"GEOCHEMISTRY OF CARBONATITES AND RELATED ROCKS
FROM SOUTH NYANZA, KENYA".

A thesis submitted to the Faculty of Science,
Leicester University
for the degree of
Doctor of Philosophy
by
CHRISTOPHER BARBER, B.Sc.

October 1971.
ABSTRACT.

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 Budedaa, 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-earth), 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-earth) 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
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.
CONTENTS

CHAPTER 1.

1.1 Introduction 1
1.2 Petrography and mineralogy of the carbonatites, peralkaline silicate rocks and fenites 3
   (i) Carbonatites. 3
   (ii) Peralkaline silicate rocks. 6
1.3 Selection of samples for analysis. 8
1.4 Mineralogy of the analysed samples. 9
1.5 Analysis of the samples and selection of trace and minor elements for analysis 12
1.6 Acknowledgements. 13

CHAPTER 2.

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 14
2.2 Choice of specimens for analysis 15
2.3 Method of analysis 15
2.4 (a) Distribution of La, Ce, Nd and Y in the analysed carbonatites, carbonatitic breccias and feldspathised rocks associated with carbonatites. 16
2.4 (b) The relationship between rare-earth element distribution and mineralogy of the carbonatites. 19
2.4 (c) Discussion 21
2.5 (a) The distribution of La, Ce, Nd and Y in silicate rocks of carbonatite complexes of W. Kenya and E. Uganda. 23
2.5 (b) The relationship between mineralogy of silicate rocks and concentrations of Ce, La, and Y. 25
2.5 (c) Evidence for derivation of peralkaline rocks and fenites. 27
2.6 Relationship between rare-earth distribution in carbonatites and in their associated silicate rocks. 28
### CHAPTER 3.
The distribution of some trace and minor elements in carbonatites and carbonatitic breccias from Western Kenya and Eastern Uganda.

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Introduction.</td>
<td>30</td>
</tr>
<tr>
<td>3.2 Choice of specimens for analysis.</td>
<td>30</td>
</tr>
<tr>
<td>3.3 Method of analysis.</td>
<td>31</td>
</tr>
<tr>
<td>3.4 Results of analyses.</td>
<td>32</td>
</tr>
<tr>
<td>3.5 Discussion.</td>
<td>33</td>
</tr>
<tr>
<td>(i) Strontium and Barium.</td>
<td>33</td>
</tr>
<tr>
<td>(ii) Niobium.</td>
<td>35</td>
</tr>
<tr>
<td>(iii) Manganese and Iron</td>
<td>36</td>
</tr>
<tr>
<td>(iv) Titanium, Vanadium, Chromium, Cobalt and Copper.</td>
<td>37</td>
</tr>
<tr>
<td>(v) Zinc and Lead.</td>
<td>39</td>
</tr>
<tr>
<td>(vi) Zirconium.</td>
<td>40</td>
</tr>
<tr>
<td>(vii) Lithium and Molybdenum</td>
<td>41</td>
</tr>
<tr>
<td>(viii) Magnesium.</td>
<td>41</td>
</tr>
<tr>
<td>(ix) Aluminium.</td>
<td>42</td>
</tr>
<tr>
<td>3.6 Distribution of trace elements in feldspathised country rock adjacent to carbonatite intrusions</td>
<td>42</td>
</tr>
<tr>
<td>3.7 Multivariate statistical analysis of trace and major element data in carbonatites and carbonatitic breccias.</td>
<td>43</td>
</tr>
<tr>
<td>(i) Correlation analysis</td>
<td>44</td>
</tr>
<tr>
<td>(ii) Principal component analysis</td>
<td>46</td>
</tr>
<tr>
<td>3.8 Discussion.</td>
<td>49</td>
</tr>
<tr>
<td>3.9 Conclusions.</td>
<td>54</td>
</tr>
</tbody>
</table>

### CHAPTER 4.
The distribution of minor and trace elements in peralkaline silicate rocks, phonolitic rocks and fenites, associated with carbonatites from W. Kenya and E. Uganda.

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Introduction.</td>
<td>56</td>
</tr>
<tr>
<td>4.2 Choice of Specimens.</td>
<td>56</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>4.3</td>
<td>Analytical method.</td>
</tr>
<tr>
<td>4.4</td>
<td>Results of analyses.</td>
</tr>
<tr>
<td>4.5</td>
<td>Discussion of results.</td>
</tr>
<tr>
<td></td>
<td>(i)(a) Strontium and Barium in the intrusive peralkaline rocks.</td>
</tr>
<tr>
<td></td>
<td>(b) Strontium and Barium in phonolitic rocks</td>
</tr>
<tr>
<td></td>
<td>(c) Strontium and Barium in fenitic rocks.</td>
</tr>
<tr>
<td></td>
<td>(ii)(a) Niobium and Zirconium in intrusive peralkaline rocks.</td>
</tr>
<tr>
<td></td>
<td>(b) Niobium and Zirconium in phonolitic rocks.</td>
</tr>
<tr>
<td></td>
<td>(c) Niobium and Zirconium in fenitic rocks.</td>
</tr>
<tr>
<td></td>
<td>(iii)(a) Lead and Zinc in intrusive peralkaline rocks</td>
</tr>
<tr>
<td></td>
<td>(b) Lead and Zinc in phonolitic rocks.</td>
</tr>
<tr>
<td></td>
<td>(c) Lead and Zinc in fenitic rocks.</td>
</tr>
<tr>
<td></td>
<td>(iv) Chromium, Nickel, Cobalt, Copper, Vanadium and Titanium</td>
</tr>
<tr>
<td></td>
<td>(a) Vanadium and Titanium in peralkaline intrusive rocks.</td>
</tr>
<tr>
<td></td>
<td>(b) Cr, Ni, Cu, Co, V and Ti in phonolitic rocks and melanephelinites</td>
</tr>
<tr>
<td></td>
<td>(c) Cr, Ni, Cu, Co, V and Ti in fenitic rocks.</td>
</tr>
<tr>
<td></td>
<td>(v) (a) Ga in peralkaline silicate rocks and fenites.</td>
</tr>
<tr>
<td></td>
<td>(b) Ga in phonolitic rocks and melanephelinites.</td>
</tr>
<tr>
<td></td>
<td>(c) Ga in fenitic rocks.</td>
</tr>
<tr>
<td></td>
<td>(vi) Be, Li and Sn.</td>
</tr>
<tr>
<td>4.6</td>
<td>Multivariate statistical analysis of geochemical data for peralkaline</td>
</tr>
<tr>
<td></td>
<td>silicate rocks and fenites.</td>
</tr>
<tr>
<td></td>
<td>Correlation analysis.</td>
</tr>
<tr>
<td>4.7</td>
<td>Discussion.</td>
</tr>
<tr>
<td>4.8</td>
<td>Evidence for the origin of peralkaline silicate rocks and fenites.</td>
</tr>
<tr>
<td>4.9</td>
<td>Conclusions.</td>
</tr>
</tbody>
</table>
CHAPTER 5.

Comparative geochemistry of carbonatite and silicate rocks from Western Kenya and Eastern Uganda and discussion on the origins of these rocks.

5.1 Introduction. 87

5.2 (a) The carbonatitic rocks. 88

5.2 (b) The peralkaline silicate rocks and fenites 89

5.2 (c) The relationship between trace element distributions of carbonatite and related peralkaline silicate rocks from W. Kenya and E. Uganda. 90

5.3 Origin of the peralkaline silicate rocks and carbonatites. 91

5.4 Comparison of trace element distributions of carbonatites and peralkaline rocks with the distribution of trace elements in other igneous rocks 94

APPENDIX

APPENDIX ONE.

A. Preparation of samples for analysis A 1

B. X-ray fluorescence analysis for Ce, La, Nd, Dy and Y. A 2

C. Spectrometric analysis A 3

(i) Carbonatite rocks and minerals A 5

(ii) Peralkaline silicate rocks and fenites and silicate minerals A 8

D. Chemical analysis of silicate rocks. A 11

(i) Na₂O and K₂O. A 11

(ii) FeO A 11

APPENDIX TWO.

Tables of data collected during this study. A 12

Appendix Table 1 Field data concerning analysed specimens A 13

Key to Appendix Table 2 A 20

Appendix Table 2(a) Mineralogy of analysed carbonatites A 21

Appendix Table 2(b) Mineralogy of silicate rocks A 24
### APPENDIX TWO (continued).

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 3(a)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>detection limits for elements in Appendix Tables 3a-c</td>
<td>A 29a</td>
</tr>
<tr>
<td></td>
<td>major and trace element analyses of carbonate rocks</td>
<td>A 29b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 3(b)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(i) Analyses of magnetite from carbonate</td>
<td>A 35</td>
</tr>
<tr>
<td></td>
<td>(ii) Analyses of calcite from carbonate</td>
<td>A 36</td>
</tr>
<tr>
<td></td>
<td>(iii) Analyses of pyroxene and mica from carbonate</td>
<td>A 36b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 3(c)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spectrometric analyses of feldspathised country rock adjacent to carbonate intrusions</td>
<td>A 38b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 4(a)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>chemical analyses of intrusive peralkaline silicate rocks</td>
<td>A 39a</td>
</tr>
<tr>
<td></td>
<td>spectrometric analyses for major elements in peralkaline intrusive silicate rocks.</td>
<td>A 39b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 4(b)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>trace element data for intrusive peralkaline silicate rocks.</td>
<td>A 40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 4(c)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>chemical analyses of peralkaline silicate rocks, (phonolites)</td>
<td>A 50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 5(a)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spectrometric and other analyses for major elements in phonolitic rocks.</td>
<td>A 52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 5(b)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>trace elements in phonolitic rocks.</td>
<td>A 54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 5(c)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>chemical analyses of fenitic rocks.</td>
<td>A 56</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 6(a)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spectrometric and other analyses for major elements in fenitic rocks.</td>
<td>A 57</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 6(b)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>trace element in fenitic rock.</td>
<td>A 59</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 6(c)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spectrometric analyses of pyroxene and amphibole.</td>
<td>A 61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Table 7(a)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spectrometric analyses of nepheline.</td>
<td>A 63</td>
</tr>
</tbody>
</table>
### APPENDIX TWO (continued).

