon powder (Magicol Black 888) mixed in the ratio 1:2, were added to the silica and powder, and a 'spex-ball' was placed in the vial which was then sealed. The powders were mixed on a Wig-L-Bug mixer for 1-2 minutes.

Standards for major elements in the carbonatites were made up by sintering a mixture of specpure oxides in a platinum crucible at $1000^{\circ}C$, giving a top standard on dilution with specpure $CaCO_3$ of Fe_2O_3 (15%), MgO (5%), TiO_2 (5%), Al_2O_3 (5%), MnO (0.5%), K_2CO_3 (5%), and Na_2CO_3 (5%). The fused material was then recrushed and diluted logarithmically with specpure $CaCO_3$ to give a range of major element standards. Each standard was thoroughly mixed in a Glencreston mixer.

Standards for the trace elements were produced by dilution of 'spexmix' powder with a base made up of specpure $CaCO_3$ and highest major element standard, in the ratio 1:3, to give 1000ppm of each element. $BaCO_3$ was added to this standard to give a total of 5000ppm Ba,

and the mixture was thoroughly mixed. Logarithmic
dilution of this standard gave a range of trace element
standards from 0ppm in pure base, 10ppm, 100ppm, 250ppm,
500ppm to 1000ppm, whilst Ba in these standards varied
from 0ppm through 50ppm, 500ppm, 1250ppm, 2500ppm to
5000ppm. Each standard was then mixed with specpure
silica, carbon, and buffer in the same way as the samples.

Each sample and standard were then loaded into graphite
electrodes made from Ringsdorff R.W.403 graphite rods of
diameter 6.15mm, with aperture 2.91mm. and depth of
electrode cavity 5mm. prior to arcing, these being stored
in a desiccator to avoid absorption of moisture by the
samples.

The electrodes were arced in a 15-amp DC arc, using
anode excitation, and flat ended graphite counter electrode,
the electrode gap being 3mm. The period of excitation was
kept constant for each burn, as is routine procedure with
this instrument at Leicester.

Due to selective volatolisation of elements in the arc,
the integration period,when radiation falling on a
particular slit is measured,has been split into two periods.
The elements Ag, Bi, Cd, Ga, Ge, Pb, Sn and Zn were
measured in the first integration period of 45 seconds,
whilst spectral lines emitted by other elements were
measured in a second 55 second period, giving a total
burn of 100 seconds.

No internal standard was used for the analyses due to
the diversity of spectral lines used for analysis in the
Leicester instrument. The accuracy of the analyses depend
to a large extent on calibration of the instrument with a
standard trace element base of similar major element
composition to the samples. The similarity of the base
composition to the sample composition is monitored by the
background (dark current) slit (Tennant and Sewell, 1969).

In the case of these analyses the background remained
constant to within a few digits for both samples and
standards.

The standards were run first each day after the
instrument had been warmed up and stabilised, generally
three burns for each standard being run. Two burns for
each sample were run, but in cases where great variation
between the digital output for the two runs was found, a
third analysis was made to check the previous results.
Calibration graphs were drawn by eye for both major and
trace elements, and concentration of each element in the
samples were read off from the graph in the usual manner.

In addition to the samples and standards, a precision
sample was made up and run every eighth sample, in order
to check the precision of the results throughout the
analysis. The standard deviation and coefficient of
variation of the results for each element calculated
from the precision sample are shown in Table 3.

From Table 3, the trace element data is shown to be
generally better than + or - 10%, except for Ni, Pb and
Mo which were present in low concentrations, whilst the
major element data is generally better than + or - 30%.
The coefficient of variation of Mg is high due to the
low concentration of this element in the precision sample.

Samples of the mineral calcite were analysed in the
same way as the carbonatite samples, using the same
standards.

Element/Oxide	Mean	2X Standard Deviation	Coefficient of Variation	No. of Analyses
Al_2O_3	0.13%	0.017%	25.6%	18
Fe_2O_3	3.11%	0.51%	30.4%	18
MgO	0.14%	0.045%	64%	18
MnO	0.61%	0.26%	27.8%	18
TiO_2	0.17%	0.028%	28.0%	18
Ba	355ppm	30ppm	8.5%	18
Li	28ppm	3.2ppm	9.8%	18
Mo	23ppm	3.2ppm	14.0%	18
Nb	375ppm	25ppm	15%	18
Ni	8ppm	2.2ppm	27%	18
Pb	12ppm	2.5ppm	20%	18
Sr	970ppm	97ppm	10%	18
V	54ppm	2.8ppm	5.2%	18
Zn	64ppm	2.8ppm	4.5%	18
Zr	55ppm	3.8ppm	7%	18

Table 3. Mean, 2X standard deviation, and coefficient of variation ($2s/\bar{x}$ X 100) at the 95% confidence level for the precision sample, spectrometric analyses. Elements Cr, Cu, Co, Ga, Ge, Be and Sn not detectable in this sample.

(ii) Peralkaline silicate rocks and fenites, and silicate minerals.

Spectrometric analyses of the silicate rocks was carried out using routine procedures in the laboratory at Leicester

University, Department of Geology.

Each sample was dried at 110°C before analysis, and 100mg. of this sample mixed with carbon powder and NaF buffer in the ratio 2:2:1. This mixture was mixed in a plastic vial in the same way as the carbonate samples, and loaded into electrodes as with the carbonate samples.

Two standard bases were made up for trace elements by sintering mixtures of specpure oxides in a platinum crucible at 1000°C for 4 hours. One base corresponded in major element content to a Ca-rich ijolite, to serve as standards for ijolite, melanite ijolite, pyroxenite, urtite. The other base corresponded to the composition of syenite fenite, which serves as a base for nepheline-syenite, syenitic fenite, and fenite, and feldspathised rock. Series of standards were made from these bases by dilution of spexmix with each base to give 1000ppm of each element. After thorough mixing this and subsequent standards were diluted to give a range of standards from 0ppm in each base, through 10ppm, 100ppm, 250ppm, 500ppm to 1000ppm. Each standard was mixed with carbon and NaF buffer in the same way as the samples.

Standards and samples were analysed in the same way as the carbonate rich rocks, however U.S.G.S. standards were used for major element standards (G2, DTS1, BCR1, PCC1, AGV1, GSP1). A precision sample was run every eighth sample to check precision of analyses during the analysis.

Analyses of minerals pyroxene, nepheline, feldspar, wollastonite, and amphibole were carried out using the same standards as for the silicate rocks. Melanite garnet and magnetite were compared to trace element standards made up from bases corresponding to the major element compositions of each of these minerals.

The mean value, standard deviation, and coefficient

of variation for the precision sample are shown in Table
4 below. The trace element data is seen to be generally
better than + or - 10% at 95% confidence level. Major
element analyses are generally better than ∓ 30%.

Element	Mean $\bar{x}$	s Standard Deviation	$2s/\bar{x} \cdot 100$ Coefficient of Variation	No. of Analyses.
Al_2O_3	13.0%	0.9%	15%	16
CaO	9.3%	0.67%	18%	16
Fe_2O_3	12.3%	0.8%	13%	16
MgO	20%	-	-	16
MnO	0.15%	0.005%	25%	16
SiO_2	41.57%	2.97%	14%	16
TiO_2	1.07%	0.14%	26%	16
Ba	328ppm	16ppm	10%	16
Be	10ppm	1ppm	10%	16
Co	72ppm	3ppm	8.5%	16
Cr	369ppm	15ppm	8%	16
Cu	74ppm	4.5ppm	12%	16
Ga	25ppm	1.8ppm	14%	16
Nb	212ppm	50ppm	50%	16
Ni	121ppm	6ppm	10%	16
Pb	15ppm	2ppm	26%	16
Sn	25ppm	2ppm	16%	16
Sr	411ppm	20ppm	9.5%	16
V	295ppm	15ppm	10%	16
Zn	103ppm	15ppm	30%	16
Zr	98ppm	5ppm	10%	16

Table 4. Mean, standard deviation, and coefficient
of variation at 95% confidence level for
analyses of the precision sample.
Elements Li, Bi, Ge, Mo, not detected in
this sample.

D. <u>Chemical Analyses of Silicate Rocks.</u>

Analyses for Fe (ferrous ion) and alkali metals Na and
K were carried out on peralkaline silicate rocks and fenites.
Standard procedures used in routine analysis for these
elements in the geology department at Leicester University
were employed.   These are described below.

(i) Na_2O and K_2O.

These elements were determined using an EEL flame photometer.
Digestion of O.1gms. of rock was achieved by adding a mixture of
10mls. 40% Analar grade HF, and 1ml. perchloric acid, and
evaporating the whole to dryness. The residue is then taken up
in 0.5mls. perchloric acid and a little distilled water. The
solution (solution B) was transferred quantitatively to a
100ml. flask, then made up to 100mls. with deionised water.
Aliquots of solution B were pipetted into a 50ml. volumetric
flask, and made up to 50mls. with deionised water.

The flame photometer was run for 20 minutes prior to
analysis, spraying deionised water. The diluted sample
solutions were then sprayed into the flame of the flame
photometer, and compared with standards of 0-5 ug/ml Na_2O
and K_2O. The instrument was set so that full scale deflection
was achieved when spraying the top standard. The top standard
and blank were run between each analysis to check calibration
of the instrument.

Several scale readings for each solution were taken, and
the average value calculated for each sample. The process was
repeated for each rock.

(ii) <u>FeO</u>.

Ferrous ion was determined by a conventional titrimetric
method using standard potassium dichromate solution, and sodium
diphenylamine sulphonic acid indicator (Shapiro and Brannock,
1956).

APPENDIX TWO.

Specimen Number	Rock Type	Centre	Locality	Form of Occurrence
		HOMA MOUNTAIN		
HF15	Ferruginous alvikite		Got Bonde Ridge	Cone sheet
HFR19	Sovite		Rongo	Cone sheet
HC54	Slightly fenitised lava		Homa main	Nyanzian basement
HF115	Ferruginous alvikite		Got Bonde Ridge	Cone sheet
HF160	Carbonatitic intrusive breccia		Got Akwach	-
HF195	Carbonatitic intrusive breccia		Nyasanga	-
HF199	Ferruginous alvikite		Homa Mountain	Cone sheet
HF209	Alvikite		Nyasanga	Cone sheet
HF212	Alvikite		Nyasanga	Cone sheet
HF225	Ferruginous alvikite		Nyamatoto	Cone sheet
HF230	Intrusive carbonatitic breccia		Nyasanga	-
HC258	Alvikite		S.Cliff, Homa Mountain	Cone sheet
HC309	Ijolite		W. of Rapogi	Ijolite mass
HC312	Ijolite		W. of Rapogi	Ijolite mass
HC320	Intrusive carbonatitic breccia		W. of Rapogi	-
HC323	Ijolite		Yusoo	Ijolite mass
HC324	Ijolite		Yusoo	Massive ijolite
HF329	Phonolite		Homa	Plug.
HC338	Sovite		Homa main intrusion	Massive sovite
HF350	Alvikite		Nyamatoto	Cone sheet
HC366	Alvikite		Ndiru cliff	Plug
HC367	Alvikite		Ndiru Hill	Cone sheet

Appendix Table 1. Field data concerning analysed specimens.

Specimen Number	Rock Type	Centre	Locality	Form of Occurrence
HOMA MOUNTAIN, (continued).				
HC374	K-rich trachyte		Home South Ridge	Dyke
HF377	Intrusive carbonatitic breccia		Nyasanga	-
HC384	Intrusive carbonatitic breccia		Nyasanga	-
HC396	Melilite-pseudomorph carbonatite		Chiewo vent	Dyke
HC401	Melilite-pseudomorph carbonatite		Chiewo vent	Dyke
HF462	Alvikite		Homa Mountain	Dyke
HF490	Ferruginous alvikite		Homa Mountain summit	Dyke
HF508	Alvikite		Homa Point East	Cone sheet
HC541	Feldspar Rock		Simbi	-
HF559	Alvikite		Homa Mountain	Cone sheet
HF578	Ferruginous alvikite		Homa Mountain	Cone sheet
HF583	Ferruginous alvikite		Nyasanga	Cone sheet
HC594	Alvikite		Homa Mountain	Cone sheet
HF597	Alvikite		S.Cliff, Homa Mountain	Cone sheet
HF603	Alvikite		Got Ayuaya	Cone sheet
HF609	Alvikite		Got Ayuaya	Cone sheet
HC613	Alvikite		Homa Mountain	Cone sheet
HC614	Alvikite		Homa Mountain	Cone sheet
HF621	Intrusive carbonatitic breccia		Homa Mountain	-
HC629	Alvikite		Homa Mountain	Cone sheet
HF636	Alvikite		Got Ayuaya	Cone sheet
HC639	Melilite-pseudomorph carbonatite		Chiewo	Dyke
HC649	Alvikite		Ndiru	Cone sheet
HC653	Feldspar rock		-	-
HC659	Alvikite		Homa Mountain	Cone sheet
HF666	Ferruginous alvikite		-	-

Appendix Table 1, (continued)

Specimen Number	Rock Type	Centre	Locality	Form of Occurrence
		HOMA MOUNTAIN, (Continued).		
HC698	Alvikite		Homa Mountain	Cone sheet
HC731	Feldspar rock		Ndiru M'bili	-
HC732	Feldspar rock		Ndiru M'bili	-
HC741	Ijolite		N.W. of Ndiru	Massive ijolite
HC743	Ijolite		Yusoo	Massive ijolite
HC744	Ijolite		Yusoo	Massive ijolite
HC748	K-rich trachyte		Yusoo	Dyke
HC7616	Phonolite		Homa Mountain	-
HC797	Fenite		Yusoo	-
HC800	Fenite		Yusoo	-
HC825	Fenite		E. of Yusoo	-
HC912	Micro ijolite		Bala	-
HC865	Micro ijolite		Bala	-
HC930	Medium grained ijolite		Yusoo	Massive ijolite
HC934	Ijolite		W. of Rapogi	Massive ijolite
HC964	Ijolite		S. Rapogi	Massive ijolite
HC965	Sovite		Rapogi	Massive sovite
HC988	Pyroxenite		Homa Mountain South	-
HC993	Ijolite		Homa Mountain South	Xenolith in phonolite
HC999	Coarse ijolite		Homa Mountain South	Loose block
HC1005	Phonolite		Homa Mountain	-
U48	Phonolite		Samanga Hill	Plug

Appendix Table 1. (continued).