<table>
<thead>
<tr>
<th>Appendix Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7(c)</td>
<td>Spectrometric analyses of feldspar</td>
<td>A 64</td>
</tr>
<tr>
<td>7(d)</td>
<td>Spectrometric analyses of garnet and wollastonite</td>
<td>A 65</td>
</tr>
<tr>
<td>8(a)</td>
<td>Electron microprobe analyses of mica, melanite, garnet and sphene</td>
<td>A 66</td>
</tr>
<tr>
<td>8(b)</td>
<td>Electron microprobe analyses for Le and La in apatite, calcite, and pyrochlore from carbonatite and related silicate rocks.</td>
<td>A 67</td>
</tr>
<tr>
<td>8(c)</td>
<td>Electron microprobe analyses of calcite and magnetite from carbonatite</td>
<td>A 70</td>
</tr>
<tr>
<td>9(a)</td>
<td>Correlation matrix for major and trace elements in carbonatites.</td>
<td>A 71</td>
</tr>
<tr>
<td>9(b)</td>
<td>Correlation matrix for major and trace elements in peralkaline silicate rocks and fenites.</td>
<td>A 72</td>
</tr>
<tr>
<td>10</td>
<td>Eigenvectors, contribution of each principal component to the total correlation, and values of each eigenvalue for eight principal components.</td>
<td>A 73</td>
</tr>
</tbody>
</table>
CHAPTER ONE.

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 $\text{Ca}_3\text{Na}_2\text{W}_2\text{O}_{18}\text{F}$, bastnaesite $\text{REE}_3\text{Ce}_5\text{CO}_3\text{F}$, baddeleyite $\text{ZrO}_2$).

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 nepheline and olivine melilitite occur, and fenitisation
Key to fig. 1.

- - Tertiary to Recent alkaline igneous rocks.
\(\times\) 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.


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).


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 preceded 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.


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 the sovites 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, occurring 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.

<table>
<thead>
<tr>
<th>Early magmatic</th>
<th>Late magmatic</th>
<th>Postmagmatic</th>
<th>Deuteric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diopsidic Pyroxene</td>
<td>Aegirine-augite</td>
<td>Calcite</td>
<td>Phlogopite</td>
</tr>
<tr>
<td>Nepheline</td>
<td>Nepheline</td>
<td>Apatite 2</td>
<td>Cancrinite</td>
</tr>
<tr>
<td>Perovskite</td>
<td>Melanite/sphene</td>
<td>Feldspar</td>
<td>Sericite</td>
</tr>
<tr>
<td>Apatite 1</td>
<td>Wollastonite</td>
<td></td>
<td>Natrolite, Alcanite, Pectolite</td>
</tr>
</tbody>
</table>

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 iolites the pyroxenes were more acmiteic. Magnetite was less abundant in the iolites 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 acmiteic 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 amphibole, apatite, magnetite, and wollastonite. Endialyte 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), diopsideic 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, analcime, 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 rocks 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 feniic 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 feniites 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 feniitic 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. 29000E 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.

1.6Acknowledgements.

I would like to thank Dr. M. J. Le Bas for supervision of the work contained in this thesis. I would also like to acknowledge the help from other members of the East African Research Team at Leicester University and Bedford College, London, who collected the samples analysed in this study, and whose helpful suggestions are greatly appreciated.

I would also like to thank Mrs. K. Barber for the typing of the manuscript, and Dr. G. Hornung of Leeds University for instruction in the X-ray fluorescence analysis of the rare-earth elements. Thanks are also due to Dr. Joan Rooke, also of Leeds University for instruction in the use of optical emission spectrograph, and to Dr. D.S. Sutherland (Mrs. Milne) for discussion of chemical analyses.

This work was carried out during the tenure of a N.E.R.C. grant, which is gratefully acknowledged.

Finally, I would like to thank my wife, Ann, for encouragement and help during the period of research for this thesis.
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
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.

<table>
<thead>
<tr>
<th></th>
<th>Ce</th>
<th></th>
<th>La</th>
<th></th>
<th>Ye</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;50ppm</td>
<td>&gt;8000ppm</td>
<td>&lt;35ppm</td>
<td>&gt;6000ppm</td>
<td>&lt;50ppm</td>
<td></td>
</tr>
<tr>
<td>Sovite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Alvikite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ferruginous alvikite</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
fig. 2.1a.

fig. 2.1b.

fig. 2.1c.

fig. 2.1d.

KEY:
- Sovite
- Alvikite
- Ferruginous
- alvikite
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, intrusive silicate rocks, phonolitic rocks, and fentes respectively.

2.4 Discussion of results.

(a) The distribution of La, Ce, Nd, and Y in the analysed carbonatites, carbonatic 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.
Table 2.1. Geometric means and ranges of concentration of Ce, La, Nd and Y in carbonatitic rocks.

<table>
<thead>
<tr>
<th></th>
<th>Ce</th>
<th>La</th>
<th>Nd</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovite</td>
<td>Mean</td>
<td>560 ppm</td>
<td>330 ppm</td>
<td>145 ppm</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>70-2500 ppm</td>
<td>125-1000 ppm</td>
<td>12-920 ppm</td>
<td>&lt;5 ppm</td>
</tr>
<tr>
<td>Alvikite</td>
<td>Mean</td>
<td>1830 ppm</td>
<td>730 ppm</td>
<td>470 ppm</td>
<td>34 ppm</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>808-6856 ppm</td>
<td>250-3578 ppm</td>
<td>17-2000 ppm</td>
<td>&lt;15-600 ppm</td>
</tr>
<tr>
<td>Ferruginous Alvikite</td>
<td>Mean</td>
<td>598 ppm</td>
<td>760 ppm</td>
<td>89 ppm</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>10000 ppm</td>
<td>17-6000 ppm</td>
<td>78-2450 ppm</td>
<td>22-210 ppm</td>
</tr>
<tr>
<td>Melilitite Pseudomorph carbonatite</td>
<td>Mean</td>
<td>2860 ppm</td>
<td>2530 ppm</td>
<td>566 ppm</td>
<td>101 ppm</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>1479-4595 ppm</td>
<td>1530-3535 ppm</td>
<td>520-590 ppm</td>
<td>78-130 ppm</td>
</tr>
</tbody>
</table>

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 albikite to ferruginous albikite, 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 albikites, 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 alvike and ferruginous alvike, than between sovite and either of the other two carbonatite groups.

Both the carbonatitic breccias, and the melilite-
psedomorph 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 individual 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 of La, 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 trend, 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 EC258. Monazite (CePO₄) 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-H₂O. 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
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.

<table>
<thead>
<tr>
<th></th>
<th>La &lt;35 ppm</th>
<th>Ce &lt;50 ppm</th>
<th>Y &lt;5 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxenite</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Ijolite</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Urtite</td>
<td>-</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Nepheline-syenite</td>
<td>-</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Phonolite</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Fenite</td>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
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 minerallogically 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.
<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Lanthanum Range</th>
<th>Cerium Range</th>
<th>Yttrium Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxenite</td>
<td>&lt;35-800ppm</td>
<td>130-3500ppm</td>
<td>&lt;5-77ppm</td>
<td>6</td>
</tr>
<tr>
<td>Ijolite</td>
<td>135-250ppm</td>
<td>&lt; 50-370ppm</td>
<td>&lt;5-14ppm</td>
<td>3</td>
</tr>
<tr>
<td>Melanite ijolite</td>
<td>&lt;30-200ppm</td>
<td>&lt; 50-900ppm</td>
<td>&lt;5-147ppm</td>
<td>7</td>
</tr>
<tr>
<td>Feldspathic ijolite</td>
<td>45-110ppm</td>
<td>500-580ppm</td>
<td>&lt;5-32ppm</td>
<td>3</td>
</tr>
<tr>
<td>Urtite</td>
<td>180-330ppm</td>
<td>&lt; 50-80ppm</td>
<td>&lt; 5ppm</td>
<td>5</td>
</tr>
<tr>
<td>Nepheline syenite</td>
<td>80-1000ppm</td>
<td>&lt; 50-1100ppm</td>
<td>&lt;5-80ppm</td>
<td>11</td>
</tr>
<tr>
<td>Melanepheline syenite</td>
<td>&lt; 35ppm</td>
<td>350-580ppm</td>
<td>&lt;3-25ppm</td>
<td>3</td>
</tr>
<tr>
<td>Nepheline syenite</td>
<td>240-500ppm</td>
<td>300-1100ppm</td>
<td>7-45ppm</td>
<td>3</td>
</tr>
<tr>
<td>Phonolitic nepheline</td>
<td>155-500ppm</td>
<td>600-1100ppm</td>
<td>9-38ppm</td>
<td>4</td>
</tr>
<tr>
<td>Analcime-phonolite</td>
<td>300-700ppm</td>
<td>&lt; 50-1300ppm</td>
<td>7-270ppm</td>
<td>7</td>
</tr>
<tr>
<td>Cancrinite-phonolite</td>
<td>300ppm</td>
<td>&lt; 50ppm</td>
<td>19ppm</td>
<td>1</td>
</tr>
<tr>
<td>Syenitic fenite with nepheline</td>
<td>350-450ppm</td>
<td>&lt; 50ppm</td>
<td>&lt;5-40ppm</td>
<td>2</td>
</tr>
<tr>
<td>Syenitic fenite</td>
<td>50-1350ppm</td>
<td>&lt; 50-930ppm</td>
<td>&lt;5-57ppm</td>
<td>7</td>
</tr>
<tr>
<td>Regional fenite</td>
<td>170-1600ppm</td>
<td>880-2700ppm</td>
<td>&lt;5-65ppm</td>
<td>5</td>
</tr>
</tbody>
</table>

**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 tuffs from carbonatitic complexes in W Kenya and E Uganda.

Fig 2.6. Plot of approximate total rare-earth concentration expressed as $\text{Ce} + \text{La} + \text{Y}$ 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 Ce, 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 semiquantitative 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 leucocratic 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
29.

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 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.
CHAPTER THREE

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\(_2\)O\(_3\)) were investigated in a number of carbonatites, carbonatitic breccias, and feldspathised country rocks.

The distributions 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°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 1000 ppm 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
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.

<table>
<thead>
<tr>
<th>Element</th>
<th>Sovite</th>
<th>Alvikite</th>
<th>Ferruginous Alvikite</th>
<th>Detection Limit</th>
<th>Upper Limit of Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>50 ppm</td>
<td>1000 ppm</td>
</tr>
<tr>
<td>MnO</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.1%</td>
<td>3%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0.1%</td>
<td>3%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>12</td>
<td>13</td>
<td>10</td>
<td>0.1%</td>
<td>5%</td>
</tr>
<tr>
<td>Zn</td>
<td>4</td>
<td>1</td>
<td>-</td>
<td>10 ppm</td>
<td>2000 ppm</td>
</tr>
<tr>
<td>Zr</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>10 ppm</td>
<td>1000 ppm</td>
</tr>
<tr>
<td>Li</td>
<td>-</td>
<td>7</td>
<td>5</td>
<td>10 ppm</td>
<td>1000 ppm</td>
</tr>
<tr>
<td>MgO</td>
<td>13</td>
<td>7</td>
<td>7</td>
<td>0.1%</td>
<td>10%</td>
</tr>
<tr>
<td>Mo</td>
<td>-</td>
<td>9</td>
<td>2</td>
<td>10 ppm</td>
<td>1000 ppm</td>
</tr>
<tr>
<td>Ba</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>10 ppm</td>
<td>40000 ppm</td>
</tr>
</tbody>
</table>
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 micas 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Strontium</th>
<th>Barium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Sovite</td>
<td>1200ppm</td>
<td>70-2550ppm</td>
</tr>
<tr>
<td>Alvikite</td>
<td>930ppm</td>
<td>545-1820ppm</td>
</tr>
<tr>
<td>Ferruginous Alvikite</td>
<td>810ppm</td>
<td>230-1880ppm</td>
</tr>
<tr>
<td>Melilite-pseudomorph carbonate</td>
<td>661ppm</td>
<td>380-1175ppm</td>
</tr>
<tr>
<td>Carbonatitic Breccia</td>
<td>297ppm</td>
<td>65-1015ppm</td>
</tr>
</tbody>
</table>

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 intrusive 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 acmite 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 occurrence of pyrochlore (CaNaNb₂O₆F) 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 sphe ne, 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).

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Geometric mean</th>
<th>Range</th>
<th>No. Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovite</td>
<td>69 ppm</td>
<td>≤50-700 ppm</td>
<td>16</td>
</tr>
<tr>
<td>Alvikite</td>
<td>290 ppm</td>
<td>≤50-1000 ppm</td>
<td>35</td>
</tr>
<tr>
<td>Ferruginous Alvikite</td>
<td>87 ppm</td>
<td>≤50-1000 ppm</td>
<td>14</td>
</tr>
<tr>
<td>Melilitite-pseudomorph</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbonatitic breccia</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Table 3.2. The distribution of Nb in the analysed carbonatitic rocks of W. Kenya and E. Uganda.
(iii) **Manganese and Iron.**

The distribution of Mn (as MnO) and Fe (as total Fe expressed as Fe$_2$O$_3$) 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$_2$O$_3$ 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$_2$O$_3$ shows a similar distribution to MnO, although the ferruginous alvikites show great variability in the content of Fe$_2$O$_3$. The carbonatitic breccias, thought to have been intruded with the alvikites, also contain large concentration of Fe$_2$O$_3$ relative to the sovites and alvikites.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>MnO</th>
<th>Range</th>
<th>Fe$_2$O$_3$</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovite</td>
<td>0.33%</td>
<td>0.1 - 0.8%</td>
<td>1.44%</td>
<td>0.1 - 6.7%</td>
</tr>
<tr>
<td>Alvikite</td>
<td>0.92%</td>
<td>0.33 - 3.2%</td>
<td>5.01%</td>
<td>0.8 - 30%</td>
</tr>
<tr>
<td>Ferruginous Alvikite</td>
<td>2.5%</td>
<td>1.6 - 3%</td>
<td>8.5%</td>
<td>2.0 - 30%</td>
</tr>
<tr>
<td>Melilite- pseudomorph carbonatite</td>
<td>0.76%</td>
<td>0.25 - 2.0%</td>
<td>3.43%</td>
<td>3.1 - 3.6%</td>
</tr>
<tr>
<td>Carbonatitic breccia</td>
<td>0.86%</td>
<td>0.56 - 2.32%</td>
<td>8.77%</td>
<td>5.6 - 13.9%</td>
</tr>
</tbody>
</table>

**Table 3.3.** Geometric means and ranges of concentration of MnO and Fe$_2$O$_3$ 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>TiO₂ Wt.%</th>
<th>Vanadium ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovite</td>
<td>&lt; 0.1 - 0.35%</td>
<td>40ppm</td>
</tr>
<tr>
<td>Alvikite</td>
<td>&lt; 0.1 - 0.96%</td>
<td>87ppm</td>
</tr>
<tr>
<td>Ferruginous Alvikite</td>
<td>&lt; 0.1 - 0.8%</td>
<td>140ppm</td>
</tr>
<tr>
<td>Melilite-pseudomorph Carbonatites</td>
<td>-</td>
<td>82ppm</td>
</tr>
<tr>
<td>Carbonatitic breccia</td>
<td>1.02%</td>
<td>0.4 - 1.9%</td>
</tr>
</tbody>
</table>

Table 3.4. Geometric means and ranges of concentration of TiO₂ 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 TiO₂ 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 fromsovite 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% TiO₂, and was also found in pyroxene (0.7 – 1.35% TiO₂) and mica (1.5 – 2.4% TiO₂), from carbonatites, (Appendix Table 3 (b) (iii)). Vanadium follows Titanium to a large extent in the carbonatic 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 carbonatic 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Zinc Range</th>
<th>Lead Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovite</td>
<td>&lt; 10-180ppm</td>
<td>&lt;10-45ppm</td>
</tr>
<tr>
<td>Alvikite</td>
<td>&lt; 10-2000ppm</td>
<td>&lt;10-170ppm</td>
</tr>
<tr>
<td>Ferruginous Alvikite</td>
<td>110-2000ppm</td>
<td>20-460ppm</td>
</tr>
<tr>
<td>Melilite-pseudomorph carbonatite</td>
<td>115-240ppm</td>
<td>15-90ppm</td>
</tr>
<tr>
<td>Carbonatitic breccia</td>
<td>110-255ppm</td>
<td>&lt; 10-40ppm</td>
</tr>
</tbody>
</table>

**Table 3.5.** The distributions of Zinc and Lead in the carbonatic rocks and carbonatic 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 occurrence of sphalerite and galena, as late stage replacement veins and carbonatic 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 carbonatic 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 carbonatic breccias are given in Table 3.6 below, as ranges of concentration within the petrographic groups.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Zirconium Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovite</td>
<td>&lt;10-50ppm</td>
</tr>
<tr>
<td>Alvikite</td>
<td>&lt;10-240ppm</td>
</tr>
<tr>
<td>Ferruginous alvikite</td>
<td>&lt;10-90ppm</td>
</tr>
<tr>
<td>Melilite-pseudomorph carbonate</td>
<td>30-60ppm</td>
</tr>
<tr>
<td>Carbonatic breccia</td>
<td>40-100ppm</td>
</tr>
</tbody>
</table>

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

Analyses of carbonatic pyrochlore presented in the literature show Zr to be present in this mineral in amounts
The variability of the concentration of Zr in the carbonatites will thus, like Nb, be related to the sporadic occurrence of pyrochlore. In addition, Zr was found in minor concentration in pyroxene from carbonatite (1450-2300 ppm), and in much smaller concentration in magnetite, (10-70 ppm). 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 \((\text{CaZr}_2\text{TiO}_9)\) 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 (100-680 ppm). 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
Pyroxene and mica contained varying amounts of Mg.

(ix) Aluminium.

Alumina was undetected in most analysed carbonatites, which reflects the paucity of aluminosilicate 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>$\text{Al}_2\text{O}_3$</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovite</td>
<td>0.1-0.95%</td>
<td></td>
</tr>
<tr>
<td>Alvikite</td>
<td>0.1-1.25%</td>
<td></td>
</tr>
<tr>
<td>Ferruginous Alvikite</td>
<td>0.1-0.7%</td>
<td></td>
</tr>
<tr>
<td>Melilite-pseudomorph carbonatite</td>
<td>0.1-0.15%</td>
<td></td>
</tr>
<tr>
<td>Carbonatitic breccia</td>
<td>5.35-10.2%</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.7. Ranges of concentration of $\text{Al}_2\text{O}_3$ in carbonatites and carbonatitic breccias, from W. Kenya and E. Uganda.

The distribution trace elements in feldspathised country rock adjacent to carbonatite intrusions.

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 carbonite.

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, 1965)). 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

\[
 r_{xy} = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2 / N - 1}} \]

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 coefficients. The product moment correlation coefficient 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.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlated variables in order of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe$_2$O$_3$</td>
<td>V, Zn, MnO, MgO, TiO$_2$.</td>
</tr>
<tr>
<td>MnO</td>
<td>Fe$_2$O$_3$, Ce, Ba, Zn, Nd, La, Fe$_2$O$_3$.</td>
</tr>
<tr>
<td>MgO</td>
<td>MnO.</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>Fe$_2$O$_3$.</td>
</tr>
<tr>
<td>Ba</td>
<td>MnO, Ce, Zn.</td>
</tr>
<tr>
<td>Ce</td>
<td>La, Nd, MnO, Ba, Zn.</td>
</tr>
<tr>
<td>Li</td>
<td>Mo.</td>
</tr>
<tr>
<td>Mo.</td>
<td>Li.</td>
</tr>
<tr>
<td>Nb</td>
<td>Zr.</td>
</tr>
<tr>
<td>Nd</td>
<td>Ce, La, MnO.</td>
</tr>
<tr>
<td>Sr</td>
<td>-</td>
</tr>
<tr>
<td>V</td>
<td>Zn, Fe$_2$O$_3$.</td>
</tr>
<tr>
<td>Zn</td>
<td>Fe$_2$O$_3$, MnO, V, Ba, Ce.</td>
</tr>
<tr>
<td>Y</td>
<td>-</td>
</tr>
<tr>
<td>Zr</td>
<td>Nb.</td>
</tr>
</tbody>
</table>