Specimen Number	Rock Type	Locality	Form of Occurrence
		NORTH RURI	
N24	Alvikite	S. North Ruri	Cone sheet
N85	Phonolite	Gotjope	Plug
N90	Phonolite	N. North Ruri	Plug
N142	Alvikite	S. North Ruri	Cone sheet
N158	Phonolite	Near Kabonga	Plug
N177	Sovite	Central N. Ruri	Block in agglomerate
N225	Nepheline-microsyenite	S. North Ruri	Minor intrusion
N266	Nepheline-microsyenite	Summit N. Ruri	Block in agglomerate
U326	Alvikite	Okuge	Ring complex
N339	Ferruginous alvikite	Central N. Ruri	Cone sheet
N348	Alvikite	Central N.Ruri	Cone sheet
N427	Alvikite	W. North Ruri	Cone sheet
N429	Alvikite	W. North Ruri	Cone sheet
N464	Nepheline-microsyenite	N. side, North Ruri	Massive n.-syenite instrusion
N503	Nepheline-microsyenite	N.W. spur, North Ruri	Minor intrusion
N593	Melanephelinite	N. Okuge	Lava
N595	Melanephelinite	N. Okuge	Lava
N683	Pyroxenite	S. spur, North Ruri	Block in agglomerate
N688	Nepheline-microsyenite	S. spur, North Ruri	Block in agglomerate
N694	Pyroxenite	Summit, North Ruri	Block in agglomerate
N712	Melanephelinite	N. North Ruri	Block in agglomerate
N729	Fenite	N.E. North Ruri	-
N734	Fenite	N.E. North Ruri	-
N801	Alvikite	S. spur, North Ruri	Dyke

Appendix Table 1, (continued).

Specimen Number	Rock Type	Locality	Form of Occurrence
	WASAKI CENTRES.		
U88	Ijolite	West Usaki	Central ijolite
U149	Micro-ijolite	Waiga School Hill	-
U156	Phonolite	Kimbo	Lava
U162	Phonolite	Kimbo	Lava
U207	Micro-ijolite	Nyakoya	Marginal ijolite intrusion
U211	Wollastonite-urtite	East Usaki	Central ijolite intrusion
U278	Phonolite	Kisumu	Lava
U296	Phonolite	South Usaki	Plug
U301	Phonolite	Gotrateng	Plug
U345	Micro-ijolite	East Usaki	Marginal ijolite intrusion
U369	Ijolite	Got Oyoma	Central ijolite intrusion
U382	Phonolite	Sondu-Kericho	Lava
U416	Ferruginous alvikite	North Kimbo	Dyke
U455	Sovite	Sokolo	Massive intrusion
U595	Ferruginous alvikite	East Nyamaji	6" dyke
U602	Alvikite	Nyamaji	Dyke
U692	Alvikite	Uyi	Vein
U771	Sovite	Sokolo	2' dyke
U774	Alvikite	Sokolo	Dyke cutting carbonatite
U782	Alvikite	Sokolo	Dyke
U783	Alvikite	Sokolo	Dyke
U784	Sovite	Sokolo	Massive carbonatite
U786	Alvikite	Sokolo	Dyke
U788	Ferruginous alvikite	Sokolo summit	Dyke
U839	Ferruginous alvikite	Sokolo	Dyke

Appendix Table 1, (continued).

Specimen Number	Rock Type	Locality	Form of Occurrence

WASAKI CENTRES, (continued).

U842	Sovite	Uyi	Massive carbonatite
U847	Sovite	Uyi	Massive carbonatite
U875	Sovite	Uyi	Massive carbonatite
U890	Melanephelinite	Ogoro	Lava
U926	Melanephelinite	Omuga	Lava
U954	Ferruginous alvikite	Sokolo	Patchy massive carbonatite
U1054	Urtite	Waiga School Hill	Ijolite intrusion
U1099	Pyroxenite	Central Usaki	Ijolite intrusion
U1111	Urtite	Otaragoge	Ijolite intrusion
U1229	Sovite	Sokolo	Massive carbonatite

BUDEDA COMPLEX

SuB7a	Ijolite	Siroko	-
SuB27	Melteijite	Siroko	-
SuB218	Fenite	North summit, Budeda Hill	-
SuB223	Fenite	Spur, N.W. Galala Hill	-
SuB232	Ijolite	Summit, Galala Hill	-
SuB242	Fenite	South Galala Hill	-
SuB247	Cancrinite-syenite	South Galala Hill	-
SuB254	Sovite	Main carbonatite intrusive	Massive carbonatite
SuB262	Cancrinite-syenite	Disiyi River	-

Appendix Table 1, (continued)

Specimen Number	Rock Type	Locality	Form of Occurrence

BUDEDA COMPEX, (continued).

Specimen Number	Rock Type	Locality	Form of Occurrence
SuB265	Cancrinite-syenite	Disiyi Island	-
SuB266	Ijolite	Disiyi River	Xenolith
SuB269	Phonolite	Disiyi River	-
SuB279	Fenite	East slope, Budeda Hill	-
SuB302	Ijolite	Bundagala Hill	-
SuB311	Nepheline-syenite	Siroko	-

NAPAK COMPLEX

Specimen Number	Rock Type	Locality	Form of Occurrence
SuN5	Urtite	W. of Lokopoi	-
SuN35	Pyroxenite	W. of Lokopoi	-
SuN63	Urtite	W. of Lokopoi	-
SuN102	Feldspar rock	W. of Lokopoi	-
SuN106	Nepheline-syenite	S. of Lokopoi	-
SuN521	Ijolite	E. of Lokopoi	-

TOROBO COMPLEX

Specimen Number	Rock Type	Locality	Form of Occurrence
SuTo25	Sovite	Main carbonatite intrusion	Massive carbonatite
SuTo38	Nepheline-syenite	N.E. slope, Limekiln Hill	-
SuTo171a	Sovite	Main sovite intrusion	Massive carbonatite
SuTo171b	Alvikite	Main sovite intrusion	Vein cutting SuTo171a
SuTo509	Fenite	East Knoll, Limekiln Hill	-
SuTo510	Fenite	East Road	-
SuTo514	Fenite	East Knoll	-

Appendix Table 1, (continued).

Specimen Number	Rock Type	Locality	Form of Occurrence
		TORORO COMPLEX, (continued).	
SuTo536	Fenite	W. of carbonatite lower quarry	-
SuTo581	Alvikite	Limekiln Hill	Dyke
SuTo590	Ijolite	Limekiln Hill	-
SuTo594	Sovite	Limekiln Hill	Massive carbonatite
SuTo595	Sovite	Limekiln Hill	Massive carbonatite
SuTo598	Fenite	S.E. slope, Limekiln Hill	-
		TOROR COMPLEX	
SuT125	Phonolite	North slope, Toror Hills	-
SuT134	Orthoclasite	North Ridge	Dyke

Appendix Table 1. (continued)

Key to Appendix Table 2.

Table 2a.   M = major mineral (greater than 1%).

                         m = minor mineral (less than 1%).

                         a = accessory mineral.

Tables 2b

(i) - (iii)   MM = greater than 50%.

                         M = 20% - 50%.

                        Mm = 5% - 20%.

                        am = 1% - 5%.

                         m = 0.5% - 1%.

                         a = accessory mineral.

Specimen Number	Calcite	Opaque Oxide	Apatite	Pyrochlore	Biotite	Aegirine	Orthoclase	Fluorite	Barite	Monazite	Limonite	Amphibole	Nepheline
HF209	M	M	m	-	m	-	-	-	-	-	-	-	-
HF212	M	M	a	a	-	-	-	-	-	-	-	-	-
HC258	M	M	M	m	m	-	-	m	-	-	a	-	-
HF350	M	M	a	-	a	a	-	-	-	-	-	-	-
HC366	M	M	m	-	-	a	-	-	-	-	-	-	-
HC367	M	M	m	m	-	-	-	-	-	-	-	a	-
HF462	M	M	a	a	-	m	-	-	-	-	-	-	-
HF508	M	M	-	-	m	m	-	-	-	-	-	-	-

Specimen Number

Specimen Number	Calcite	Opaque Oxide	Apatite	Pyrochlore	Biotite	Aegirine	Orthoclase	Fluorite	Barite	Monazite	Limonite	Amphibole	Nepheline
HFR19	M	M	a	-	-	-	-	-	-	-	-	-	-
HF84	M	M	a	a	a	a	-	-	-	-	-	-	-
HC338	M	M	a	a	-	-	-	-	-	-	-	-	-
HC965	M	M	-	-	-	-	a	-	-	-	-	-	-
H177	M	M	a	a	-	-	-	-	-	-	-	-	-
U771	M	M	M	a	a	-	-	-	-	-	-	a	-
U842	M	M	M	-	a	-	-	-	-	-	-	a	-
U847	M	M	M	-	a	-	-	-	-	-	-	-	-
U1229	M	M	-	-	-	-	-	-	-	-	-	-	-

Appendix Table 2a. Mineralogy of analysed carbonatites. See key to Table 2 for explanation of symbols.

Specimen Number	Calcite	Opaque oxide	Apatite	Pyrochlore	Biotite	Aegirine	Orthoclase	Fluorite	Barite	Monazite	Limonite	Amphibole	Nepheline
HC698	M	M	-	a	-	-	-	-	-	-	-	a	-
N24	M	m	-	-	-	-	-	-	a	-	a	-	-
N142	M	M	M	-	-	-	-	-	-	-	a	-	-
N348	M	M	-	-	a	-	-	-	-	-	-	-	-
N427	M	M	-	-	-	-	-	m	m	-	-	-	-
N429	M	M	-	-	a	-	-	-	-	-	-	-	-
N801	M	M	-	-	m	a	-	-	-	-	-	-	-
U326	M	M	m	m	m	-	a	-	-	-	-	-	-
U602	M	M	-	-	-	-	a	-	-	-	-	-	-
U692	M	M	-	-	-	-	-	-	-	-	m	-	-

Specimen Number	Calcite	Opaque Oxide	Apatite	Pyrochlore	Biotite	Aegirine	Orthoclase	Fluorite	Barite	Monazite	Limonite	Amphibole	Nepheline
HF559	M	M	-	a	a	-	-	-	-	-	-	-	-
HC594	M	M	a	-	-	-	-	a	-	-	a	-	-
HC597	M	M	m	-	-	-	a	-	-	-	m	-	-
HF603	M	M	-	a	-	-	-	-	-	-	a	-	-
HF609	M	M	-	-	-	-	-	-	-	-	a	-	-
HC613	M	M	-	-	a	-	-	-	-	-	a	-	-
HC614	M	M	M	-	-	-	-	-	-	-	a	-	-
HF636	M	M	-	m	-	-	-	-	-	-	-	-	-
HF649	M	M	M	m	-	-	-	-	-	-	-	-	-
HC659	M	M	m	-	-	-	a	-	-	-	-	-	-

Appendix Table 2a, (continued). Mineralogy of analysed carbonatites. See key to Table 2 for explanation of symbols.

Specimen Number	Calcite	Opaque Oxide	Apatite	Pyrochlore	Biotite	Aegirine	Orthoclase	Fluorite	Barite	Monazite	Limonite	Amphibole	Nepheline
HF225	M	M	-	-	-	-	-	m	m	m	m	-	-
HF490	M	M	-	-	-	-	-	M	M	m	M	-	-
HF578	M	M	-	-	-	-	-	M	M	m	M	-	-
HF583	M	M	-	-	-	-	-	m	M	m	M	-	-
HF666	M	M	-	-	-	-	-	m	M	-	m	-	-
N339	M	M	-	-	-	-	-	-	M	m	M	-	-
U595	M	M	-	-	-	-	-	-	m	-	M	-	-
U788	M	M	-	-	-	-	-	-	m	-	M	-	-
U839	M	M	-	a	-	-	-	-	a	-	M	-	-
U954	M	M	-	-	-	-	-	-	m	-	M	-	-

Specimen Number	Calcite	Opaque Oxide	Apatite	Pyrochlore	Biotite	Aegirine	Orthoclase	Fluorite	Barite	Monazite	Limonite	Amphibole	Nepheline
U744	M	M	m	a	m	-	-	-	-	-	a	-	-
U782	M	M	-	m	a	-	-	-	-	-	a	-	-
U783	M	M	-	m	m	-	-	-	-	-	a	-	-
U786	M	m	-	m	-	-	-	-	-	-	a	-	-
Melilite-pseudomorph carbonatites.													
HC396	M	M	-	-	-	-	-	-	-	-	a	-	-
HC401	M	m	-	-	-	-	-	-	-	-	m	-	-
HC639	M	M	-	-	-	-	-	-	-	-	m	-	-
Ferruginous alvikites.													
HF115	M	M	-	-	m	-	-	-	M	m	M	-	-
HF199	M	M	-	-	-	-	a	-	M	m	M	-	-

Appendix Table 2a, (continued). Mineralogy of analysed carbonatites . See key to Table 2 for explanation of symbols.

	Pyroxene	Nepheline	Feldspar	Garnet	Sphene	Cancrinite	Apatite	Calcite	Magnetite	Mica	Analcime	Wollastonite
HC998	MM	m	a	a	-	-	am	-	-	-	-	-
N683	MM	Mm	-	m	a	-	a	a	-	-	-	-
N694	MM	m	-	m	a	a	am	-	-	-	-	-
U1099	MM	Mm	am	am	nd	nd	nd	nd	nd	nd	nd	nd
SuB27	MM	m	-	-	-	nd	nd	nd	nd	nd	nd	nd
SuN35	MM	m	-	m	nd	nd	nd	nd	nd	nd	nd	nd
HC930	Mm	M	-	-	-	a	-	a	-	-	-	-
SuTo590	M	M	am	am	nd	nd	nd	nd	nd	nd	nd	nd
SuB7a	Mm	M	-	-	nd	nd	nd	nd	nd	nd	nd	nd
SuB266	M	M	am	am	nd	nd	nd	nd	nd	nd	nd	nd
U211	m	MM	-	a	-	-	-	a	-	-	-	m
U1054	m	MM	-	a	-	-	am	-	-	-	-	m

Appendix Table 2b(i).   Mineralogy of analysed peralkaline intrusive silicate rocks. See key for
explanation of symbols .