*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$_2$O$_3$ 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 Fe₂O₃, 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.
<table>
<thead>
<tr>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>TiO₂</th>
<th>MgO</th>
<th>Ba</th>
<th>Ce</th>
<th>Li</th>
<th>Mo</th>
<th>Nb</th>
<th>Nd</th>
<th>Sr</th>
<th>V</th>
<th>Y</th>
<th>Zn</th>
<th>Zr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0236</td>
<td>-0.2207</td>
<td>-0.3450</td>
<td>-0.3054</td>
<td>-0.3054</td>
<td>-0.3690</td>
<td>-0.3263</td>
<td>-0.2641</td>
<td>-0.3023</td>
<td>-0.0289</td>
<td>-0.3160</td>
<td>-0.1709</td>
<td>-0.2758</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4672</td>
<td>0.3322</td>
<td>0.1988</td>
<td>-0.2646</td>
<td>-0.3940</td>
<td>-0.0512</td>
<td>-0.1731</td>
<td>-0.2015</td>
<td>0.0303</td>
<td>0.0666</td>
<td>0.1885</td>
<td>-0.1486</td>
<td>-0.1515</td>
<td>0.3950</td>
<td>-0.2931</td>
</tr>
<tr>
<td>0.1096</td>
<td>-0.0525</td>
<td>0.2089</td>
<td>0.0593</td>
<td>-0.1703</td>
<td>-0.4785</td>
<td>-0.2176</td>
<td>-0.1276</td>
<td>0.1903</td>
<td>0.0033</td>
<td>0.2684</td>
<td>-0.3703</td>
<td>-0.1610</td>
<td>-0.3620</td>
<td>-0.0387</td>
</tr>
<tr>
<td>0.0903</td>
<td>0.0006</td>
<td>-0.2787</td>
<td>-0.1438</td>
<td>-0.0268</td>
<td>-0.4664</td>
<td>0.3828</td>
<td>0.1961</td>
<td>-0.2742</td>
<td>-0.0353</td>
<td>0.0575</td>
<td>0.0902</td>
<td>0.2742</td>
<td>0.2781</td>
<td>-0.3960</td>
</tr>
<tr>
<td>-0.2839</td>
<td>-0.3259</td>
<td>0.0578</td>
<td>-0.0188</td>
<td>0.5813</td>
<td>0.1078</td>
<td>0.0626</td>
<td>-0.0185</td>
<td>0.0733</td>
<td>-0.3759</td>
<td>0.3781</td>
<td>0.1588</td>
<td>-0.1919</td>
<td>0.1333</td>
<td>0.0404</td>
</tr>
<tr>
<td>-0.2000</td>
<td>-0.1847</td>
<td>-0.2995</td>
<td>-0.0359</td>
<td>0.2644</td>
<td>0.0757</td>
<td>0.0865</td>
<td>0.0801</td>
<td>0.0373</td>
<td>0.1799</td>
<td>-0.1546</td>
<td>-0.8126</td>
<td>0.0764</td>
<td>0.1274</td>
<td>0.0412</td>
</tr>
<tr>
<td>-0.1126</td>
<td>0.0666</td>
<td>-0.0926</td>
<td>-0.0538</td>
<td>0.3362</td>
<td>-0.1266</td>
<td>0.0263</td>
<td>-0.1285</td>
<td>-0.1811</td>
<td>0.7461</td>
<td>-0.1026</td>
<td>0.2618</td>
<td>-0.2431</td>
<td>-0.1284</td>
<td>0.1683</td>
</tr>
<tr>
<td>-0.5437</td>
<td>0.7513</td>
<td>-0.0222</td>
<td>-0.1168</td>
<td>0.0524</td>
<td>-0.1936</td>
<td>-0.0175</td>
<td>0.0037</td>
<td>0.0339</td>
<td>-0.2410</td>
<td>-0.0642</td>
<td>-0.0632</td>
<td>-0.0330</td>
<td>0.0092</td>
<td>0.1259</td>
</tr>
</tbody>
</table>

**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 3.9); 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$_2$O$_3$ 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, \( \text{gen. formula } \text{CaNa} \left( \text{NbTi} \right)_{2} \text{O}_{6} \text{F} \), 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 titanomagnetite 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 Akjoujt, 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. 33. Geometric means and ranges of concentration of Sr, Nb, Zr, Ti (as TiO₂), Fe (as Fe₂O₃), 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 detection.
pseudomorph carbonatite, and carbonatitic breccia are summarised in Figure 5.3.

The distinction, geochemical and petrographic, between the carbonatite groups, suggests that at least the sositites 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 alcalis to compositions in the system calcite-barite-fluorite-H₂O, 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-earth 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.
CHAPTER FOUR.

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 Bueda in E. Uganda. More detailed accounts of each centre are given in Appendix 1.
4.3 Analytical method.

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. H₂SO₄/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 fенites, 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 fенite), 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 Results of Analyses.

The results of spectrometric analyses of major and trace elements in the intrusive silicate rocks, Phonolitic rocks and fенite 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, 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
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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Zr</th>
<th>Zn</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxenite</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ijolite</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Urtite</td>
<td>3</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Nepheline-syenite</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phonolite</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fenite</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>
Fig. 6.6-g. The distributions of Sr, Ba, Zr, Zn, Y, Ti, (as TiO₂), and Ge in peralkaline calc-alkaline rocks and tuffs from carbonatites complexes in W. Kenya and E. Uganda. "Sphene" includes melilite, jadeite, and kalsilite, "Egyptite" includes nepheline-enstatite, nepheline-olivine, nepheline-nepheline, and anorthite-nepheline.
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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Strontium</th>
<th>Barium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Pyroxenite</td>
<td>615</td>
<td>300-1550</td>
</tr>
<tr>
<td>Ijolite</td>
<td>850</td>
<td>630-1680</td>
</tr>
<tr>
<td>Melanite Ijolite</td>
<td>550</td>
<td>300-1100</td>
</tr>
<tr>
<td>Feldspathic Ijolite</td>
<td>890</td>
<td>730-1090</td>
</tr>
<tr>
<td>Urtite</td>
<td>415</td>
<td>210-690</td>
</tr>
<tr>
<td>Nepheline Syenite</td>
<td>825</td>
<td>215-1420</td>
</tr>
<tr>
<td>Micro Ijolite</td>
<td>690</td>
<td>530-1040</td>
</tr>
</tbody>
</table>

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

Sr 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.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Rock Type</th>
<th>Strontium ppm Range</th>
<th>Barium ppm Range</th>
<th>Number of Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxene</td>
<td>Pyroxenite</td>
<td>320 ppm</td>
<td>70 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Ijolite</td>
<td></td>
<td>420-1160 ppm</td>
<td>110-500 ppm</td>
<td>4</td>
</tr>
<tr>
<td>Microijolite</td>
<td></td>
<td>370-750 ppm</td>
<td>50-260 ppm</td>
<td>4</td>
</tr>
<tr>
<td>Nepheline-syenite</td>
<td></td>
<td>660-950 ppm</td>
<td>300-330 ppm</td>
<td>2</td>
</tr>
<tr>
<td>Nepheline</td>
<td>Ijolite</td>
<td>670-3000 ppm</td>
<td>300-4000 ppm</td>
<td>7</td>
</tr>
<tr>
<td>Urtite</td>
<td></td>
<td>250-580 ppm</td>
<td>50-150 ppm</td>
<td>3</td>
</tr>
<tr>
<td>Foldspar</td>
<td>Microijolite</td>
<td>380-1250 ppm</td>
<td>6000 ppm</td>
<td>4</td>
</tr>
<tr>
<td>Nepheline</td>
<td>Nepheline-syenite</td>
<td>190-1025 ppm</td>
<td>6000 ppm</td>
<td>9</td>
</tr>
<tr>
<td>Melanite</td>
<td>Melanite</td>
<td>320-540 ppm</td>
<td>100-380 ppm</td>
<td>4</td>
</tr>
<tr>
<td>garnet</td>
<td>ijolite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wollastonite</td>
<td>Urtite</td>
<td>1360 ppm</td>
<td>280 ppm</td>
<td>1</td>
</tr>
</tbody>
</table>

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\(_2\)O and Sr/CaO, as in Figure 4.2, where the plutonic rocks have been compared with similar parameters for phonolitic rocks and fentitic rocks.

In Figure 4.2, there is a general increase in Ba/K\(_2\)O 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
Fig 4.2. Variation of Ba/K₂O and Sr/ CaO in peralkaline intrusive silicate rocks and fennites 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Strontium Range</th>
<th>Barium Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melanephelinite</td>
<td>720-1700ppm</td>
<td>950-6000ppm</td>
</tr>
<tr>
<td>Nepheline</td>
<td>1000-1230ppm</td>
<td>1000-7280ppm</td>
</tr>
<tr>
<td>Phonolitic nepheline</td>
<td>880-1820ppm</td>
<td>870-4000ppm</td>
</tr>
<tr>
<td>Analcime-phonolite</td>
<td>150-1650ppm</td>
<td>480-3400ppm</td>
</tr>
<tr>
<td>Cancrinite-phonolite</td>
<td>970ppm</td>
<td>1150ppm</td>
</tr>
</tbody>
</table>

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 melanepehelineites, nephelineites, and phonolitic nephelineites (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 nephelineites and in the analcime phonolites, however, suggest that to a large extent, the earlier feldspar of the phonolitic nephelineites 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.
Table 4.4. Geometric means and ranges of Nb and Zr in peralkaline silicate rocks of W. Kenya and E. Uganda.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Mean Nb</th>
<th>Range</th>
<th>Mean Zr</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxenite</td>
<td>400ppm</td>
<td>185-860ppm</td>
<td>400ppm</td>
<td>100-1000ppm</td>
</tr>
<tr>
<td>Ijolite</td>
<td>330ppm</td>
<td>&lt;50-1350ppm</td>
<td>680ppm</td>
<td>170-840ppm</td>
</tr>
<tr>
<td>Melanite Ijolite</td>
<td>290ppm</td>
<td>220-670ppm</td>
<td>670ppm</td>
<td>320-1350ppm</td>
</tr>
<tr>
<td>Feldspathic Ijolite</td>
<td>135 ppm</td>
<td>&lt;50-830ppm</td>
<td>870ppm</td>
<td>500-1280ppm</td>
</tr>
<tr>
<td>Ijolite Urtite</td>
<td>&lt;50ppm</td>
<td>&lt;50ppm</td>
<td>&lt;10ppm</td>
<td>&lt;10-350ppm</td>
</tr>
<tr>
<td>Nepheline Syenite</td>
<td>&lt;50ppm</td>
<td>&lt;50-330ppm</td>
<td>510ppm</td>
<td>110-1900ppm</td>
</tr>
<tr>
<td>Microijolite</td>
<td>&lt;50ppm</td>
<td>&lt;50ppm</td>
<td>390ppm</td>
<td>200-510ppm</td>
</tr>
</tbody>
</table>

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 acmite 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 acmite 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Zr Range</th>
<th>No. of Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxenite</td>
<td>470 ppm</td>
<td>1</td>
</tr>
<tr>
<td>Ijolite</td>
<td>650-2060 ppm</td>
<td>4</td>
</tr>
<tr>
<td>Microijolite</td>
<td>280-1150 ppm</td>
<td>4</td>
</tr>
<tr>
<td>Nepheline Syenite</td>
<td>1000-1150 ppm</td>
<td>2</td>
</tr>
<tr>
<td>Melanephelinite</td>
<td>140-1140</td>
<td>3</td>
</tr>
<tr>
<td>Phonolite</td>
<td>960-1460</td>
<td>2</td>
</tr>
</tbody>
</table>

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 acmite 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Niobium Range</th>
<th>Zirconium Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melanephelinite</td>
<td>&lt; 50-400ppm</td>
<td>300-790ppm</td>
</tr>
<tr>
<td>Nephelinite</td>
<td>300-560ppm</td>
<td>590-1500ppm</td>
</tr>
<tr>
<td>Phonolitic nephelinite</td>
<td>&lt; 50-950ppm</td>
<td>550-1500ppm</td>
</tr>
<tr>
<td>Analcime-phonolite</td>
<td>&lt; 50-200ppm</td>
<td>800-1740ppm</td>
</tr>
<tr>
<td>Cancrinite phonolite</td>
<td>&lt; 50ppm</td>
<td>1680ppm</td>
</tr>
</tbody>
</table>

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 perovskite 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 acmite 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 acmite 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 (EC54) 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 2500 ppm 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 fenes 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 fenes, occurring locally in accessory Ti-rich minerals, generally in amounts greater than 1000ppm, and also in pyroxenes of intrusive ijolitic rocks, phonolitic rocks and fenes. Generally the more acmite 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 acmite pyroxene of nepheline-syenite and fene, and the sporadic occurrence of Nb in fene 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 fenes is given in Figure 4.1(d).