	Pyroxene	Nepheline	Feldspar	Garnet	Sphene	Cancrinite	Apatite	Calcite	Magnetite	Mica	Analcime	Wollastonite
U1111	m	MM	-	a	-	-	-	-	-	-	-	am
SuN5	m	MM	-	a	nd	nd	nd	nd	nd	nd	nd	nd
SuN63	m	MM	-	am	nd	nd	nd	nd	nd	nd	nd	nd
HC309	m	M	m	M	am	-	a	a	-	a	-	-
HC324	M	M	-	M	am	-	a	a	-	am	-	-
HC741	M	m	m	M	-	-	am	am	-	-	-	-
HC993	M	M	-	M	-	-	a	a	-	am	-	-
U88	m	M	-	m	a	a	a	a	a	-	-	a
U369	M	M	-	M	-	-	-	-	-	-	-	-
SuN521	M	M	-	M	nd	nd	nd	nd	nd	nd	nd	nd
HC323	M	M	m	M	m	-	a	a	a	-	-	-
HC934	M	M	m	m	am	-	-	a	-	-	-	-
HC964	M	M	m	m	am	a	-	-	-	-	-	-
HC999	am	M	m	M	-	-	-	-	-	-	-	-
SuB232	M	M	m	-	nd	nd	nd	nd	nd	nd	nd	nd
SuB302	M	M	M	-	nd	nd	nd	nd	nd	nd	nd	nd

Appendix Table 2b(i), (continued).   Mineralogy of analysed peralkaline silicate rocks .

	Pyroxene	Nepheline	Feldspar	Garnet	Sphene	Cancrinite	Apatite	Calcite	Magnetite	Mica	Analcime	Wollastonite
N225	M	M	M	am	a	a	a	-	-	-	-	-
N266	m	m	m	am	a	am	am	a	-	-	-	-
N464	M	M	M	-	-	am	-	-	a	-	-	-
N503	M	m	M	am	-	a	-	-	-	-	-	-
N688	M	M	M	am	-	-	a	a	-	-	-	-
SuTo38	M	m	M	-	nd	nd	nd	nd	nd	nd	nd	nd
SuB247	m	m	M	am	nd	nd	nd	nd	nd	nd	nd	nd
SuB262	m	M	M	-	nd	nd	nd	nd	nd	nd	nd	nd
SuB265	m	M	M	-	nd	nd	nd	nd	nd	nd	nd	nd
SuB 311	M	M	M	am	nd	nd	nd	nd	nd	nd	nd	nd
SuN106	m	m	M	-	nd	nd	nd	nd	nd	nd	nd	nd
U149	M	M	M	am	am	-	-	-	-	-	-	am
U207	M	M	M	am	-	-	a	-	-	-	-	am
U242	M	M	m	-	am	am	a	a	-	-	-	-
U345	M	M	M	-	am	-	-	-	-	-	-	-

Appendix Table 2b(i), (continued). Mineralogy of peralkaline intrusive silicate rocks.

	Pyroxene	Nepheline	Feldspar	Garnet	Sphene	Cancrinite	Apatite	Calcite	Magnetite	Mica	Analcime	Wollastonite
N593	MM	m	-	-	-	-	-	-	m	-	-	-
N595	MM	m	-	-	-	-	a	-	M	-	-	-
N712	MM	m	-	-	M	-	-	-	M	-	-	-
U156	m	MMM	-	am	-	-	-	a	m	-	-	-
HF89a	m	M	M	Am	-	-	-	-	am	-	am	-
HC583	M	M	M	-	-	-	-	-	-	-	-	-
HC761b	M	M	M	-	-	-	-	-	-	-	am	-
HC1005	M	M	M	am	-	-	-	-	-	-	am	-
N85	M	M	M	-	-	-	-	-	a	M	a	-
U162	M	M	M	am	-	-	am	-	-	-	-	-
N90	M	M	M	am	-	-	-	-	-	-	M	-
N185	M	M	M	-	-	-	-	-	a	-	M	-
U48	M	m	M	a	-	-	a	-	-	-	M	-
U278	M	M	M	-	-	-	-	-	-	-	M	-
U296	M	M	M	-	-	-	-	-	-	-	M	-
U301	M	M	M	-	-	-	a	-	-	-	M	-
U382	M	M	M	-	-	-	-	-	-	-	M	-

Appendix Table 2b(ii).   MINERALOGY OF PHONOLITIC ROCKS.   See key to Table 2 for explanation of symbols.

	Pyroxene	Nepheline	Feldspar	Garnet	Sphene	Cancrinite	Apatite	Calcite	Magnetite	Mica	Analcime	Quartz
HC54	am	-	M	-	-	-	-	-	-	-	-	M
HC653	m	-	M	-	-	-	-	-	-	-	-	M
HC743	M	-	M	-	-	-	-	am	-	-	-	-
HC744	M	-	M	-	-	m	-	am	-	-	-	-
HC797	M	-	M	-	-	-	a	am	-	-	-	-
HC800	M	-	M	-	-	-	-	-	-	-	-	m
HC825	M	-	M	-	-	-	-	a	-	-	-	-
N729	M	-	M	-	-	-	-	a	-	-	-	-
N734	M	-	M	-	-	-	-	-	-	-	-	-

Appendix Table 2b(iii).   Mineralogy of fenitie rocks . See key to Table 2 for explanation of symbols.

In Tables 3a, 3b and 3c, detection limits for the various elements, and the upper limits of sensitivity for each element in the various rocks and minerals are as follows.

Element/oxide	Detection Limit	Upper limit of Sensitivity.
Fe_2O_3	0.1%	30%
MnO	0.1%	3%
MgO	0.1%	10%
TiO_2	0.1%	5%
Ba	10ppm	40000ppm
Li	10ppm	1000ppm
Mo	10ppm	1000ppm
Nb	50ppm	1000ppm
Sr	10ppm	4000ppm
V	10ppm	1000ppm
Zn	10ppm	1000ppm
Zr	10ppm	1000ppm
Ce	50ppm	10000ppm
La	35ppm	6000ppm
y	5ppm	1000ppm
Dy	10ppm	1000ppm
Cr	10ppm	1000ppm
Ni	10ppm	1000ppm
Cu	10ppm	1000ppm
Pb	10ppm	1000ppm
Co	10ppm	1000ppm

Specimen Number	Fe₂O₃ wt.%	MnO wt.%	MgO wt.%	TiO₂ wt.%	Ba ppm	Li ppm	Mo ppm	Nb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	La ppm	Nd ppm	Dy ppm	Y ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Co ppm
HFR19	1.1	0.6	-	-	2800	15	5	-	2260	35	30	20	700	340	70	150	-	-	-	-	-	-
HF84	0.7	0.3	-	-	860	20	10	-	1610	10	-	-	nd	nd	nd	nd	nd	-	10	-	-	-
HC338	-	0.2	-	-	940	25	20	50	2550	10	-	-	529	333	55	180	31	-	5	-	-	-
HC965	2.1	0.21	-	-	600	20	10	-	2320	40	20	10	475	374	82	110	-	10	23	60	-	10
N177	3.7	0.41	-	0.1	700	20	5	50	800	40	120	10	505	263	202	-	47	5	-	-	45	-
U455	2.2	0.33	-	-	3280	20	20	100	1820	70	55	50	400	125	12	-	-	6	8	-	-	-
U771	2.7	0.1	0.4	0.1	360	55	20	220	1600	70	30	25	808	252	202	nd	-	6	7	-	-	-
U784	1.7	0.39	-	-	460	20	30	50	860	35	40	-	550	130	300	nd	-	6	5	-	-	-
U842	1.0	0.33	-	-	1600	20	10	60	745	25	135	-	792	297	50	nd	-	5	-	-	-	-
U847	2.7	0.34	-	0.1	360	35	20	220	70	70	30	25	700	250	120	nd	-	6	8	-	-	-
U875	0.4	0.16	-	-	400	25	10	50	1860	25	10	50	693	128	137	nd	-	12	35	-	-	-
U1229	1.7	0.82	0.1	-	1500	25	30	500	770	80	60	10	2500	1000	920	nd	110	6	5	-	-	-
SuB254	6.7	0.32	2.0	0.35	260	25	25	250	1410	70	35	35	525	441	126	nd	31	10	10	5	-	10

Appendix Table 3a.   Analyses of sovitic carbonatites from W. Kenya and E. Uganda.

- element not detected   ,   nd   element not determined.

Elements Ga, Ge and Be not detected.

Specimen Number	Fe$_2$O$_3$ wt.%	MnO wt.%	MgO wt.%	TiO$_2$ wt.%	Ba ppm	Li ppm	Mo ppm	Nb ppm	Sr ppm	V ppm	Zn ppm	ZR ppm	Ce ppm	La ppm	Nd ppm	Dy ppm	Y ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Co ppm
SuTo171	1.6	0.59	-	-	370	50	48	700	1255	70	180	35	400	250	200	-	-	6	10	5	40	10
SuTo594	2.0	0.4	-	-	420	25	10	-	1350	45	-	10	600	480	260	-	-	-	-	-	-	-
SuTo595	0.85	0.32	-	-	2480	50	40	250	1950	30	-	15	594	415	218	-	-	8	5	15	-	-
Alvikite carbonatites.																						
HF209	4.4	1.17	1.4	0.1	4800	25	20	500	835	50	160	45	2215	936	644	-	255	5	-	-	60	-
HF212	4.6	0.9	1.6	-	3900	25	15	400	1090	40	135	25	1648	627	507	-	114	6	5	-	20	-
HC258	9.3	1.24	1.15	0.3	>8000	110	40	>1000	790	155	500	45	6856	3758	2003	-	142	14	25	-	55	13
HF350	2.5	0.35	0.25	-	3800	25	15	650	710	35	390	15	3400	1705	1155	-	145	6	-	15	20	-
HC366	1.5	0.87	0.25	-	1450	25	-	150	940	45	40	-	2140	901	906	-	110	6	5	-	10	-
HC367	15.0	0.96	0.35	0.7	2100	20	17	>1000	1210	205	190	240	2640	1127	967	-	113	6	8	-	40	-
HF462	5.6	0.97	4.5	0.2	2580	25	20	575	1175	70	105	30	2545	1026	723	-	25	6	8	-	20	10
HF508	3.8	0.56	0.3	0.1	1010	30	10	450	845	55	165	25	1786	787	503	-	53	6	5	5	20	-
HF559	3.1	0.61	0.5	0.2	355	28	23	375	970	55	60	55	1717	691	559	-	53	8	5	-	-	-
HC594	20.9	0.79	0.2	0.4	2980	25	25	800	620	296	286	90	1900	831	605	-	35	10	35	-	20	-

Appendix Table 3a , (continued). Analyses of sovite and alvikite carbonatites from W. Kenya and E. Uganda.

- element not detected, nd analysis not attempted. Elements Ga, Ge and Be not detected.

Specimen Number	Fe$_2$O$_3$ wt%	MnO wt.%	MgO wt.%	TiO$_2$ wt.%	Ba ppm	Li ppm	Mo ppm	Nb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	La ppm	Nd ppm	Y ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Co ppm
HC597	6.0	1.9	2.2	-	6400	30	25	700	1620	100	210	215	2933	1831	627	97	5	5	-	95	-
HF603	5.1	0.75	1.75	-	4460	30	30	675	1150	55	90	40	2295	994	704	112	8	8	-	60	12
HF609	13.0	2.15	0.3	0.15	4550	20	70	500	940	65	100	35	2750	1234	995	86	10	5	-	30	10
HC613	5.3	0.95	1.9	0.1	1280	25	20	425	1190	110	465	50	1350	1060	777	89	8	10	5	15	-
HC614	18.4	0.87	-	0.35	680	15	5	850	545	240	50	50	2908	1156	72	50	5	10	-	35	-
HC629	1.7	0.32	-	-	1520	-	-	350	840	65	35	30	1500	675	560	150	8	20	-	10	-
HF636	5.5	0.81	-	0.1	1180	25	25	350	1025	150	110	70	1600	907	881	88	10	8	-	10	10
HF649	6.4	3.2	0.5	0.35	4050	50	5	400	1620	100	75	80	858	263	17	25	10	25	-	-	10
HC659	1.9	0.76	-	0.15	2450	25	15	200	830	30	50	-	1456	627	559	43	6	5	-	25	-
HC698	18.4	0.89	1.8	0.5	520	15	5	>1000	995	260	285	235	1911	732	662	47	16	45	-	-	10
N24	2.2	>3.0	-	-	4520	-	-	100	1340	215	240	-	7500	3500	1400	360	-	-	-	110	-
N142	1.3	>3.0	0.5	-	680	-	35	>1000	1200	230	70	65	4900	260	1200	600	6	5	-	25	-

Appendix table 3a (continued).

Analyses of alvikite carbonatites from W. Kenya and E. Uganda,

- element not detected   nd analysis not attempted. Elements Dy, Ga, Ge and Be not detected .

Specimen Number	Fe$_2$O$_3$ wt.%	MnO wt.%	MgO wt.%	TiO$_2$ wt.%	Ba ppm	Li ppm	Mo ppm	Nb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	La ppm	Nd ppm	Y ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Co ppm
N348	17.5	0.75	0.25	0.85	1050	25	10	375	845	150	335	25	1350	655	448	65	-	-	-	-	-
N427	>30.0	>3.0	0.1	-	40000	30	-	100	1260	150	900	20	4480	1366	732	12	-	-	10	170	-
N429	16.0	>3.0	1.0	0.1	2060	25	-	900	1320	170	2000	-	1854	141	448	65	-	-	-	70	-
N801	2.2	1.48	0.1	0.25	450	25	30	625	550	50	35	20	2550	1200	1000	60	6	5	5	15	-
U326	5.9	0.9	0.25	0.15	1000	55	35	800	800	105	210	210	1920	936	614	118	6	8	-	10	10
U602	3.6	1.9	-	-	1600	-	-	-	650	100	190	-	2884	1803	721	10	20	-	-	60	-
U692	4.0	1.92	0.3	0.96	3280	-	-	-	710	110	160	40	2369	1390	566	40	15	-	10	61	-
U774	2.9	1.2	-	-	1720	-	-	-	560	100	40	-	1200	330	350	10	15	55	-	40	-
U782	0.8	0.9	0.1	-	1250	15	5	300	690	450	50	10	2500	900	760	90	5	5	-	-	-
U783	4.6	1.6	0.4	0.3	1400	25	20	>1000	1145	165	425	75	5250	2060	1597	nd	6	10	-	20	-
U786	1.3	0.54	0.4	-	465	35	30	250	1120	35	40	15	1200	450	520	-	6	-	-	-	-
Suto171b	4.7	0.84	1.45	0.1	600	25	10	100	1200	85	-	10	1248	608	406	67	8	5	-	-	-
Suto581	.4	0.93	1.6	0.5	520	-	-	-	1090	165	270	-	940	580	317	70	-	-	10	10	-

Appendix Table 3a (continued) . Analyses of alvikite carbonatites from W. Kenya and E. Uganda.

- element not detected   nd analysis not attempted. Elements Dy,

Ga, Ge and Be not detected.

Specimen Number	Fe$_2$O$_3$ wt.%	MnO wt.%	MgO wt.%	TiO$_2$ wt.%	Ba ppm	Li ppm	Mo ppm	Nb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	La ppm	Nd ppm	Y ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Co ppm
Melilite-pseudomorph carbonatites.																					
HC396	3.4	0.25	0.5	-	4880	-	-	840	380	140	170	60	4545	3535	590	103	-	-	-	90	-
HC401	3.6	0.87	1.1	-	2480	50	35	650	1175	80	115	50	1479	1530	520	130	10	10	5	15	-
HC639	3.1	2.0	0.25	-	7600	20	5	625	650	50	240	30	3502	3008	590	78	12	5	5	55	-
Ferruginous alvikites.																					
HF15	>30.0	>3.0	2.4	0.8	>40000	25	20	100	680	100	440	-	11596	4681	1729	74	-	40	300	-	-
HF115	6.2	2.72	-	-	>40000	25	60	-	1070	70	2000	-	4250	1467	1213	210	-	-	30	50	-
HF199	>30.0	>3.0	4.8	-	>40000	25	110	-	610	100	1700	-	6520	935	1200	22	-	-	300	-	-
HF225	>30.0	>3.0	2.4	0.8	>40000	25	30	920	960	450	2000	70	7956	2130	1257	112	20	40	150	-	-
HF490	2.0	0.8	0.8	-	>40000	25	10	700	800	180	330	30	>10000	9200	2450	22	-	10	160	-	-
HF578	>30.0	>3.0	2.2	-	>40000	25	100	-	1460	100	430	20	598	100	78	81	-	-	320	-	-
HF583	10.2	>3.0	1.5	0.1	>40000	25	20	100	1880	100	440	-	11582	3316	1754	94	-	-	360	-	-
HF666	3.6	1.9	-	-	>40000	25	680	-	440	70	680	90	940	100	446	163	-	-	460	-	-

Appendix Table 3a (continued). Analyses of melilite-pseudomorph carbonatites and ferruginous alvikites from W. Kenya and E. Uganda. - element not detected, nd element not determined. Elements Dy, Ga, Ge, AND Be not detected.

Specimen Number	Fe$_2$O$_3$ wt.%	MnO wt.%	MgO wt.%	TiO$_2$ wt.%	Ba ppm	Li ppm	Mo ppm	Nb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	La ppm	Nd ppm	Y ppm	Cr ppm	Ni ppm	Cu ppm	Pb ppm	Co ppm
N339	10.0	3.08	-	-	>40000	-	20	-	1300	110	220	-	>10000	>6000	900	220	-	-	-	20	-
U416	3.0	>3.0	-	-	>40000	-	30	240	860	90	180	60	5720	5250	260	130	-	-	-	200	-
U595	>30.0	3.0	-	-	1220	35	20	550	710	60	130	40	4583	1339	463	ND	5	5	-	30	-
U788	5.8	1.9	-	-	2280	-	-	-	230	180	140	-	821	111	372	nd	-	-	-	30	-
U839	20.2	1.7	0.4	0.4	2240	-	-	1150	860	940	480	30	4313	1230	1230	80	-	25	-	40	-
U954	4.6	2.6	-	-	2640	-	10	-	980	170	110	20	3380	1560	884	110	-	15	30	60	-
Carbonatitic Breccias.																					
HF160	9.4	0.6	0.5	1.9	2000	-	-	-	200	180	140	60	125	590	350	40	nd	nd	10	-	-
HF195	7.0	0.6	2.2	1.3	4900	25	5	200	1015	120	185	80	nd	nd	nd	nd	nd	nd	15	25	-
HF230	5.6	2.7	1.3	1.0	660	15	-	-	240	70	110	100	500	295	118	25	nd	nd	5	-	-
HF377	13.7	2.3	0.5	0.4	5360	-	10	480	620	170	240	40	nd	nd	nd	nd	nd	nd	-	40	-
HF384	9.5	0.2	0.9	1.6	960	45	-	-	65	95	255	50	125	-	-	100	nd	nd	30	20	-
HF621	9.6	0.9	0.7	2.2	2800	-	-	-	350	170	200	80	nd	nd	nd	nd	nd	nd	10	30	-

Appendix Table 3a (continued). Analyses of ferruginous alvikites and carbonatitic breccias from W. Kenya and E. Uganda. - element not detected, nd analysis not attempted.

Elements Ga, Dy, Ge, and Be not detected in these samples.

Specimen Number	Al$_2$O$_3$ wt.%	MgO wt.%	TiO$_2$ wt.%	MnO wt.%	Ba ppm	Be ppm	Co ppm	Cu ppm	Mo ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
HC258	<0.05	0.35	2.2	1.0	190	10	5	5	5	5	30	3720	1600	70	Alvikite
HF462	<0.05	0.1	2.4	0.6	1250	40	5	5	5	130	270	4720	1050	20	Alvikite
HC613	<0.05	0.1	1.9	0.8	660	20	5	5	5	58	155	4600	1800	20	Alvikite
HC614	<0.05	0.1	2.1	0.7	410	10	5	5	5	40	70	4560	1250	10	Alvikite
HC629	<0.05	0.2	1.4	1.0	1200	30	5	5	5	45	275	3730	1080	40	Alvikite
HC649	<0.05	0.5	>5.0	0.6	1750	20	35	15	20	20	250	2700	780	55	Alvikite
U389	<0.05	0.1	1.1	0.4	680	10	5	10	5	5	50	6500	950	10	Alvikite
U783	<0.05	0.4	1.0	1.9	2250	20	5	10	5	120	490	6200	1900	20	Alvikite
N348	<0.05	0.1	4.3	0.8	370	10	20	5	5	170	25	1800	1940	10	Alvikite
N427	<0.05	1.6	0.1	1.5	2000	10	10	20	110	300	900	250	1380	25	Alvikite

Appendix Table 3b(i). Spectrometric analyses of magnetite from carbonatites. The elements Cr, Bi, Ge, Ni, Sn, Ag, Li, and Ga were below the limits of detection.

Specimen Number	Fe_2O_3 wt.%	MgO wt.%	MnO wt.%	Ba ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
HF84	0.3	0.3	0.3	460	-	2200	-	-	-	Sovite
HC338	-	-	0.2	810	-	4000	20	-	-	Sovite
HC965	-	-	0.1	460	-	4000	-	-	-	Sovite
U771	-	0.3	0.2	250	-	2440	15	-	-	Sovite
HC258	0.55	0.3	0.1	3000	-	890	-	65	95	Alvikite
HC366	0.7	0.7	0.7	1660	-	1290	55	15	13	Alvikite
HF462	0.9	1.6	0.3	2560	10	1390	-	20	-	Alvikite
HF508	0.4	0.2	0.2	800	10	1620	-	70	-	Alvikite
HC509	-	0.2	0.3	560	-	2480	20	10	-	Alvikite
HC613	-	-	0.2	400	-	1580	40	120	-	Alvikite
HC629	-	0.2	0.2	940	-	1250	20	25	15	Alvikite
HC649	0.3	0.2	0.1	860	-	2400	-	-	-	Alvikite

Appendix Table 3b(ii). Spectrometric analyses of calcite from carbonatites, from W. Kenya and E. Uganda. The elements Be, Bi, Co, Cr, Cu, Ga, Ge, Li, Ni, Sn, Nb, and Mo were below the limits of detection.   - element not detected .

Specimen Number	Fe$_2$O$_3$ wt.%	MgO wt.%	MnO wt.%	Ba ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
U783	2.4	0.7	0.7	450	10	1140	15	340	35	Alvikite
U786	0.9	0.4	0.4	260	-	1480	-	10	-	Alvikite
U842	0.5	-	0.1	1050	-	1040	-	45	-	Alvikite
U786	-	-	0.2	410	-	2800	-	-	-	Alvikite
N348	0.8	-	0.6	960	-	1480	-	78	-	Alvikite

Appendix Table 3b(ii) , (continued). Spectrometric analyses of calcite from carbonatites from W. Kenya and E. Uganda. The elements Be, Bi,Co,Cr,Cu,Ga,Ge,Li,Ni,Sn,Nb, and Mo were below the limits of detection. - element not detected .

PYROXENE.

Al_2O_3 wt.%	CaO wt.%	Fe_2O_3 wt.%	K_2O wt.%	MgO wt.%	MnO wt.%	TiO_2 wt.%	Ba ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Specimen Number
1.0	14.6	>20.0	0.9	6.0	0.3	1.4	760	10	45	10	22	10	40	35	-	1450	>2000	200	2160	HC509
1.2	5.7	>20.0	0.3	5.2	0.3	0.7	60	10	-	5	20	-	-	-	-	150	>2000	100	1450	S19
0.8	5.3	>20.0	0.2	5.1	0.2	0.7	30	5	20	15	25	-	15	-	65	160	>2000	70	2300	S20

MICA.

Al_2O_3 wt.%	CaO wt.%	Fe_2O_3 wt.%	K_2O wt.%	MgO wt.%	MnO wt.%	TiO_2 wt.%	Ba ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Specimen Number
10.6	11.0	>20.0	8.0	nd	0.2	1.5	800	20	-	-	120	-	-	-	-	640	1200	740	300	U771
10.8	11.0	>20.0	8.0	12.4	0.3	2.4	4000	40	80	-	40	-	-	80	40	1960	480	680	-	HF89

Appendix Table 3b(iii).   Spectrometric analyses of pyroxene and mica from carbonatites from W. Kenya and E. Uganda.   −   element not detected,   nd   analysis not attempted.

Specimen Number	Fe$_2$O$_3$	MnO	TiO$_2$	CaO	Ba	Be	Co	Cr	Cu	Ga	Li	Nb	Ni	Pb	Sn	Sr	V	Zn	Zr	Ce	Y	La
	wt.%	wt.%	wt.%	wt.%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
HC320	18.6	0.3	1.2	0.9	1080	30	8	-	4	175	-	670	39	105	15	270	130	nd	2350	nd	nd	nd
HC541	11.0	0.1	0.9	2.5	8000	30	20	nd	50	80	-	170	nd	10	-	470	310	140	420	110	26	180
HC597	20.0	0.2	0.9	6.4	4400	70	15	nd	70	56	-	330	nd	28	10	900	430	275	800	225	44	110
HC731	7.2	0.2	0.4	>10.0	1500	30	32	5	52	30	72	670	20	50	20	1650	210	15	180	110	9	285
HC732	8.0	0.1	1.1	6.6	5680	30	10	nd	5	35	-	330	310	25	-	580	140	435	710	nd	nd	nd
SuN102	4.3	0.1	0.3	2.3	1650	10	-	-	-	50	-	-	-	25	-	660	15	460	540	150	-	250
SuT 134	6.4	0.2	0.8	2.0	2400	30	-	-	84	55	-	670	-	30	30	650	110	290	680	350	45	300

Appendix Table 3c. Spectrometric analyses for major and trace elements in feldspathised country rock adjacent to carbonatite intrusions in W. Kenya and E. Uganda.

APPENDIX TABLES 4a, 5a, and 6a.

Abbreviations used for the analyst of the respective chemical analyses in the above Tables are as follows:-

DSS	-	Dr. D.S. Sutherland
MB	-	M. Blackley
MJLeB	-	Dr. M. J. LeBas
MT	-	M. Thind
RT	-	R. Tyler
WHH	-	W.H. Herdsman

Data for analyses performed by Dr. D.S. Sutherland, M. Blackley and R. Tyler, are taken from Sutherland, 1966 (Unpublished PhD. thesis, University of London).

In Tables 4c,5c,6c and7a-d, the detection limits for the various elements, and the upper limits of sensitivity for these elements in the silicate rocks and minerals are shown below.

Element	Detection Limit	Upper limit of Sensitivity
Ba	10ppm	5000ppm
Be	5ppm	1000ppm
Co	5ppm	1000ppm
Cr	5ppm	1000ppm
Cu	5ppm	1000ppm
Ga	5ppm	1000ppm
Li	5ppm	1000ppm
Nb	50ppm	1000ppm
Ni	5ppm	1000ppm
Pb	5ppm	1000ppm
Sn	5ppm	1000ppm
Sr	5ppm	4000ppm
V	5ppm	1000ppm
Zn	10ppm	1000ppm
Zr	5ppm	1000ppm
Ce	50ppm	10000ppm
La	35ppm	6000ppm
Nd	10ppm	6000ppm
Y	5ppm	1000ppm

	U1099	SuB27	SuN35	SuB7p	SuB266	U211	U1054
SiO_2	44.80	45.68	41.39	45.49	49.47	42.80	43.11
TiO_2	0.96	0.64	2.55	0.41	1.00	0.52	0.13
Al_2O_3	13.21	3.33	4.91	11.99	15.26	19.47	21.27
Fe_2O_3	2.64	6.71	10.37	7.08	5.05	3.24	1.54
FeO	9.38	9.50	9.77	6.46	4.71	2.18	0.73
MnO	0.19	0.41	0.21	0.35	0.33	0.15	0.18
MgO	5.16	6.89	10.06	3.82	2.47	2.61	0.19
CaO	15.88	20.28	18.02	12.32	8.61	13.30	15.74
Na_2O	5.26	2.86	1.52	5.45	8.59	9.35	9.95
K_2O	1.75	0.10	1.40	1.35	3.29	4.01	4.73
P_2O_5	0.17	2.10	0.02	0.16	0.57	0.36	0.41
H_2O+		0.46		2.94	0.78	0.77	0.75
H_2O-						0.13	0.18
CO_2	0.44	0.11		1.01	0.68	1.00	0.59
Total	100.05	99.07	100.22	98.83	100.80	99.91	99.95
Analyst	MT	DSS	RT	DSS	DSS	MT	MT

Appendix Table 4a.   Chemical analyses of intrusive peralkaline silicate

rocks from W. Kenya and E. Uganda.