Zinc is generally more concentrated in the nepheline syenite, phonolite and fenes 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.
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 50 ppm.

**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, 10-60 ppm Zn and 5-20 ppm Pb were found, whilst in nepheline, 25-60 ppm Zn and 5-20 ppm Pb were found by spectrometric analysis. Zn is more concentrated in the mafic minerals. 100-1300 ppm Zn were found in pyroxene, and 170-360 ppm 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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Zinc Range</th>
<th>Lead Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melanephelinite</td>
<td>100-360ppm</td>
<td>&lt; 5-50ppm</td>
</tr>
<tr>
<td>Nephelinite</td>
<td>140-360ppm</td>
<td>&lt; 5-50ppm</td>
</tr>
<tr>
<td>Phonolitic nephelinite</td>
<td>120-400ppm</td>
<td>25-80ppm</td>
</tr>
<tr>
<td>Analcime phonolite</td>
<td>250-470ppm</td>
<td>15-100ppm</td>
</tr>
<tr>
<td>Cancrinite phonolite</td>
<td>160ppm</td>
<td>10ppm</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Cr Range PPM</th>
<th>Ni Range PPM</th>
<th>Cu Range PPM</th>
<th>Co Range PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxenite</td>
<td>&lt;5-354</td>
<td>&lt;5-184</td>
<td>10-100</td>
<td>20-79</td>
</tr>
<tr>
<td>Ijolite</td>
<td>&lt;5-26</td>
<td>10-130</td>
<td>&lt;5-75</td>
<td>22-33</td>
</tr>
<tr>
<td>Melanite</td>
<td>&lt;5</td>
<td>10-40</td>
<td>&lt;5-44</td>
<td>10-30</td>
</tr>
<tr>
<td>Ijolite</td>
<td>&lt;5</td>
<td>10-40</td>
<td>&lt;5-44</td>
<td>10-30</td>
</tr>
<tr>
<td>Melanite Ijolite</td>
<td>&lt;5-30</td>
<td>&lt;5-62</td>
<td>&lt;5-70</td>
<td>&lt;5-30</td>
</tr>
<tr>
<td>Urtite</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5-5</td>
</tr>
<tr>
<td>Microijolite</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5-20</td>
<td>&lt;5-10</td>
</tr>
<tr>
<td>Nepheline Syenite</td>
<td>&lt;5-12</td>
<td>&lt;5-10</td>
<td>&lt;5-5</td>
<td>&lt;5-12</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Vanadium ppm</th>
<th>TiO$_2$ wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Pyroxenite</td>
<td>250</td>
<td>130-380</td>
</tr>
<tr>
<td>Ijolite</td>
<td>175</td>
<td>100-325</td>
</tr>
<tr>
<td>Melanite-Ijolite</td>
<td>320</td>
<td>240-660</td>
</tr>
<tr>
<td>Feldspathic-Ijolite</td>
<td>165</td>
<td>120-475</td>
</tr>
<tr>
<td>Urtite</td>
<td>20</td>
<td>10-250</td>
</tr>
<tr>
<td>Microijolite</td>
<td>250</td>
<td>125-700</td>
</tr>
<tr>
<td>Nepheline-Syenite</td>
<td>87</td>
<td>20-275</td>
</tr>
</tbody>
</table>

*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 250-1550 ppm 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.
<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Cr Range</th>
<th>Ni Range</th>
<th>Cu Range</th>
<th>Co Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melanephelinite</td>
<td>50-410 ppm</td>
<td>30-120 ppm</td>
<td>110-215 ppm</td>
<td>50-60 ppm</td>
</tr>
<tr>
<td>Nephelinite</td>
<td>&lt;5-236 ppm</td>
<td>&lt; 5-54 ppm</td>
<td>&lt;5-110 ppm</td>
<td>&lt; 5-30 ppm</td>
</tr>
<tr>
<td>Phonolitic nephelinite</td>
<td>&lt; 5-40 ppm</td>
<td>&lt; 5-36 ppm</td>
<td>&lt;5-102 ppm</td>
<td>&lt; 5-22 ppm</td>
</tr>
<tr>
<td>Analcine Phonolite</td>
<td>&lt; 5 ppm</td>
<td>&lt; 5 ppm</td>
<td>&lt;5-20 ppm</td>
<td>&lt; 5 ppm</td>
</tr>
<tr>
<td>Cancrinite Phonolite</td>
<td>12 ppm</td>
<td>&lt; 5 ppm</td>
<td>&lt;5 ppm</td>
<td>&lt; 5 ppm</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Vanadium Range (ppm)</th>
<th>Titanium Range (wt.% TiO$_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melanephelinite</td>
<td>220-750</td>
<td>0.84 - 3.5</td>
</tr>
<tr>
<td>Nephelinite</td>
<td>80-600</td>
<td>0.55 - 1.55</td>
</tr>
<tr>
<td>Phonolitic nephelinite</td>
<td>125-675</td>
<td>0.65 - 1.6</td>
</tr>
<tr>
<td>Analcine phonolite</td>
<td>20-260</td>
<td>0.39 - 1.89</td>
</tr>
<tr>
<td>Cancrinite phonolite</td>
<td>60</td>
<td>0.54</td>
</tr>
</tbody>
</table>

**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)(d) 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.
Table 4.13. Geometric means and ranges of concentration of Ga in the intrusive silicate rocks.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxenite</td>
<td>20ppm</td>
<td>10-30ppm</td>
</tr>
<tr>
<td>Ijolite</td>
<td>26ppm</td>
<td>25-50ppm</td>
</tr>
<tr>
<td>Melanite Ijolite</td>
<td>30ppm</td>
<td>20-35ppm</td>
</tr>
<tr>
<td>Feldspathic Ijolite</td>
<td>41ppm</td>
<td>35-56ppm</td>
</tr>
<tr>
<td>Urtite</td>
<td>49ppm</td>
<td>35-60ppm</td>
</tr>
<tr>
<td>Microlite Ijolite</td>
<td>50ppm</td>
<td>35-58ppm</td>
</tr>
<tr>
<td>Nepheline-syenite</td>
<td>45ppm</td>
<td>10-80ppm</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Gallium Range ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melanephelinite</td>
<td>10-40</td>
</tr>
<tr>
<td>Nephelinite</td>
<td>35-50</td>
</tr>
<tr>
<td>Phonolitic Nephelinite</td>
<td>33-50</td>
</tr>
<tr>
<td>Analcime Phonolite</td>
<td>35-80</td>
</tr>
<tr>
<td>Cancrinite Phonolite</td>
<td>58</td>
</tr>
</tbody>
</table>

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) Ga in the fenites.

Ga varies from 25–150 ppm 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) Beryllium, Lithium and Tin.

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 900 ppm Li), (Appendix Table 7 (d)).

Be has been reported as the mineral baryllite \( \text{Be}_2\text{BaSi}_2\text{O}_7 \) 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 - MgO
- Fe$_2$O$_3$ - MnO, TiO$_2$, Nb, V, Zr
- MnO - Li, Nb
- MgO - CaO, Co, V
- K$_2$O - Ca, Ba
- TiO$_2$ - MgO, Fe$_2$O$_3$, Co, Nb, V, Zr
- Ba - Sr, K$_2$O
- V - Fe$_2$O$_3$, Nb, TiO$_2$
- Zr - Fe$_2$O$_3$, 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:

- \( \text{Na}_2\text{O} \) - Co
- FeO - Fe\(_2\)O\(_3\)
- K\(_2\)O - 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\(_2\)O, 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, Sr, Ca, Cr, Ni, Cu, Ti, Co, Ga, Nb, Sr, Ir, In, Y, La, and Mn. in pyroxene, epidote, melanoite, epidote, urtite, epidotaphtic epidote, nepheline syenite, micro-epidote and femrite, associated with carbonatites in N. 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 Blinde (1963) for the Magnet Cove peralkaline complex, Arkansas.

b - data from this study, e - data from Erikson and Blinde (1963), 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 4.5.

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 noteworthy. 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, 1966; 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 acmite 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 relationship 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, j). 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 \( \text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{Fe}_2\text{O}_3-\text{SiO}_2 \).

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 melanepheline-phonolitic nepheline-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.
Chapter Five.

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, 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, Ca, Ce, and Ag were rarely present in concentration greater than 10 ppm 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 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 melilitite-pseudomorph carbonatites also contained a characteristic assemblage of trace elements, which were characteristic of the carbonatites proper (sovite, alvikite and ferruginous alvikite). Similarly, the melilitite-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 Co-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 Be, 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; van Hambke, 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. 51. 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 NaAlSiO₄-CaCO₃-H₂O 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); Fleek, (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 NaAlSi₂O₆-Na₂CO₃-H₂O (van Groos and Wyllie, 1968) were shown to contain immiscible carbonate and silicate liquids coexisting with vapour, under conditions of high $P_{CO₂}$.

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

3. Average basic rock, Vinogradov 1961.
5. Average Ca-poor acid rock, Turekian and Wedepohl 1961.
6. Average Ca-rich acid rock, Turekian and Wedepohl 1961.
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.
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 tholeiitic 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 \[ \text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{Fe}_2\text{O}_3 \] 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 undersaturated (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.
APPENDIX ONE.

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°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%.