	SuN5	SuN63	HC309	HC741	U369	HC964
SiO_2	41.69	40.79	39.80	44.52	38.98	42.04
TiO_2	-	-	2.54	1.36	3.29	0.44
Al_2O_3	22.19	24.11	14.99	10.32	20.26	20.58
Fe_2O_3	2.59	2.27	6.08	11.88	5.87	4.34
FeO	0.97	0.52	2.73	1.72	2.75	1.20
MnO	0.14	0.13	0.19	0.24	0.16	0.20
MgO	1.64	1.58	4.02	0.51	3.65	3.11
CaO	13.97	12.44	14.72	17.50	14.77	10.11
Na_2O	11.33	12.98	7.15	2.11	7.09	11.41
K_2O	5.14	5.34	3.60	4.03	2.94	4.60
P_2O_5	0.46	0.21	0.61	0.14	0.04	0.32
H_2O+	-	-	0.88	1.49	0.27	1.64
H_2O-				0.56	0.10	0.13
CO_2	0.25	0.50	0.98	3.28	0.32	-
Total	100.62	100.02	98.29	99.66	100.52	100.12
Analyst	DSS	DSS	MJleB	WHH	MT	MT

Appendix Table 4a (continued). Chemical analyses of intrusive peralkaline silicate rocks from W. Kenya and E. Uganda.

	SuB247	SuB262	SuB265	SuB311	SuN106	SuTo38
SiO_2	48.18	47.70	50.25	53.93	54.38	43.34
TiO_2	0.60	0.49	0.62	0.32	0.58	0.59
Al_2O_3	17.24	13.65	19.50	18.27	17.02	13.95
Fe_2O_3	2.84	3.27	2.42	1.54	4.67	5.69
FeO	3.16	3.10	2.51	2.15	2.57	3.96
MnO	0.16	0.25	0.20	0.11	0.12	0.27
MgO	1.34	0.43	0.41	1.08	1.09	1.58
CaO	8.26	11.23	5.67	5.15	3.79	12.40
Na_2O	6.91	4.93	6.90	7.94	5.55	3.97
K_2O	5.64	6.04	6.50	5.66	9.54	5.89
P_2O_5	0.49	0.55	0.32	0.26	0.35	0.01
H_2O+ H_2O-	2.14	1.58	2.87	0.72	-	2.62
CO_2	2.71	5.2	1.86	1.96	-	4.40
Total	99.65	98.42	100.23	99.09	99.66	99.67
Analyst	DSS	DSS	DSSS	DSS	DSS	MB

Appendix Table 4a (continued). Chemical analyses of intrusive

peralkaline silicate rocks from W. Kenya and E. Uganda.

Specimen Number	SiO$_2$ wt.%	Al$_2$O$_3$ wt.%	FeO wt.%	Fe$_2$O$_3$ wt.%	MgO wt%	MnO wt.%	CaO wt.%	Na$_2$O wt.%	K$_2$O wt.%	TiO$_2$ wt.%	Rock Type
HC988	39	5.4	2.9	9.2	7.8	0.4	>20.0	2.6	1.1	1.1	Pyroxenite
N683	40	6.0	6.4	6.7	7.6	0.2	>20.0	2.04	0.6	1.6	do.
U1099	55	13.5	8.8	4.5	9.6	0.2	13.6	4.96	1.7	0.9	do.
SuB27	47	3.2	9.5	6.7	6.7	0.5	>20.0	2.9	0.1	0.6	do.
SuN35	42	7.4	5.8	16.1	9.0	0.2	18.4	3.7	1.6	2.3	do.
N694	45	5.4	6.0	10.8	5.8	0.5	>20.0	2.8	4.0	0.9	do.
HC312	42	5.1		2.6	5.8	0.5	>20.0	-	-	0.3	Ijolite
HC930	49	9.8	5.3	7.8	5.7	0.6	19.6	5.0	1.6	0.5	do.
SuB7a	47	11.6	6.5	7.1	2.9	0.4	10.7	5.5	1.4	0.4	do.
SuB266	49	14.9	4.7	5.1	2.4	0.3	7.9	8.4	3.3	1.1	do.
SuTo590	43	12.8	4.7	16.2	1.0	0.3	14.8	6.9	3.1	2.0	do.
U211	47	14.8	2.2	5.8	2.7	0.2	16.8	7.8	3.4	0.8	Urtite
U1054	43	16.2	0.5	1.1	0.2	0.2	>10.0	9.8	4.6	0.2	do.

Appendix Table 4b.   Spectrometric analyses for major elements in peralkaline intrusive silicate rocks

from W. Kenya and E. Uganda.   - analysis not attempted .

Specimen Number	SiO$_2$ wt.%	Al$_2$O$_3$ wt.%	FeO wt.%	Fe$_2$O$_3$ wt.%	MgO wt.%	MnO wt.%	CaO wt.%	Na$_2$O wt.%	K$_2$O wt%	TiO$_2$ wt.%	Rock Type
U1111	45	19.7	0.4	-	0.2	0.1	10.8	11.3	4.7	0.1	Urtite
SuN5	36	14.6	0.3	0.3	0.1	0.1	16.0	11.4	4.3	0.1	do.
SuN63	35	11.3	0.1	-	0.1	0.7	10.8	13.0	4.1	0.1	do.
HC309	43	13.9	1.5	6.3	1.9	0.1	11.0	8.0	4.0	4.0	Melanite ijolite
HC324	39	12.6	2.4	6.2	2.9	0.2	12.6	7.2	3.1	2.8	do.
HC741	45	11.8	1.0	13.9	0.2	0.2	17.6	2.0	5.3	1.7	do.
HC993	38	9.7	1.7	10.2	2.3	0.3	>20.0	4.4	2.1	2.6	do.
U88	48	11.9	1.4	7.2	2.4	6.3	>20.0	7.3	3.2	0.8	do.
U369	46	13.4	2.5	8.7	5.3	0.2	11.2	6.0	2.4	4.2	do.
SuN521	40	7.4	4.4	9.0	4.2	0.3	>20.0	2.4	0.6	0.8	do.
HC323	43	13.7	1.7	6.5	2.8	0.2	15.9	7.6	3.0	2.2	Feldspathic ijolite
HC934	40	14.0	1.8	6.3	2.2	0.2	9.2	7.4	3.3	1.8	do.
HC964	42	20.6	1.2	4.3	3.1	0.2	10.1	11.41	4.6	0.4	do.
HC999	40	12.1	1.6	7.4	1.0	0.2	15.6	5.3	2.7	3.8	do.

Appendix Table 4b (continued). Spectrometric analyses for major element in peralkaline intrusive silicate rocks

from W. Kenya and E. Uganda .   - ELEMENT not detected.

Specimen Number	SiO$_2$ wt.%	Al$_2$O$_3$ wt.%	FeO wt.%	Fe$_2$O$_3$ wt.%	MgO wt.%	MnO wt.%	CaO wt.%	Na$_2$O wt.%	K$_2$O wt.%	TiO$_2$ wt.%	Rock Type
SuB247	48	15.7	3.2	2.8	0.7	0.2	8.1	6.9	5.6	0.8	Nepheline-syenite
SuB262	53	11.8	3.1	3.3	0.8	0.3	10.3	4.8	6.1	0.4	do.
SuB265	51	17.9	2.5	2.4	0.3	0.2	5.6	6.9	6.5	0.7	do.
SuB311	51	16.3	2.2	1.5	0.5	0.1	4.9	7.9	5.7	0.3	do.
SuN106	49	16.7	1.6	4.3	0.3	0.1	1.8	4.6	8.7	0.3	do.
SuTo38	48	12.1	4.0	5.7	0.6	0.2	11.0	4.0	5.9	0.7	do.
N225	40	15.1	3.6	1.0	0.2	0.1	>10.0	8.9	3.1	0.4	do.
N266	42	15.5	1.3	3.0	0.6	0.2	9.7	9.8	5.0	0.5	do.
N464	47	17.0	1.4	3.8	0.5	0.2	5.1	9.9	3.3	0.5	do.
N503	50	16.4	0.6	4.8	0.4	0.2	5.1	9.8	6.1	0.5	do.
N688	40	10.0	3.3	5.8	3.9	3.8	>20.0	5.9	2.0	0.5	do.

Appendix Table 4b (continued). Spectrometric analyses for major elements peralkaline intrusive silicate rocks from W. Kenya and E. Uganda .

Specimen Number	SiO$_2$ wt.%	Al$_2$O$_3$ wt.%	FeO wt.%	Fe$_2$O$_3$ wt.%	MgO wt.%	MnO wt.%	CaO wt.%	Na$_2$O wt.%	K$_2$O wt.%	TiO$_2$ wt.%	Rock Type
HC865	41	12.7	2.0	7.0	5.0	0.2	11.4	nd	nd	1.5	Microijolite
HC912	42	12.0	2.6	5.5	4.6	0.3	12.4	7.1	3.2	1.1	do.
U149	41	17.0	1.7	4.0	0.5	0.2	7.2	8.6	5.2	0.6	do.
U207	49	15.8	10.2		1.7	0.3	9.6	3.4	3.7	1.0	do.
U242	47	17.0	2.9	8.5	1.2	0.3	5.7	8.3	4.7	0.4	do.
U345	47	17.4	1.9	4.6	0.5	0.2	4.2	8.4	6.1	0.8	do.

Appendix Table 4b (continued). Spectrometric analyses for major elements in peralkaline silicate intrusive rocks from W. Kenya and E. Uganda .

Specimen Number	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Nb ppm	Ni ppm	Pb ppm	Sn ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	Y ppm	La ppm	Nd ppm	Rock Type
HC988	240	10	30	5	14	24	25	330	15	10	28	760	380	160	480	610	20	140	-	Pyroxenite
N683	300	10	20	10	25	10	30	500	-	50	25	750	190	140	600	800	25	100	-	Pyroxenite
N694	1600	30	40	-	100	25	60	860	-	40	25	1550	370	330	1000	3500	77	800	nd	Pyroxenite
U1099	340	10	79	354	80	25	-	185	184	15	30	430	275	160	100	130	9	100	-	Pyroxenite
SuB27	150	20	31	98	22	18	20	370	28	38	30	440	130	145	540	400	-	250	-	Pyroxenite
SuN35	230	-	35	-	10	30	-	400	15	50	30	300	260	300	270	250	20	-	-	Pyroxenite
HC312	1220	-	30	-	75	25	-	-	130	-	-	1680	165	100	170	nd	nd	nd	nd	Ijolite
HC930	970	30	30	-	5	32	38	440	15	18	30	870	310	250	420	nd	nd	nd	nd	Ijolite
SuB7a	1500	30	22	20	-	25	10	170	10	15	10	630	100	230	840	-	-	250	-	Ijolite
SuB266	1030	30	22	26	-	38	-	280	20	15	15	650	125	355	600	370	14	135	-	Ijolite
SuTo590	960	30	33	-	12	50	33	1350	10	10	15	1160	325	140	770	200	5	170	-	Ijolite
U211	280	5	5	-	-	42	-	-	-	-	7	680	250	200	350	-	-	200	-	Urtite
U1054	180	10	-	-	-	60	-	-	-	30	-	690	140	260	50	-	-	210	-	Urtite

Appendix Table   4c.   Trace elements in peralkaline intrusive silicate rocks from W. Kenya and E. Uganda.

- element below detection limit,   nd analysis not attempted.

Specimen Number	Rock Type	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Nb ppm	Ni ppm	Pb ppm	Sn ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	Y ppm	La ppm	Nd ppm
U1111	Urtite	380	5	-	-	-	62	-	-	-	-	-	600	20	250	-	80	-	180	-
SuN5	Urtite	340	-	-	-	-	35	-	-	-	-	-	210	-	100	-	-	-	330	-
SuN63	Urtite	290	-	-	-	-	45	-	-	-	-	-	210	-	100	-	-	-	200	-
HC309	Melanite ijolite	100	20	26	-	44	36	15	330	10	8	20	500	275	65	1350	250	147	200	-
HC324	Melanite ijolite	300	30	22	-	8	35	20	440	10	15	18	1070	310	200	750	760	52	-	-
HC741	Melanite ijolite	3080	30	15	-	25	55	33	620	10	20	15	1100	660	100	1200	900	83	105	-
HC993	Melanite ijolite	2200	30	22	-	40	35	38	640	10	15	15	790	460	100	340	125	37	110	-
U88	Melanite ijolite	430	-	15	-	25	35	30	250	30	-	10	830	380	120	450	250	-	160	-
U369	Melanite ijolite	200	10	10	-	-	30	15	250	40	-	-	390	420	180	920	-	103	-	-
SuN521	Melanite ijolite	110	-	30	-	-	20	45	220	25	25	10	300	240	100	320	-	-	150	-
HC323	Feldspathic ijolite	410	30	25	25	5	30	32	830	25	15	20	1090	475	185	1150	500	30	45	-
HC934	Feldspathic ijolite	780	10	30	30	30	38	5	410	62	15	15	980	230	90	500	580	-	110	-
HC964	Feldspathic ijolite	200	10	22	-	70	30	-	-	-	5	-	730	120	300	180	880	32	nd	nd
HC999	Feldspathic ijolite	1510	30	20	-	12	30	28	290	10	10	15	830	150	60	1280	nd	nd	nd	nd

Appendix Table 4c, (continued). Trace elements in peralkaline intrusive silicate rocks from W. Kenya and E. Uganda. - element not detected, nd analysis not attempted.

Specimen Number	Rock Type	Nd ppm	La ppm	Y ppm	Ce ppm	Zr ppm	Zn ppm	V ppm	Sr ppm	Sn ppm	Pb ppm	Ni ppm	Nb ppm	Li ppm	Ga ppm	Cu ppm	Cr ppm	Co ppm	Be ppm	Ba ppm
SuB247	Nepheline-syenite	-	600	9	300	750	120	125	1420	5	5	-	330	20	46	5	-	12	30	3240
SuB262	do.	-	350	-	400	880	60	75	1100	12	10	10	250	16	35	-	12	12	30	4480
SuB265	do.	-	250	25	300	350	230	60	1050	-	10	-	-	-	44	-	-	-	10	1840
SuB311	do.	-	200	42	-	470	220	90	970	-	-	-	-	-	46	-	10	-	10	2100
SuN106	do.	-	200	18	-	110	275	75	215	-	-	-	-	-	35	-	-	-	-	3400
SuTo38	do.	-	350	12	400	590	145	275	1300	5	10	-	330	20	46	5	-	12	30	4600
N225	do.	-	180	14	200	140	220	100	440	-	-	-	-	-	45	-	-	-	10	1800
N266	do.	-	1000	20	700	700	270	75	1000	-	20	-	-	-	40	-	-	-	10	1800
N464	do.	-	350	49	150	900	460	20	700	-	60	-	-	-	50	-	-	-	10	1100
N503	do.	-	450	48	1100	1900	370	160	1150	50	200	-	-	-	80	-	-	-	15	2400
N688	do.	-	80	80	1000	550	80	220	1100	-	25	-	200	30	10	-	-	-	10	1700

Appendix Table 4c (continued). Trace elements in peralkaline intrusive silicate rocks from W. Kenya and E. Uganda.   - element below detection limit, nd   analysis not attepted.