<table>
<thead>
<tr>
<th>Element</th>
<th>Peak 2θ</th>
<th>Background 2θ</th>
<th>Scintillation counter</th>
<th>Gas flow counter</th>
<th>Radiation Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>23.78</td>
<td>23.0</td>
<td>X</td>
<td></td>
<td>KAl W</td>
</tr>
<tr>
<td>La</td>
<td>82.72</td>
<td>84.0</td>
<td>X</td>
<td></td>
<td>LAl Cr</td>
</tr>
<tr>
<td>Ce</td>
<td>71.76</td>
<td>71.2</td>
<td>X</td>
<td></td>
<td>LBl W</td>
</tr>
<tr>
<td>Nd</td>
<td>72.22</td>
<td>73.0</td>
<td>X</td>
<td></td>
<td>LAl W</td>
</tr>
<tr>
<td>Dy</td>
<td>50.26</td>
<td>51.0</td>
<td>X</td>
<td></td>
<td>LBl W</td>
</tr>
</tbody>
</table>

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 emission 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).
<table>
<thead>
<tr>
<th>Element</th>
<th>Line (Å)</th>
<th>Slit Width (μ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>2378.4</td>
<td>75</td>
</tr>
<tr>
<td>Ca</td>
<td>3158.9</td>
<td>150</td>
</tr>
<tr>
<td>Fe</td>
<td>2739.6</td>
<td>150</td>
</tr>
<tr>
<td>Mg</td>
<td>2790.8</td>
<td>75</td>
</tr>
<tr>
<td>Mn</td>
<td>2933.0</td>
<td>75</td>
</tr>
<tr>
<td>Si</td>
<td>2435.2</td>
<td>75</td>
</tr>
<tr>
<td>Ti</td>
<td>3653.5</td>
<td>75</td>
</tr>
<tr>
<td>Ba</td>
<td>4550.0</td>
<td>50</td>
</tr>
<tr>
<td>Be</td>
<td>3130.4</td>
<td>50</td>
</tr>
<tr>
<td>Bi</td>
<td>3067.7</td>
<td>50</td>
</tr>
<tr>
<td>Co</td>
<td>3453.5</td>
<td>50</td>
</tr>
<tr>
<td>Cr</td>
<td>4254.4</td>
<td>50</td>
</tr>
<tr>
<td>Cu</td>
<td>3274.5</td>
<td>75</td>
</tr>
<tr>
<td>Ga</td>
<td>2943.6</td>
<td>75</td>
</tr>
<tr>
<td>Ge</td>
<td>3039.1</td>
<td>75</td>
</tr>
<tr>
<td>Li</td>
<td>6103.1</td>
<td>50</td>
</tr>
<tr>
<td>Mo</td>
<td>3170.3</td>
<td>50</td>
</tr>
<tr>
<td>Nb</td>
<td>3195.0</td>
<td>50</td>
</tr>
<tr>
<td>Ni</td>
<td>3424.7</td>
<td>50</td>
</tr>
<tr>
<td>Pb</td>
<td>2833.1</td>
<td>50</td>
</tr>
<tr>
<td>Sn</td>
<td>2840.0</td>
<td>50</td>
</tr>
<tr>
<td>Sr</td>
<td>4607.3</td>
<td>50</td>
</tr>
<tr>
<td>V</td>
<td>4379.2</td>
<td>75</td>
</tr>
<tr>
<td>Zn</td>
<td>4810.5</td>
<td>75</td>
</tr>
<tr>
<td>Zn</td>
<td>2183.6</td>
<td>50</td>
</tr>
<tr>
<td>Zr</td>
<td>3392.0</td>
<td>50</td>
</tr>
</tbody>
</table>

*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. 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°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°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°C, giving a top standard on dilution with specpure CaCO$_3$ of Fe$_2$O$_3$ (15%), MgO (5%), TiO$_2$ (5%), Al$_2$O$_3$ (5%), MnO (0.5%), K$_2$CO$_3$ (5%), and Na$_2$CO$_3$ (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 1:5, 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.
A. 8

<table>
<thead>
<tr>
<th>Element/Oxide</th>
<th>Mean</th>
<th>2X Standard Deviation</th>
<th>Coefficient of Variation</th>
<th>No. of Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>0.13%</td>
<td>0.017%</td>
<td>25.6%</td>
<td>18</td>
</tr>
<tr>
<td>Fe&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>3.11%</td>
<td>0.51%</td>
<td>30.4%</td>
<td>18</td>
</tr>
<tr>
<td>MgO</td>
<td>0.14%</td>
<td>0.045%</td>
<td>64%</td>
<td>18</td>
</tr>
<tr>
<td>MnO</td>
<td>0.61%</td>
<td>0.26%</td>
<td>27.8%</td>
<td>18</td>
</tr>
<tr>
<td>TiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.17%</td>
<td>0.028%</td>
<td>28.0%</td>
<td>18</td>
</tr>
<tr>
<td>Ba</td>
<td>355ppm</td>
<td>30ppm</td>
<td>8.5%</td>
<td>18</td>
</tr>
<tr>
<td>Li</td>
<td>28ppm</td>
<td>3.2ppm</td>
<td>9.8%</td>
<td>18</td>
</tr>
<tr>
<td>Mo</td>
<td>23ppm</td>
<td>3.2ppm</td>
<td>14.0%</td>
<td>18</td>
</tr>
<tr>
<td>Nb</td>
<td>375ppm</td>
<td>25ppm</td>
<td>15%</td>
<td>18</td>
</tr>
<tr>
<td>Ni</td>
<td>8ppm</td>
<td>2.2ppm</td>
<td>27%</td>
<td>18</td>
</tr>
<tr>
<td>Pb</td>
<td>12ppm</td>
<td>2.5ppm</td>
<td>20%</td>
<td>18</td>
</tr>
<tr>
<td>Sr</td>
<td>970ppm</td>
<td>97ppm</td>
<td>10%</td>
<td>18</td>
</tr>
<tr>
<td>V</td>
<td>54ppm</td>
<td>2.8ppm</td>
<td>5.2%</td>
<td>18</td>
</tr>
<tr>
<td>Zn</td>
<td>64ppm</td>
<td>2.8ppm</td>
<td>4.5%</td>
<td>18</td>
</tr>
<tr>
<td>Zr</td>
<td>55ppm</td>
<td>3.8ppm</td>
<td>7%</td>
<td>18</td>
</tr>
</tbody>
</table>

**Table 3.** Mean, 2X standard deviation, and coefficient of variation (2s/√n 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 fennites, 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 specmix 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%.

<table>
<thead>
<tr>
<th>Element</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Coefficient of Variation</th>
<th>No. of Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>13.0%</td>
<td>0.9%</td>
<td>15%</td>
<td>16</td>
</tr>
<tr>
<td>CaO</td>
<td>9.3%</td>
<td>0.67%</td>
<td>18%</td>
<td>16</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>12.3%</td>
<td>0.8%</td>
<td>13%</td>
<td>16</td>
</tr>
<tr>
<td>MgO</td>
<td>20%</td>
<td>-</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>MnO</td>
<td>0.15%</td>
<td>0.005%</td>
<td>25%</td>
<td>16</td>
</tr>
<tr>
<td>SiO₂</td>
<td>41.57%</td>
<td>2.97%</td>
<td>14%</td>
<td>16</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.07%</td>
<td>0.14%</td>
<td>26%</td>
<td>16</td>
</tr>
<tr>
<td>Ba</td>
<td>328ppm</td>
<td>16ppm</td>
<td>10%</td>
<td>16</td>
</tr>
<tr>
<td>Be</td>
<td>10ppm</td>
<td>1ppm</td>
<td>10%</td>
<td>16</td>
</tr>
<tr>
<td>Co</td>
<td>72ppm</td>
<td>3ppm</td>
<td>8.5%</td>
<td>16</td>
</tr>
<tr>
<td>Cr</td>
<td>369ppm</td>
<td>15ppm</td>
<td>8%</td>
<td>16</td>
</tr>
<tr>
<td>Cu</td>
<td>74ppm</td>
<td>4.5ppm</td>
<td>12%</td>
<td>16</td>
</tr>
<tr>
<td>Ga</td>
<td>25ppm</td>
<td>1.8ppm</td>
<td>14%</td>
<td>16</td>
</tr>
<tr>
<td>Nb</td>
<td>212ppm</td>
<td>50ppm</td>
<td>50%</td>
<td>16</td>
</tr>
<tr>
<td>Ni</td>
<td>121ppm</td>
<td>6ppm</td>
<td>10%</td>
<td>16</td>
</tr>
<tr>
<td>Pb</td>
<td>15ppm</td>
<td>2ppm</td>
<td>26%</td>
<td>16</td>
</tr>
<tr>
<td>Sn</td>
<td>25ppm</td>
<td>2ppm</td>
<td>16%</td>
<td>16</td>
</tr>
<tr>
<td>Sr</td>
<td>411ppm</td>
<td>20ppm</td>
<td>9.5%</td>
<td>16</td>
</tr>
<tr>
<td>V</td>
<td>295ppm</td>
<td>15ppm</td>
<td>10%</td>
<td>16</td>
</tr>
<tr>
<td>Zn</td>
<td>103ppm</td>
<td>15ppm</td>
<td>30%</td>
<td>16</td>
</tr>
<tr>
<td>Zr</td>
<td>98ppm</td>
<td>5ppm</td>
<td>10%</td>
<td>16</td>
</tr>
</tbody>
</table>

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. Chemical Analyses of Silicate Rocks.

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 0.1gms. 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) $FeO$.

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 Table 1. Field data concerning analysed specimens.