Specimen Number	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Nb ppm	Ni ppm	Pb ppm	Sn ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	Y ppm	La ppm	Nd ppm	Rock Type
HC865	3200	-	5	-	5	35	-	-	-	-	-	1040	700	60	510	nd	nd	nd	nd	Microijolite
HC912	960	-	5	10	20	35	-	-	-	-	-	700	660	70	430	nd	nd	nd	nd	do.
U149	2800	10	-	-	-	56	-	-	-	-	-	950	250	300	200	220	-	300	-	do.
U207	1000	10	10	-	15	50	-	-	-	-	-	660	500	460	400	200	-	200	-	do.
U242	2400	10	-	-	-	58	5	50	-	10	5	920	400	450	350	nd	nd	nd	nd	do.
U345	3200	10	-	-	-	45	-	-	-	-	-	530	125	320	320	160	-	155	-	do.

Appendix Table 4c (continued).   Trace elements in peralkaline intrusive silicate rocks from W. Kenya

and E. Uganda.   nd   below detection limit,   nd   analysis not attempted.

- element   below detection limit,   nd   analysis not attempted.

	N595	U890	U926	HF329	U156	U162	HF89A
SiO_2	40.47	43.86	43.79	44.94	50.76	51.39	45.64
TiO_2	3.25	2.51	2.65	1.49	0.56	0.58	1.50
Al_2O_3	8.75	11.51	13.27	16.64	20.42	20.10	15.44
Fe_2O_3	11.86	6.66	8.50	5.54	5.14	3.74	4.86
FeO	2.80	5.80	5.00	2.06	0.62	1.61	2.73
MnO	0.17	0.20	0.20	0.21	0.26	0.27	0.23
MgO	9.77	7.96	6.25	2.87	0.52	0.21	1.85
CaO	14.33	10.91	9.70	8.75	2.04	4.71	9.81
Na_2O	2.24	4.00	3.33	6.39	8.92	10.31	6.30
K_2O	1.14	2.00	2.42	3.88	6.75	5.09	2.93
P_2O_5	0.5	0.25	0.25	0.48	0.14	0.13	0.50
H_2O+	3.6	3.57	3.14	2.02	1.48	2.47	4.15
H_2O-		0.73	0.90	1.96	1.90		0.32
CO_2	0.32	-	-	0.69	0.10	-	3.74
TOTAL	99.48	99.96	99.40	97.92	99.97	100.61	100.00
Analyst	M.J.LeB	M.T	M.T.	M.T	M.T.	M.J.LeB	W.H.H.

Appendix Table 5a , Chemical analyses of peralkaline silicate rocks.

Phonolites.

	U48	U278	U296	U301	U382	N90	SuB269
SiO$_2$	45.37	57.87	52.06	53.09	55.72	49.71	49.55
TiO2	1.59	0.31	0.44	0.42	0.61	0.92	0.42
Al$_2$O$_3$	15.50	16.46	19.63	19.56	18.69	18.76	16.80
Fe$_2$O$_3$	4.93	2.84	4.27	3.76	1.58	4.30	4.30
Fe O	3.22	3.11	0.33	0.73	3.22	2.16	2.92
MnO	0.23	0.36	0.18	0.19	0.25	0.21	0.46
MgO	3.07	0.37	0.33	0.56	0.66	0.72	0.17
CaO	10.42	1.66	3.40	2.08	2.50	6.16	6.39
Na$_2$O	4.05	7.76	8.32	8.76	6.95	9.93	8.91
K$_2$O	3.89	6.00	4.29	5.52	5.51	4.33	4.96
P$_2$O$_5$	0.75	0.05	0.04	0.02	0.14	0.20	0.35
H$_2$O+	5.99	2.64	5.40	4.53	3.86	1.97	1.83
H$_2$O-	0.68	0.57	1.35		0.39	0.18	
CO$_2$	–	–	0.23	–	–	0.09	3.43
Total	99.69	100.00	100.27	99.22	100.08	99.63	100.49
Analyst	MT	MT	MT	MJleB	MT	MJleB	DSS

Appendix Table 5a (continued). Chemical analyses of phonolitic rocks from W. Kenya andE. Uganda.

Specimen Number	SiO$_2$ wt. %	Al$_2$O$_3$ wt. %	FeO wt. %	Fe$_2$O$_3$ wt. %	MgO wt. %	MnO wt. %	CaO wt. %	Na$_2$O wt. %	K$_2$O wt. %	TiO$_2$ wt. %	Rock Type
N593	46	11.6	2.0	12.8	7.8	0.3	15.2	3.0	1.7	1.7	Melanephelinite
N595	43	8.9	3.2	14.8	10.2	0.2	15.2	2.5	1.3	3.5	do.
N712	50	11.5	4.0	10.4	9.6	0.3	16.0	2.0	0.8	0.8	do.
U890	44	9.7	6.1	5.4	6.3	0.2	10.1	4.2	2.0	1.8	do.
U926	45	13.2	4.8	8.0	6.0	0.3	11.4	3.4	2.3	3.0	do.
HF329	46	14.4	1.8	4.8	4.0	0.2	8.5	6.9	3.2	1.6	Nephelinite
SuT125	44	13.0	4.4	5.9	2.4	0.4	16.8	5.3	3.7	1.1	do.
U156	49	19.0		6.3	2.9	0.3	1.6	8.6	6.3	0.6	do.
U162	49	17.8	1.6	1.1	0.3	0.2	3.5	4.9	2.5	0.7	Phonolitic nephelinite
HF89a	48	15.9	2.5	6.4	4.3	0.3	8.9	6.3	3.6	1.6	do.
HC583	46	16.3	0.6	3.5	4.1	0.1	4.0	8.1	4.7	0.8	do.
HC761b	55	16.8	1.6	7.5	2.1	0.3	7.5	8.0	3.8	1.0	do.

Appendix Table 5b. Spectrometric and other analyses for major elements in phonolitic rocks from W. Kenya and E. Uganda .

Specimen Number	SiO$_2$ wt.%	Al$_2$O$_3$ wt.%	FeO wt.%	Fe$_2$O$_3$ wt.%	MgO wt.%	MnO wt.%	CaO wt.%	Na$_2$O wt.%	K$_2$O wt.%	TiO$_2$ wt.%	Rock Type
HC1005	41	13.4	2.7	5.4	1.3	0.3	8.1	8.4	3.6	1.5	Phonolitic nephelinite
N85	49	15.5	1.8	6.4	2.1	0.2	6.2	7.1	4.6	1.3	do.
U48	54	15.8	2.8	6.4	1.7	0.2	nd	4.4	3.6	1.9	Analcime phonolite
U278	55	18.6	2.4	4.2	0.3	0.3	1.1	8.0	2.0	0.5	do.
U296	56	19.1	0.2	3.7	0.4	0.2	1.9	8.9	4.4	0.4	do.
U301	59	19.7	0.5	4.6	0.5	0.2	1.3	7.6	5.4	0.6	do.
U382	57	20.5	2.0	1.9	0.5	0.2	1.45	6.7	5.4	0.5	do.
N90	48	16.2	2.1	5.7	0.5	0.2	4.6	8.9	4.5	1.1	do.
N158	50	17.0	0.9	4.1	0.2	0.2	2.8	8.4	6.4	0.4	do.

Appendix Table 5b (continued). Spectrometric and other analyses for major elements in phonolitic rocks from W. Kenya and E. Uganda. ND analysis not attempted.

Specimen Number	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Nb ppm	Ni ppm	Pb ppm	Sn ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	Y ppm	La ppm	Nd ppm	Rock Type
N593	3200	15	50	50	210	35	30	400	50	40	25	880	550	150	790	500	25	-	-	Melanephelinite
N595	1700	10	60	410	215	10	15	200	120	40	25	720	310	260	300	350	19	-	-	do.
N712	6000	15	60	250	180	40	45	250	110	50	10	1300	220	360	510	580	3	-	-	do.
U890	950	-	60	350	155	25	-	-	105	-	-	1050	675	100	310	nd	nd	nd	nd	do.
U926	1300	-	50	65	110	28	-	-	30	-	-	1700	750	125	450	nd	nd	nd	nd	do.
HF329	7280	30	30	236	44	45	-	560	54	30	20	1230	80	185	820	1100	7	240	-	Nephelinite
SuT125	3000	-	15	-	110	35	60	300	-	50	-	1000	130	360	590	400	45	250	-	do.
U156	1000	10	-	-	-	50	-	-	-	-	-	1150	600	140	1500	300	35	500	-	do.
U162	2560	5	-	-	-	50	10	-	-	80	-	1250	200	400	950	1000	38	500	-	Phonolitic nephelinite
HF89a	2050	10	5	5	35	35	10	-	-	25	-	1820	675	120	550	700	28	180	-	do.
HC583	>4000	20	-	25	30	45	-	-	-	30	-	1550	630	160	1500	nd	nd	nd	nd	do.
HC761b	1800	40	22	32	102	50	25	950	38	55	15	1450	220	390	1210	nd	nd	nd	nd	do.

Appendix Table 5c.   Trace elements in phonolitic rocks from W. Kenya and E. Uganda.

- element not detected,   nd analysis not attempted.

Specimen Number	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Nb ppm	Ni ppm	Pb ppm	Sn ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	Y ppm	La ppm	Nd ppm	Rock Type
HC1005	870	20	12	-	23	33	10	250	-	15	-	900	125	145	550	1100	25	155	-	Phonolitic nephelinite
N85	1350	10	-	40	45	40	5	200	-	60	-	880	130	410	1000	600	9	350	-	do.
U48	3400	10	-	-	20	35	8	250	-	15	7	1650	260	450	1000	800	44	330	-	Analcime-phonolite
U296	550	10	-	-	-	80	-	200	-	75	-	830	60	460	1600	320	18	300	-	do.
U301	480	10	-	-	-	80	-	200	-	95	-	570	150	470	1000	-	7	300	-	do.
U382	680	10	-	-	-	50	-	-	-	15	-	150	20	400	1140	700	58	700	-	do.
N90	2500	10	-	-	10	40	-	200	-	75	-	1400	150	400	800	1300	270	500	-	do.
N158	960	15	-	-	-	60	10	-	-	100	-	1000	75	250	1000	700	53	450	-	do.
SuB269	970	30	-	12	-	58	-	-	-	10	-	1150	60	160	1680	-	19	300	-	do.

Appendix Table 5c (continued).   Trace elements in phonolitic rocks x from W. Kenya and E. Uganda.

- element not detected,   nd   analysis not attempted.

	SuB218	SuB223	SuB242	SuB279	SuTo509	SuTo510	SuTo514	SuTo536	SuTo598	HC54	HC744	HC825
SiO_2	55.85	64.79	59.36	57.61	63.86	72.99	67.01	51.14	54.56	71.54	54.08	56.38
TiO_2	0.98	0.43	0.41	0.68	0.72	0.18	0.79	0.44	0.36	0.48	0.50	0.51
Al_2O_3	12.90	17.78	15.50	16.30	16.73	14.64	14.63	14.69	11.92	12.42	17.04	14.08
Fe_2O_3	4.42	2.05	2.43	2.36	4.05	1.26	3.54	1.12	6.93	1.19	4.90	5.91
FeO	3.79	0.88	2.24	3.03	0.49	0.06	0.54	2.33	0.49	3.12	2.59	0.83
MnO	0.19	0.09	0.09	0.19	0.35	0.10	0.23	0.16	0.50	0.08	0.22	0.16
MgO	1.82	0.40	1.00	1.64	0.54	0.01	0.95	0.04	0.08	2.26	0.68	0.87
CaO	7.47	2.21	4.43	5.38	1.59	1.11	0.81	8.68	8.01	0.77	3.50	4.00
Na_2O	4.48	8.42	3.59	7.71	5.16	4.09	6.06	1.08	3.77	5.21	5.96	3.31
K_2O	4.38	3.19	9.17	4.05	5.53	5.63	5.19	10.43	6.86	0.60	6.10	11.44
P_2O_5	1.11	0.19	0.25	0.54	0.07	0.08	0.05	1.03	0.17	0.10	–	0.04
H_2O^+	0.92	0.33	0.33	1.00	0.88	0.43	0.20	0.52	0.91	1.81	1.83	
H_2O^-	–	–	–		0.09	–	0.03	–	–	0.09	0.22	0.45
CO_2	–	–	–	0.30	0.07	0.08	0.08	7.00	4.91	0.24	1.27	2.03
Total	97.52	100.76	100.51	99.89	100.32	100.66	100.11	97.68	99.50	99.91	98.89	100.82
Analyst	DSS	DSS	DSS	DSS	MB	MB	MB	MB	MB	MT	WHH	MJleB

APPENDIX TABLE 6a.   Chemical analyses of fenitic rocks from W. Kenya and E. Uganda .

Specimen Number	SiO$_2$ wt.%	Al$_2$O$_3$ wt.%	FeO wt.%	Fe$_2$O$_3$ wt.%	MgO wt.%	MnO wt.%	CaO wt%	Na$_2$O wt.%	K$_2$O wt.%	TiO$_2$ wt.%	Rock Type
SuB218	57	13.4	3.8	4.4	1.9	0.2	8.5	4.5	4.4	1.4	Syenitic fenite
SuB223	68	20.0	0.9	2.1	0.8	0.1	2.6	8.4	3.2	0.6	do.
SuB242	57	14.9	2.2	2.4	0.9	0.1	3.8	3.6	9.2	0.6	do. with nepheline
SuB279	55	15.1	3.0	2.4	0.9	0.1	5.1	7.7	4.1	0.6	do.
SuTo509	60	15.8	0.5	4.1	0.5	0.2	1.0	5.2	5.5	0.4	Fenite
SuTo510	73	18.0	0.1	1.3	-	0.1	0.1	4.1	5.6	0.4	do.
SuTo514	65	17.9	0.5	3.5	0.8	0.2	0.5	6.1	5.2	0.5	do.
SuTo536	47	14.3	2.4	1.1	0.3	0.1	8.2	1.1	10.4	0.5	Syenitic fenite
SuTo598	55	12.1	0.5	6.9	0.8	0.4	8.5	3.8	6.9	0.6	do.