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Centre</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF15</td>
<td>Ferruginous alvike</td>
<td>Got Bonde Ridge</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HFR19</td>
<td>Sovite</td>
<td>Rongo</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC54</td>
<td>Slightly fenitised lava</td>
<td>Homa main</td>
<td>Nyanzian basement</td>
<td></td>
</tr>
<tr>
<td>HF115</td>
<td>Ferruginous alvike</td>
<td>Got Bonde Ridge</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF160</td>
<td>Carbonatitic intrusive breccia</td>
<td>Got Akwach</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HF195</td>
<td>Carbonatitic intrusive breccia</td>
<td>Nyasanga</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HF199</td>
<td>Ferruginous alvike</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF209</td>
<td>Alvikite</td>
<td>Nyasanga</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF212</td>
<td>Alvikite</td>
<td>Nyasanga</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF225</td>
<td>Ferruginous alvike</td>
<td>Nyamatoto</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF230</td>
<td>Intrusive carbonatitic breccia</td>
<td>Nyasanga</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC258</td>
<td>Alvikite</td>
<td>S.Cliff, Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC309</td>
<td>Ijolite</td>
<td>W. of Rapogi</td>
<td>Ijolite mass</td>
<td></td>
</tr>
<tr>
<td>HC312</td>
<td>Ijolite</td>
<td>W. of Rapogi</td>
<td>Ijolite mass</td>
<td></td>
</tr>
<tr>
<td>HC320</td>
<td>Intrusive carbonatitic breccia</td>
<td>W. of Rapogi</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC323</td>
<td>Ijolite</td>
<td>Yusoo</td>
<td>Ijolite mass</td>
<td></td>
</tr>
<tr>
<td>HC324</td>
<td>Ijolite</td>
<td>Yusoo</td>
<td>Massive ijolite</td>
<td></td>
</tr>
<tr>
<td>HF329</td>
<td>Phonolite</td>
<td>Homa</td>
<td>Plug</td>
<td></td>
</tr>
<tr>
<td>HC338</td>
<td>Sovite</td>
<td>Homa main</td>
<td>Massive sovite</td>
<td></td>
</tr>
<tr>
<td>HF350</td>
<td>Alvikite</td>
<td>Nyamatoto</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC366</td>
<td>Alvikite</td>
<td>Ndirus cliff</td>
<td>Plug</td>
<td></td>
</tr>
<tr>
<td>HC367</td>
<td>Alvikite</td>
<td>Ndiru Hill</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>Specimen Number</td>
<td>Rock Type</td>
<td>Centre</td>
<td>Locality</td>
<td>Form of Occurrence</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------------------</td>
<td>-----------------</td>
<td>----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>HC374</td>
<td>K-rich trachyte</td>
<td>Home South Ridge</td>
<td>Dyke</td>
<td></td>
</tr>
<tr>
<td>HF377</td>
<td>Intrusive carbonatitic breccia</td>
<td>Nyasanga</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC384</td>
<td>Intrusive carbonatitic breccia</td>
<td>Nyasanga</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC396</td>
<td>Melilite-pseudomorph carbonatite</td>
<td>Chiewo vent</td>
<td>Dyke</td>
<td></td>
</tr>
<tr>
<td>HC401</td>
<td>Melilite-pseudomorph carbonatite</td>
<td>Chiewo vent</td>
<td>Dyke</td>
<td></td>
</tr>
<tr>
<td>HF462</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Dyke</td>
<td></td>
</tr>
<tr>
<td>HF490</td>
<td>Ferruginous alvikite</td>
<td>Homa Mountain</td>
<td>Dyke</td>
<td></td>
</tr>
<tr>
<td>HF508</td>
<td>Alvikite</td>
<td>Homa Point East</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC541</td>
<td>Feldspar Rock</td>
<td>Simbi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF559</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF578</td>
<td>Ferruginous alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF583</td>
<td>Ferruginous alvikite</td>
<td>Nyasanga</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC594</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF597</td>
<td>Alvikite</td>
<td>S.Cliff, Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF603</td>
<td>Alvikite</td>
<td>Got Ayuaya</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF609</td>
<td>Alvikite</td>
<td>Got Ayuaya</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC613</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC614</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF621</td>
<td>Intrusive carbonatitic breccia</td>
<td>Homa Mountain</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC629</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF636</td>
<td>Alvikite</td>
<td>Got Ayuaya</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC639</td>
<td>Melilite-pseudomorph carbonatite</td>
<td>Chiewo</td>
<td>Dyke</td>
<td></td>
</tr>
<tr>
<td>HC649</td>
<td>Alvikite</td>
<td>Ndiru</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC653</td>
<td>Feldspar rock</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC659</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HF666</td>
<td>Ferruginous alvikite</td>
<td></td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

*Appendix Table 1, (continued)*
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Centre</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC698</td>
<td>Alvikite</td>
<td>Homa Mountain</td>
<td>Cone sheet</td>
<td></td>
</tr>
<tr>
<td>HC731</td>
<td>Feldspar rock</td>
<td>Ndiru M'bili</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC732</td>
<td>Feldspar rock</td>
<td>Ndiru M'bili</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC741</td>
<td>Ijolite</td>
<td>N.W. of Ndiru</td>
<td>Massive ijolite</td>
<td></td>
</tr>
<tr>
<td>HC743</td>
<td>Ijolite</td>
<td>Yusoo</td>
<td>Massive ijolite</td>
<td></td>
</tr>
<tr>
<td>HC744</td>
<td>Ijolite</td>
<td>Yusoo</td>
<td>Massive ijolite</td>
<td></td>
</tr>
<tr>
<td>HC748</td>
<td>K-rich trachyte</td>
<td>Yusoo</td>
<td>Dyke</td>
<td></td>
</tr>
<tr>
<td>HC7616</td>
<td>Phonolite</td>
<td>Homa Mountain</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC797</td>
<td>Fenite</td>
<td>Yusoo</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC800</td>
<td>Fenite</td>
<td>Yusoo</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC825</td>
<td>Fenite</td>
<td>E. of Yusoo</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC912</td>
<td>Micro ijolite</td>
<td>Bala</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC930</td>
<td>Medium grained ijolite</td>
<td>Yusoo</td>
<td>Massive ijolite</td>
<td></td>
</tr>
<tr>
<td>HC934</td>
<td>Ijolite</td>
<td>W. of Rapogi</td>
<td>Massive ijolite</td>
<td></td>
</tr>
<tr>
<td>HC964</td>
<td>Ijolite</td>
<td>S. Rapogi</td>
<td>Massive ijolite</td>
<td></td>
</tr>
<tr>
<td>HC965</td>
<td>Sovite</td>
<td>Rapogi</td>
<td>Massive sovite</td>
<td></td>
</tr>
<tr>
<td>HC988</td>
<td>Pyroxenite</td>
<td>Homa Mountain South</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HC993</td>
<td>Ijolite</td>
<td>Homa Mountain South</td>
<td>Xenolith in phonolite</td>
<td></td>
</tr>
<tr>
<td>HC999</td>
<td>Coarse ijolite</td>
<td>Homa Mountain South</td>
<td>Loose block</td>
<td></td>
</tr>
<tr>
<td>HC1005</td>
<td>Phonolite</td>
<td>Homa Mountain</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>U48</td>
<td>Phonolite</td>
<td>Samanga Hill</td>
<td>Plug</td>
<td></td>
</tr>
</tbody>
</table>

Appendix Table 1. (continued).
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>N24</td>
<td>Alvikite</td>
<td>S. North Ruri</td>
<td>Cone sheet</td>
</tr>
<tr>
<td>N85</td>
<td>Phonolite</td>
<td>Gotjope</td>
<td>Plug</td>
</tr>
<tr>
<td>N90</td>
<td>Phonolite</td>
<td>N. North Ruri</td>
<td>Plug</td>
</tr>
<tr>
<td>N142</td>
<td>Alvikite</td>
<td>S. North Ruri</td>
<td>Cone sheet</td>
</tr>
<tr>
<td>N158</td>
<td>Phonolite</td>
<td>Near Kabonga</td>
<td>Plug</td>
</tr>
<tr>
<td>N177</td>
<td>Sovite</td>
<td>Central N. Ruri</td>
<td>Block in agglomerate</td>
</tr>
<tr>
<td>N225</td>
<td>Nepheline-microsyenite</td>
<td>S. North Ruri</td>
<td>Minor intrusion</td>
</tr>
<tr>
<td>N266</td>
<td>Nepheline-microsyenite</td>
<td>Summit N. Ruri</td>
<td>Block in agglomerate</td>
</tr>
<tr>
<td>U326</td>
<td>Alvikite</td>
<td>Okuge</td>
<td>Ring complex</td>
</tr>
<tr>
<td>N339</td>
<td>Ferruginous alvikite</td>
<td>Central N. Ruri</td>
<td>Cone sheet</td>
</tr>
<tr>
<td>N348</td>
<td>Alvikite</td>
<td>Central N. Ruri</td>
<td>Cone sheet</td>
</tr>
<tr>
<td>N427</td>
<td>Alvikite</td>
<td>W. North Ruri</td>
<td>Cone sheet</td>
</tr>
<tr>
<td>N429</td>
<td>Alvikite</td>
<td>W. North Ruri</td>
<td>Cone sheet</td>
</tr>
<tr>
<td>N464</td>
<td>Nepheline-microsyenite</td>
<td>N. side, North Ruri</td>
<td>Massive n.-syenite intrusion</td>
</tr>
<tr>
<td>N503</td>
<td>Nepheline-microsyenite</td>
<td>N.W. spur, North Ruri</td>
<td>Minor intrusion</td>
</tr>
<tr>
<td>N593</td>
<td>Melanephelinite</td>
<td>N. Okuge</td>
<td>Lava</td>
</tr>
<tr>
<td>N595</td>
<td>Melanephelinite</td>
<td>N. Okuge</td>
<td>Lava</td>
</tr>
<tr>
<td>N683</td>
<td>Pyroxenite</td>
<td>S. spur, North Ruri</td>
<td>Block in agglomerate</td>
</tr>
<tr>
<td>N688</td>
<td>Nepheline-microsyenite</td>
<td>S. spur, North Ruri</td>
<td>Block in agglomerate</td>
</tr>
<tr>
<td>N694</td>
<td>Pyroxenite</td>
<td>Summit, North Ruri</td>
<td>Block in agglomerate</td>
</tr>
<tr>
<td>N712</td>
<td>Melanephelinite</td>
<td>N. North Ruri</td>
<td>Block in agglomerate</td>
</tr>
<tr>
<td>N729</td>
<td>Fenite</td>
<td>N.E. North Ruri</td>
<td>-</td>
</tr>
<tr>
<td>N734</td>
<td>Fenite</td>
<td>N.E. North Ruri</td>
<td>-</td>
</tr>
<tr>
<td>N801</td>
<td>Alvikite</td>
<td>S. spur, North Ruri</td>
<td>Dyke</td>
</tr>
</tbody>
</table>