Appendix Table 6b. Spectrometric and other analyses for major elements in fenitic rocks from carbonatitic complexes in W. Kenya and E. Uganda.   - element not detected .

Specimen Number	SiO$_2$ wt.%	Al$_2$O$_3$ wt.%	FeO wt.%	Fe$_2$O$_3$ wt.%	MgO wt.%	MnO wt.%	CaO wt.%	Na$_2$O wt.%	K$_2$O wt.%	TiO$_2$ wt.%	Rock Type
HC54	69	12.6	8.6		2.5	0.1	0.6	7.3	0.6	0.8	Fenite
HC653	69	12.1	1.4	8.0	0.6	0.9	8.0	6.3	4.1	1.4	do.
HC743	45	15.7	1.5	3.4	0.6	0.2	6.9	5.0	5.1	0.7	do.
HC744	45	13.1	1.6	11.2	0.1	0.2	3.6	7.1	7.32	0.7	do.
HC800	61	12.1	1.2	>15.0	2.2	0.1	6.6	9.8	0.2	0.7	do.
HC825	50	12.8	0.4	5.8	0.3	0.2	4.3	2.5	11.75	0.7	do.
N729	57	15.1	1.2	8.3	0.9	-	5.7	3.8	7.1	0.6	do.
N734	56	12.7	2.2	11.2	0.3	0.3	3.0	5.9	5.2	1.0	do.

Appendix Table 6b (continued). Spectrometric and other analyses for major elements in fenitic rocks from carbonatitic complexes in W. Kenya and E. Uganda. - element not detected .

Specimen Number	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Nb ppm	Ni ppm	Pb ppm	Sn ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Ce ppm	Y ppm	La ppm	Nd ppm	Rock Type
SuB218	1730	10	20	nd	26	35	-	330	-	15	15	720	75	240	660	700	21	1200	-	Syenitic fenite
SuB223	720	10	12	nd	22	35	-	-	20	10	-	390	135	160	150	600	5	1350	-	do.
SuB242	5440	-	-	nd	-	35	-	-	20	-	-	800	100	90	450	-	40	450	-	do. with nepheline
SuB279	2200	10	-	nd	25	40	-	-	-	45	-	970	75	370	720	-	-	350	-	do.
SuTo509	1540	22	20	nd	32	28	59	-	-	105	-	300	-	275	280	1050	61	400	-	Fenite
SuTo514	1100	30	30	nd	30	38	-	-	-	85	15	190	55	370	110	2700	56	1600	-	Fenite
SuTo510	4240	10	60	nd	5	25	46	-	-	60	5	460	40	220	260	1550	65	800	-	Femite
SuTo598	1250	30	14	nd	5	30	10	330	-	15	15	760	190	410	190	200	41	300	-	Syenitic fenite
SuTo536	2700	10	30	nd	-	53	-	-	-	10	-	1080	50	160	1880	450	-	210	-	do.

Appendix Table 6c.   Trace elements in fenitic rocks from W. Kenya and E. Uganda.

- element not detected,   nd   analysis not attempted.

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Specimen Number	Ba	Be	Co	Cr	Cu	Ga	Li	Nb	Ni	Pb	Sn	Sr	V	Zn	Zr	Ce	Y	La	Nd	Rock Type
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	
HC54	300	8	12	5	5	25	-	-	-	12	15	90	-	190	520	nd	nd	nd	nd	Fenite
HC653	2800	40	22	5	14	150	5	295	27	300	20	1520	230	90	1160	nd	nd	nd	nd	do.
HC743	1250	10	5	-	-	50	-	100	-	5	-	940	55	240	880	580	5	170	-	do.
HC744	1930	10	5	-	-	50	-	170	-	5	-	1050	90	90	1750	nd	nd	nd	nd	do.
HC800	180	10	5	5	-	34	-	170	-	14	30	380	260	90	540	nd	nd	nd	nd	do.
HC825	5040	10	-	5	-	85	50	330	-	10	-	680	125	185	1420	700	35	180	-	do.
N729	4000	30	-	-	25	40	70	410	-	440	-	605	75	1000	1900	650	57	650	-	do.
N744	3050	25	-	-	10	70	10	600	30	85	-	505	40	640	2000	400	49	50	-	do.

Appendix Table 6c (continued).   Trace elements in fenitic rocks from W. Kenya and E. Uganda.

- element not detected, nd   element not analysed.

Specimen Number	Rock Type	Al$_2$O$_3$ wt.%	CaO wt.%	Fe$_2$O$_3$ wt.%	K$_2$O Wt.%	MgO wt.%	MnO wt.%	TiO$_2$ wt.%	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm
SuB27	Pyroxenite	1.6	15.5	>20.0	0.2	6.3	0.6	0.3	70	-	20	115	10	20	-	35	-	-	320	500	100	470
HC309	Ijolite	6.8	>20.0	18.6	1.0	12.5	0.6	1.3	200	-	50	-	25	19	-	-	-	-	1000	250	200	650
HC323	do.	5.0	>20.0	>20.0	1.5	11.0	0.9	1.6	500	-	40	-	20	20	-	-	-	-	1160	1550	200	650
U351	do.	2.4	9.4	>20.0	0.7	2.2	0.1	0.6	110	-	20	20	40	60	-	-	130	-	420	300	1300	2060
SuTo590	do.	1.4	17.6	>20.0	0.5	2.5	1.0	0.8	120	-	10	-	80	25	-	-	20	-	460	1500	350	1180
U149	Microijolite	1.4	16.8	>20.0	0.7	4.4	-	0.2	50	-	20	-	50	-	-	-	20	320	660	780	550	280
U207	do.	2.5	>20.0	>20.0	0.9	5.6	0.7	3.3	140	20	25	85	25	10	20	25	320	5	370	1150	175	1150
U242	do.	2.2	>20.0	>20.0	0.9	5.6	-	0.3	260	-	20	-	-	-	-	-	130	-	750	750	550	280
U345	do.	5.2	>20.0	>20.0	1.1	3.1	1.0	2.2	260	-	15	20	20	20	-	-	70	-	720	800	220	680
SuTo38	Nepheline-syenite	2.8	16.4	>20.0	1.2	5.5	0.8	0.5	300	20	15	-	15	30	-	35	-	-	860	1450	240	1150
SuB265	do.	3.4	>20.0	>20.0	1.0	6.7	0.9	1.0	330	50	45	45	10	15	45	115	30	5	950	1200	275	1000
RR16	Fenite	1.4	>20.0	17.0	0.5	>7.0	0.5	0.5	90	-	165	nd	10	10	50	45	60	-	700	920	160	260
RR6	do.	1.0	12.8	>20.0	0.2	6.4	0.7	0.5	40	20	25	nd	10	15	25	10	-	-	490	725	350	750
RR201	do.	3.0	8.4	>20.0	2.2	3.0	0.9	1.6	700	-	10	nd	80	10	-	-	-	-	540	900	300	520
HC797	do.	3.2	4.0	>20.0	2.8	3.2	0.6	1.8	800	10	-	nd	-	50	-	35	40	-	820	1000	460	1700
HC825	do.	2.5	12.8	>20.0	2.8	2.2	1.0	1.4	640	-	15	nd	20	35	-	-	-	-	1050	1620	350	1740

Appendix Table 7a. Spectrometric analyses of pyroxenes from peralkaline rocks and fenites. - element not detected nd analysis not attempted.

Specimen Number	Al$_2$O$_3$ wt.%	CaO wt.%	Fe$_2$O$_3$ wt.%	K$_2$O Wt.%	MgO wt.%	MnO wt.%	TiO$_2$ wt.%	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
S53	1.8	16.8	>20.0	0.4	5.5	-	0.7	210	30	10	5	75	35	-	60	25	-	450	1400	360	2450	Fenite
S30	1.7	10.8	19.0	0.5	6.0	0.4	1.0	100	-	25	nd	20	20	-	35	50	5	440	1320	160	925	do.
S63	1.3	5.8	>20.0	0.7	3.4	-	3.4	350	15	10	nd	60	52	-	20	-	20	260	480	425	1260	do.
S14	2.6	>20.0	>20.0	0.8	6.7	0.4	3.3	90	20	55	5	25	22	10	45	5	-	670	725	125	1140	Melanephelinite
S33	4.5	>20.0	10.9	0.1	>7.0	0.4	2.0	40	20	50	20	35	22	50	80	10	-	740	980	120	410	do.
S197	4.4	>20.0	10.9	-	>7.0	0.2	0.9	30	-	55	715	20	20	25	55	65	-	330	670	30	140	do.
S29	2.0	12.5	>20.0	0.5	6.0	0.5	0.9	20	-	5	5	20	18	-	45	-	-	280	1480	160	1460	Phonolite
S17	2.1	17.0	>20.0	-	4.6	0.8	0.8	20	-	10	-	20	15	-	-	-	-	250	770	150	960	do.

PYROXENES.

Specimen Number	Al$_2$O$_3$ wt.%	CaO wt.%	Fe$_2$O$_3$ wt.%	K$_2$O Wt.%	MgO wt.%	MnO wt.%	TiO$_2$ wt.%	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
HC77	1.5	0.7	16.4	2.1	>7.0	0.8	0.3	10	-	30	40	15	5	900	15	225	-	30	380	525	395	Fenite
HC189	1.8	5.0	8.8	1.5	>7.0	0.2	0.4	5	-	10	60	15	-	-	40	-	-	70	690	70	250	do.
HC634	5.0	1.2	>20.0	0.5	>7.0	0.3	1.3	150	10	21	50	90	22	-	35	-	-	95	1560	150	375	do.
SuTo63	11.5	10.4	15.8	2.9	>7.0	0.3	1.7	325	-	50	-	10	35	-	15	-	5	235	420	95	1130	do.
SuTo501	2.0	4.0	>20.0	3.7	>7.0	0.6	1.0	550	15	15	375	25	10	290	45	50	375	570	760	475	575	do.

AMPHIBOLES.

Appendix Table 7a (continued). Spectrometric analyses of pyroxenes and amphiboles from peralkaline rocks from carbonatitic complexes in W. Kenya and E. Uganda. - element not detected .

Specimen Number	Al$_2$O$_3$ wt.%	CaO wt.%	Fe$_2$O$_3$ wt.%	K$_2$O Wt.%	MgO wt.%	MnO wt.%	TiO$_2$ wt.%	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
U1054	nd	0.9	1.4	6.5	-	-	-	120	-	-	-	-	65	-	-	-	-	250	-	35	10	Urtite
U1111	nd	1.7	1.6	6.8	-	-	-	50	-	-	-	10	65	5	-	35	-	260	-	35	25	do.
U211	nd	3.2	1.2	5.5	-	-	-	150	-	-	-	-	50	5	-	10	-	580	70	25	10	do.
HC324	nd	2.8	1.3	5.4	-	-	-	1050	-	-	-	-	50	5	-	-	-	1400	20	55	160	Ijolite
HC309	nd	1.1	1.7	6.5	0.1	-	0.1	640	-	-	-	-	50	5	-	-	5	775	-	50	50	do.
HC323	nd	3.8	1.7	5.3	-	-	0.7	720	-	-	-	-	50	10	-	-	5	2100	-	30	140	do.

Appendix Table 7b.   Spectrometric analyses of nepheline separated from peralkaline silicate rocks from carbonatite

complexes in W. Kenya and E. Uganda.

- element not detected ,   nd analysis not attempted .

- element not detected .

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Specimen Number	Al$_2$O$_3$ wt.%	CaO wt.%	Fe$_2$O$_3$ wt.%	K$_2$O Wt.%	MgO wt.%	MnO wt.%	TiO$_2$ wt.%	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
SuB247	nd	0.5	0.2	11.3	-	-	-	>6000	-	-	-	-	45	5	-	-	15	1025	-	50	180	Nepheline-syenite
SuB265	nd	-	0.1	12.3	-	-	-	>6000	-	-	-	-	45	-	-	-	-	710	-	-	50	do.
SuB262	nd	0.2	0.3	12.3	-	-	-	>6000	-	-	5	-	60	-	-	-	5	870	10	10	140	do.
SuTo38	nd	0.7	1.8	11.5	-	-	-	>6000	-	-	-	-	80	20	-	-	5	550	125	50	315	do.
SuN106	nd	-	0.6	12.0	-	-	-	>6000	-	-	-	-	40	-	-	-	-	580	-	-	10	do.
N464	nd	-	0.5	nd	-	-	-	4400	-	-	-	-	40	-	-	-	15	360	-	50	225	do.
N266	nd	1.0	1.8	8.0	-	-	-	>6000	-	-	-	-	25	-	-	-	5	440	45	15	610	do.
N225	nd	0.1	0.6	11.0	-	-	-	>6000	-	-	-	-	30	-	-	-	5	675	70	10	65	do.
N503	nd	0.1	1.4	nd	-	-	-	4600	-	-	10	-	40	-	-	-	10	190	45	30	480	do.
U149	nd	-	0.8	9.0	-	-	-	>6000	-	-	-	-	45	-	-	-	5	380	-	15	90	do.
U207	nd	1.8	4.5	nd	-	-	-	>6000	-	-	-	20	30	10	-	-	5	550	110	30	135	Microijolite
U242	nd	1.6	2.3	9.4	-	-	-	>6000	-	-	-	-	50	10	-	-	10	875	55	45	350	do.
U345	nd	0.3	0.9	nd	-	-	-	>6000	-	-	-	10	35	-	-	-	5	1250	30	15	60	do.
HC320	nd	0.8	0.8	8.2	-	-	-	1920	-	-	-	-	210	-	-	-	15	290	-	50	1000	Fenite
HC825	nd	-	1.1	14.3	-	-	-	>6000	-	-	-	-	135	-	-	-	-	475	20	20	790	do.
HC790	nd	-	1.8	12.8	-	-	-	4200	-	-	-	-	170	100	-	-	-	300	-	60	425	do.

Appendix Table 7c.   Spectrometric analyses of feldspar from peralkaline rocks and fenites , from carbonatitic complexes
in W. Kenya and E. Uganda .   - element not detected , nd   analysis not attempted .

Specimen Number	Al$_2$O$_3$ wt.%	CaO wt.%	Fe$_2$O$_3$ wt.%	K$_2$O wt.%	MgO wt.%	MnO wt.%	TiO$_2$ wt.%	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
HC324	3.6	>20.0	21.0	2.0	3.3	0.6	5.6	380	-	20	20	-	40	-	-	20	-	350	1555	300	2060	Ijolite
HC323	2.6	>20.0	22.8	1.1	1.8	0.6	8.0	250	-	20	20	-	40	-	-	20	-	320	1980	360	2000	do.
HC309	6.8	>20.0	18.2	2.0	2.5	0.3	0.76	310	-	20	80	-	40	-	-	135	-	540	980	300	2760	do.
U211	2.8	>20.0	22.0	0.9	4.1	0.6	8.0	100	-	20	20	-	-	-	-	20	-	370	1380	170	1800	do.

MELANITE GARNET.

Specimen Number	Al$_2$O$_3$ wt.%	CaO wt.%	Fe$_2$O$_3$ wt.%	K$_2$O wt.%	MgO wt.%	MnO wt.%	TiO$_2$ wt.%	Ba ppm	Be ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	Li ppm	Mo ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Zn ppm	Zr ppm	Rock Type
U1111	7.8	>20.0	-	2.3	-	0.5	-	280	-	-	-	-	-	-	-	80	-	1360	20	-	-	Urtite

WOLLASTONITE.

Appendix Table 7d. Spectrometric analyses of melanite garnet and wollastonite from peralkaline rocks from carbonatitic complexes in W. Kenya and E. Uganda . - element not detected.

	Mica HC324	Garnet HC324	Garnet HC323	Dark Garnet HC741	Light Garnet HC741	Garnet HC805	Garnet HC805	Sphene HC324	Sphene HC323
SiO_2	50.44	39.85	33.49	34.25	36.59	34.75	35.29	31.74	31.15
Al_2O_3	35.60	0.66	0.63	0.69	0.98	1.62	0.83	0.95	0.68
CaO	0.03	32.31	32.74	33.32	33.71	32.70	34.62	25.25	27.69
Fe_2O_3	1.78	25.90	24.78	23.69	25.53	22.92	24.40	2.00	2.30
MgO	*	0.29	0.46	*	*	*	*	*	*
MnO	*	0.47	0.52	0.51	0.47	0.49	0.45	0.03	*
TiO_2	*	5.18	7.24	7.49	2.73	7.44	4.31	40.03	38.15
K_2O	12.10	0.06	0.09	*	*	0.03	0.04	*	*

Appendix Table 8a. Electron microprobe analyses of mica, melanite garnet and sphene from several ijolites from W. Kenya and E. Uganda.

Specimen Number	Rock Type	Cerium wt.p.c.	Lanthanum wt.p.c
HC741	Ijolite	0.07	0.1
HC805	Ijolite	0.05	*
HC324	Melanite Ijolite	0.11	0.05
U242	Ijolite	0.05	*
HC964	Ijolite	0.32	0.15
HC323	Ijolite	0.13	0.05
N684	Nepheline syenite	0.18	0.11
N688	Nepheline syenite	0.19	0.08
N266	Nepheline syenite	0.17	*
HC338	Sovite	0.12	0.05
HF508	Alvikite	0.11	*
HC649	Alvikite	0.07	*
HC367	Alvikite	0.16	*

Appendix Table 8b. Electron microprobe analyses for Ce and La in apatites from carbonatites and associated peralkaline silicate rocks from W. Kenya and E. Uganda.

Specimen Number	Rock Type	Cerium wt.p.c.	Lanthanum wt.p.c.
RR482	Fenite	0.12	0.05
RR516	Fenite	0.11	*
RR201	Fenite	0.05	*

Appendix Table 8b. (continued). Electron microprobe analyses for Ce and La in apatites from carbonatites and related silicate rocks from W. Kenya and E. Uganda.

Specimen Number	Rock Type	Cerium wt.p.c.	Lanthanum wt.p.c.
	CALCITE.		
HC338	Sovite	*	*
HF508	Alvikite	*	*
HC649	Alvikite	*	*
HC367	Alvikite	0.06	*
HF661	Ferruginous Alvikite	0.21	*
HF666	Ferruginous alvikite	0.13	*
	PYROCHLORE.		
HC367	Alvikite	0.75	0.05
HC258	Alvikite	0.70	0.07
	MONAZITE.		
HC258	Alvikite	19.75	5.51

Appendix Table 8b, (continued). Electron microprobe analyses for Ce and La in calcite, pyrochlore, and monazite from carbonatites , from W. Kenya and E. Uganda.

* element not detected.

Specimen Number	Rock Type	Fe$_2$O$_3$	MnO	TiO$_2$	ZnO
	CALCITE.				
HC338	Sovite	0.13	0.25	*	*
HF508	Alvikite	0.15	0.04	*	*
HC649	Alvikite	0.13	0.19	*	*
HC258	Alvikite	0.14	*	*	*
HF666	Ferruginous alvikite	0.92	0.73	*	*
	MAGNETITE.				
HF508	Alvikite	-	0.70	2.30	0.14
HC258	Alvikite	-	1.30	1.75	0.17
HC649	Alvikite	-	1.28	5.09	*
	PYROCHLORE.				
HC649	Alvikite	0.32	*	6.53	*
HF666	Ferruginous alvikite	0.36	*	4.80	*

Appendix Table 8c. Electron microprobe analyses of calcite, magnetite, and pyrochlore from carbonatites of W. Kenya and E. Uganda.

Analyses in wt. per cent.   * element not detected.

	Fe$_2$O$_3$	MnO	Zr	Zn	V	Mo	Li	Y	Nd	La	Ce	Sr	Nb	Ba	MgO
Fe$_2$O$_3$	1.0														
MnO	0.53	1.0													
Zr	0.21	-0.11	1.0												
Zn	0.71	0.63	0.11	1.0											
V	0.75	0.46	0.34	0.62	1.0										
Mo	0.04	0.15	0.22	0.03	-0.21	1.0									
Li	-0.11	-0.28	0.20	-0.15	-0.35	0.52	1.0								
Y	0.39	0.43	0.15	0.39	0.28	0.02	-0.04	1.0							
Nd	0.28	0.62	-0.05	0.36	0.34	0.17	-0.11	0.39	1.0						
La	0.19	0.53	0.11	0.28	0.30	0.09	-0.18	0.36	0.73	1.0					
Ce	0.38	0.73	0.00	0.51	0.44	0.13	-0.18	0.42	0.79	0.88	1.0				
Sr	-0.17	-0.01	-0.04	-0.25	-0.20	0.28	0.15	-0.09	0.06	0.19	0.07	1.0			
Nb	0.14	0.03	0.48	0.15	0.27	0.19	0.36	0.21	0.34	0.43	0.37	0.13	1.0		
Ba	0.42	0.72	-0.07	0.55	0.25	0.33	-0.10	0.39	0.34	0.41	0.61	0.04	-0.06	1.0	
MgO	0.51	0.17	0.28	0.33	0.35	-0.01	0.19	0.38	0.31	0.22	0.27	-0.07	0.39	0.12	1.0
TiO$_2$	0.47	-0.03	0.25	0.22	0.40	-0.16	0.17	0.29	0.07	0.01	0.04	-0.19	0.32	-0.22	0.43

Appendix Table 9a. Correlation matrix for major and trace elements in carbonatites from W. Kenya and E. Uganda.

	FeO	Fe₂O₃	MnO	MgO	CaO	Na₂O	K₂O	TiO₂	Ba	Be	Co	Ga	Li	Nb	Sr	V	Zn	Zr	Ce	Y
FeO	1.00																			
Fe₂O₃	0.54	1.00																		
MnO	0.51	0.61	1.00																	
MgO	0.64	0.49	0.41	1.00																
CaO	0.57	0.21	0.37	0.64	1.00															
Na₂O	-0.30	-0.40	-0.27	-0.30	-0.24	1.00														
K₂O	-0.46	-0.25	-0.39	-0.60	-0.44	0.31	1.00													
TiO₂	0.48	0.73	0.40	0.56	0.38	-0.32	-0.27	1.00												
Ba	-0.01	0.11	-0.06	-0.18	-0.13	-0.20	0.45	0.00	1.00											
Be	0.10	0.27	0.28	0.16	0.05	-0.05	-0.02	0.24	0.17	1.00										
Co	0.28	0.40	0.35	0.56	0.33	-0.56	-0.47	0.54	-0.06	0.12	1.00									
Ga	-0.34	-0.22	-0.15	-0.58	-0.31	0.60	0.42	-0.35	0.15	0.13	-0.64	1.00								
Li	0.17	0.40	0.50	0.25	0.28	-0.46	-0.38	0.45	0.02	0.15	0.61	-0.46	1.00							
Nb	0.37	0.57	0.56	0.46	0.49	-0.38	-0.34	0.68	-0.02	0.22	0.57	-0.27	0.54	1.00						
Sr	0.19	0.20	0.15	0.22	0.43	-0.13	0.13	0.26	0.56	0.30	0.12	0.00	0.23	0.27	1.00					
V	0.46	0.59	0.37	0.52	0.55	-0.33	-0.26	0.68	0.04	0.19	0.39	-0.20	0.36	0.52	0.45	1.00				
Zn	-0.04	0.07	0.17	-0.14	-0.35	-0.18	0.14	-0.17	0.10	0.04	-0.38	0.33	-0.33	-0.18	-0.13	-0.16	1.00			
Zr	0.42	0.73	0.40	0.21	0.04	-0.27	0.00	0.53	0.20	0.38	0.09	0.14	0.20	0.33	0.28	0.44	0.20	1.00		
Ce	-0.08	0.13	0.25	-0.05	-0.01	-0.18	0.00	0.27	0.16	0.28	0.29	-0.04	0.28	0.26	0.04	0.06	0.10	0.24	1.00	
Y	-0.07	0.30	0.13	-0.04	-0.26	-0.09	0.18	0.37	0.09	0.27	0.05	-0.02	0.18	0.14	-0.05	0.12	0.21	0.37	0.40	1.00
La	-0.26	-0.28	-0.12	-0.47	-0.48	0.29	0.36	-0.51	0.10	0.01	-0.37	0.27	-0.28	-0.44	-0.13	-0.39	0.12	-0.02	0.12	0.12

Appendix Table 9b. Correlation matrix for 21 trace elements and major element oxides in peralkaline silicate rocks and fenites from W. Kenya and E. Uganda .

EIGENVECTORS.

N	Fe$_2$O$_3$	MnO	TiO$_2$	MgO	Ba	Ce	Li	Mo	Nb	Nd	Sr	V	Y	Zn	Zr
1	-0.1236	-0.2207	-0.3145	-0.3450	-0.0864	-0.0507	-0.3054	-0.3690	-0.3263	-0.2641	-0.3023	-0.0289	-0.3160	-0.1709	-0.2758
2	0.4672	0.3322	0.1988	-0.2646	0.3940	-0.0512	-0.1731	-0.2015	0.0303	0.0666	0.1885	-0.1486	-0.1515	0.3059	-0.2931
3	0.1096	-0.0525	0.2089	0.0593	-0.1703	-0.4785	-0.2176	-0.1276	0.1903	0.0033	0.2684	-0.3793	-0.1610	-0.3620	-0.0387
4	0.0903	0.0006	-0.2787	-0.1438	-0.0268	-0.4664	0.3828	0.1961	-0.2742	-0.0353	0.0575	0.0902	0.2742	0.2781	-0.3969
5	-0.2839	-0.3259	0.0578	-0.0188	0.5813	0.1078	0.0626	-0.0185	0.0733	-0.3759	0.3781	0.1588	-0.1919	0.1333	0.0404
6	-0.2000	-0.1847	-0.2995	-0.0359	0.2644	0.0757	0.0865	0.0801	0.0373	0.1799	-0.1546	-0.8126	0.0764	0.1274	0.0412
7	-0.1126	0.0666	-0.0926	-0.0538	0.3362	-0.1266	0.0263	-0.1285	-0.1811	0.7461	-0.1026	0.2618	-0.2431	-0.1284	0.1683
8	-0.5437	0.7513	-0.0222	-0.1168	0.0524	-0.1936	-0.0175	0.0037	0.0339	-0.2410	-0.0642	-0.0632	-0.0330	0.0092	0.1259

Percentage of total correlation accounted for by each component.

1	2	3	4	5	6	7	8
33.57	15.13	13.72	8.71	5.94	4.95	4.32	3.36

EIGENVALUES.

5.37	2.42	2.20	1.39	0.95	0.79	0.69	0.54

Appendix Table 10a. Eigenvectors, contribution of each principal component to the total correlation, and values of each eigenvalue for eight principal components.

A 73.

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Geochemistry of carbonatites and related rocks from South Nyanza, Kenya.

A thesis submitted to Leicester University for the degree of Doctor of Philosophy by Christopher Barber .

Abstact.

The distribution of 25 trace elements and selected major elements have been investigated in carbonatites, peralkaline silicate rocks and fenites from Homa Mountain, N. Ruri, and Wasaki in W. Kenya. Comparison has been made with the distribution of these elements in similar rocks from Budeda, Toror and Tororo carbonatitic complexes, E. Uganda.

The earliest sovitic carbonatites were found to contain greater concentrations of Sr, and generally less Ba, Nb, REE(Ce-earths, and Y-earths), Fe, Mn, Zn, Zr, Ti, and V than the later alvikitic carbonatites. The later ferruginous alvikites were characteristically enriched in Fe, Mn, Ba, Zn, REE (Ce-earths) relative to other carbonatites. All carbonat ites were typically strongly Ce-earth enriched.

The peralkaline silicate rocks and fenites were similarly enriched in Sr, Ba, REE,Nb, and Ti and contained generally more Zr and Ga than the carbonatites. These rocks were also Ce-earth enriched.

The concentrations of Sr, Ba, Zr, REE, Ga and Nb in the fenites indicate that these elements are introduced into the country rock by Na-fenitising solutions. The similarity in trace element content between the fenites and nepheline-syenites suggests a genetic relationship between these rock types.

The greater concentration of Cr, Ni, and Co in the pyroxenites suggest that these rocks formed early in the crystallisation history of the carbonatite complexes, leading to the crystallisation of the ijolitic suite.

The relationship between the carbonatites and silicate rocks remains controversial. However, the concentration of Ba, REE, and Nb in the carbonatites indicates that these rocks were formed late in the history of the complexes.

A mechanism involving fractional crystallisation of a carbonated silica – undersaturated magma, leading in the later stages to liquid immiscibility

of carbonate and silicate liquids, is favoured for the origin of these rocks.