Appendix Table 1, (continued).
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>U88</td>
<td>Ijolite</td>
<td>West Usaki</td>
<td>Central ijolite</td>
</tr>
<tr>
<td>U149</td>
<td>Micro-ijolite</td>
<td>Waiga School Hill</td>
<td>-</td>
</tr>
<tr>
<td>U156</td>
<td>Phonolite</td>
<td>Kimbo</td>
<td>Lava</td>
</tr>
<tr>
<td>U162</td>
<td>Phonolite</td>
<td>Kimbo</td>
<td>Lava</td>
</tr>
<tr>
<td>U207</td>
<td>Micro-ijolite</td>
<td>Nyakoya</td>
<td>Marginal ijolite intrusion</td>
</tr>
<tr>
<td>U278</td>
<td>Phonolite</td>
<td>Kisumu</td>
<td>Lava</td>
</tr>
<tr>
<td>U296</td>
<td>Phonolite</td>
<td>South Usaki</td>
<td>Plug</td>
</tr>
<tr>
<td>U301</td>
<td>Phonolite</td>
<td>Cotrateng</td>
<td>Plug</td>
</tr>
<tr>
<td>U345</td>
<td>Micro-ijolite</td>
<td>East Usaki</td>
<td>Marginal ijolite intrusion</td>
</tr>
<tr>
<td>U369</td>
<td>Ijolite</td>
<td>Got Oyoma</td>
<td>Central ijolite intrusion</td>
</tr>
<tr>
<td>U382</td>
<td>Phonolite</td>
<td>Sondu-Kericho</td>
<td>Lava</td>
</tr>
<tr>
<td>U416</td>
<td>Ferruginous alvikite</td>
<td>North Kimbo</td>
<td>Dyke</td>
</tr>
<tr>
<td>U455</td>
<td>Sovite</td>
<td>Sokolo</td>
<td>Massive intrusion</td>
</tr>
<tr>
<td>U595</td>
<td>Ferruginous alvikite</td>
<td>East Nyamaji</td>
<td>6&quot; dyke</td>
</tr>
<tr>
<td>U602</td>
<td>Alvikite</td>
<td>Nyamaji</td>
<td>Dyke</td>
</tr>
<tr>
<td>U692</td>
<td>Alvikite</td>
<td>Uyi</td>
<td>Vein</td>
</tr>
<tr>
<td>U771</td>
<td>Sovite</td>
<td>Sokolo</td>
<td>2' dyke</td>
</tr>
<tr>
<td>U774</td>
<td>Alvikite</td>
<td>Sokolo</td>
<td>Dyke cutting carbonatite</td>
</tr>
<tr>
<td>U782</td>
<td>Alvikite</td>
<td>Sokolo</td>
<td>Dyke</td>
</tr>
<tr>
<td>U783</td>
<td>Alvikite</td>
<td>Sokolo</td>
<td>Dyke</td>
</tr>
<tr>
<td>U784</td>
<td>Sovite</td>
<td>Sokolo</td>
<td>Massive carbonatite</td>
</tr>
<tr>
<td>U786</td>
<td>Alvikite</td>
<td>Sokolo</td>
<td>Dyke</td>
</tr>
<tr>
<td>U788</td>
<td>Ferruginous alvikite</td>
<td>Sokolo summit</td>
<td>Dyke</td>
</tr>
<tr>
<td>U839</td>
<td>Ferruginous alvikite</td>
<td>Sokolo</td>
<td>Dyke</td>
</tr>
</tbody>
</table>

Appendix Table 1, (continued).
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>U842</td>
<td>Sovite</td>
<td>Uyi</td>
<td>Massive carbonatite</td>
</tr>
<tr>
<td>U847</td>
<td>Sovite</td>
<td>Uyi</td>
<td>Massive carbonatite</td>
</tr>
<tr>
<td>U875</td>
<td>Sovite</td>
<td>Uyi</td>
<td>Massive carbonatite</td>
</tr>
<tr>
<td>U890</td>
<td>Melanephelinite</td>
<td>Ogoro</td>
<td>Lava</td>
</tr>
<tr>
<td>U926</td>
<td>Melanephelinite</td>
<td>Omuga</td>
<td>Lava</td>
</tr>
<tr>
<td>U954</td>
<td>Ferruginous alvikite</td>
<td>Sokolo</td>
<td>Patchy massive carbonatite</td>
</tr>
<tr>
<td>U1054</td>
<td>Urtite</td>
<td>Waiga School Hill</td>
<td>Ijolite intrusion</td>
</tr>
<tr>
<td>U1099</td>
<td>Pyroxenite</td>
<td>Central Usaki</td>
<td>Ijolite intrusion</td>
</tr>
<tr>
<td>U1111</td>
<td>Urtite</td>
<td>Otaragoge</td>
<td>Ijolite intrusion</td>
</tr>
<tr>
<td>U1229</td>
<td>Sovite</td>
<td>Sokolo</td>
<td>Massive carbonatite</td>
</tr>
</tbody>
</table>

**BUDEDA COMPLEX**

<table>
<thead>
<tr>
<th>SuB7a</th>
<th>Ijolite</th>
<th>Siroko</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuB27</td>
<td>Melteijite</td>
<td>Siroko</td>
<td>-</td>
</tr>
<tr>
<td>SuB218</td>
<td>Fenite</td>
<td>North summit, Budea Hill</td>
<td>-</td>
</tr>
<tr>
<td>SuB223</td>
<td>Fenite</td>
<td>Spur, N.W. Galala Hill</td>
<td>-</td>
</tr>
<tr>
<td>SuB232</td>
<td>Ijolite</td>
<td>Summit, Galala Hill</td>
<td>-</td>
</tr>
<tr>
<td>SuB242</td>
<td>Fenite</td>
<td>South Galala Hill</td>
<td>-</td>
</tr>
<tr>
<td>SuB247</td>
<td>Cancrinite-syenite</td>
<td>South Galala Hill</td>
<td>-</td>
</tr>
<tr>
<td>SuB254</td>
<td>Sovite</td>
<td>Main carbonatite intrusive</td>
<td>Massive carbonatite</td>
</tr>
<tr>
<td>SuB262</td>
<td>Cancrinite-syenite</td>
<td>Disiyi River</td>
<td>-</td>
</tr>
</tbody>
</table>

*Appendix Table 1, (continued)*
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuB265</td>
<td>Cancrinite-syenite</td>
<td>Disiyi Island</td>
<td></td>
</tr>
<tr>
<td>SuB266</td>
<td>Ijolite</td>
<td>Disiyi River</td>
<td>Xenolith</td>
</tr>
<tr>
<td>SuB269</td>
<td>Phonolite</td>
<td>Disiyi River</td>
<td></td>
</tr>
<tr>
<td>SuB279</td>
<td>Fenite</td>
<td>East slope, Budeda Hill</td>
<td></td>
</tr>
<tr>
<td>SuB302</td>
<td>Ijolite</td>
<td>Bundagala Hill</td>
<td></td>
</tr>
<tr>
<td>SuB311</td>
<td>Nepheline-syenite</td>
<td>Siroko</td>
<td></td>
</tr>
</tbody>
</table>

**BUDEDA COMPLEX, (continued).**

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuN5</td>
<td>Urtite</td>
<td>W. of Lokopoi</td>
<td></td>
</tr>
<tr>
<td>SuN35</td>
<td>Pyroxenite</td>
<td>W. of Lokopoi</td>
<td></td>
</tr>
<tr>
<td>SuN63</td>
<td>Urtite</td>
<td>W. of Lokopoi</td>
<td></td>
</tr>
<tr>
<td>SuN102</td>
<td>Feldspar rock</td>
<td>W. of Lokopoi</td>
<td></td>
</tr>
<tr>
<td>SuN106</td>
<td>Nepheline-syenite</td>
<td>S. of Lokopoi</td>
<td></td>
</tr>
<tr>
<td>SuN521</td>
<td>Ijolite</td>
<td>E. of Lokopoi</td>
<td></td>
</tr>
</tbody>
</table>

**NAPAK COMPLEX**

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

**TORORO COMPLEX**

Appendix Table 1, (continued).
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuTo536</td>
<td>Fenite</td>
<td>W. of carbonatite lower quarry</td>
<td>-</td>
</tr>
<tr>
<td>SuTo581</td>
<td>Alvikite</td>
<td>Limekiln Hill</td>
<td>Dyke</td>
</tr>
<tr>
<td>SuTo590</td>
<td>Ijolite</td>
<td>Limekiln Hill</td>
<td>-</td>
</tr>
<tr>
<td>SuTo594</td>
<td>Sovite</td>
<td>Limekiln Hill</td>
<td>Massive carbonatite</td>
</tr>
<tr>
<td>SuTo595</td>
<td>Sovite</td>
<td>Limekiln Hill</td>
<td>Massive carbonatite</td>
</tr>
<tr>
<td>SuTo598</td>
<td>Fenite</td>
<td>S.E. slope, Limekiln Hill</td>
<td>-</td>
</tr>
</tbody>
</table>

**TORORO COMPLEX**

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Form of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuT125</td>
<td>Phonolite</td>
<td>North slope, Toror Hills</td>
<td>-</td>
</tr>
<tr>
<td>SuT134</td>
<td>Orthoclase</td>
<td>North Ridge</td>
<td>Dyke</td>
</tr>
</tbody>
</table>

*Appendix Table 1. (continued)*
Table 2a. 

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>major mineral (greater than 1%).</td>
</tr>
<tr>
<td>m</td>
<td>minor mineral (less than 1%).</td>
</tr>
<tr>
<td>a</td>
<td>accessory mineral.</td>
</tr>
</tbody>
</table>

Tables 2b (i) - (iii)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM</td>
<td>greater than 50%</td>
</tr>
<tr>
<td>M</td>
<td>20% - 50%</td>
</tr>
<tr>
<td>Mm</td>
<td>5% - 20%</td>
</tr>
<tr>
<td>am</td>
<td>1% - 5%</td>
</tr>
<tr>
<td>m</td>
<td>0.5% - 1%</td>
</tr>
<tr>
<td>a</td>
<td>accessory mineral.</td>
</tr>
<tr>
<td>Specimen Number</td>
<td>Calcite</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
</tr>
<tr>
<td>HFR19</td>
<td>M m a</td>
</tr>
<tr>
<td>HF209</td>
<td>M m a</td>
</tr>
<tr>
<td>HF212</td>
<td>M m a</td>
</tr>
<tr>
<td>HC258</td>
<td>M m a</td>
</tr>
<tr>
<td>HC366</td>
<td>M m a</td>
</tr>
<tr>
<td>HC367</td>
<td>M m a</td>
</tr>
<tr>
<td>HF462</td>
<td>M m a</td>
</tr>
<tr>
<td>HF508</td>
<td>M m a</td>
</tr>
</tbody>
</table>

Appendix Table 2a. Mineralogy of analysed carbonatites. See key to Table 2 for explanation of symbols.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Calcite</th>
<th>Opaque Oxide</th>
<th>Apatite</th>
<th>Pyrochlore</th>
<th>Biotite</th>
<th>Aegirine</th>
<th>Orthoclase</th>
<th>Fluorite</th>
<th>Barite</th>
<th>Monazite</th>
<th>Limonite</th>
<th>Amphibole</th>
<th>Nepheline</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF559</td>
<td>M</td>
<td>M</td>
<td>a</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC594</td>
<td>M</td>
<td>M</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC597</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HF603</td>
<td>M</td>
<td>M</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HF609</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC613</td>
<td>M</td>
<td>M</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC614</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HF636</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HF649</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC659</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Appendix Table 2a, (continued). Mineralogy of analysed carbonatites. See key to Table 2 for explanation of symbols.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Calcite</th>
<th>Opaque Oxide</th>
<th>Apatite</th>
<th>Pyrochlore</th>
<th>Biotite</th>
<th>Aegirine</th>
<th>Orthoclase</th>
<th>Fluorite</th>
<th>Barite</th>
<th>Monazite</th>
<th>Limonite</th>
<th>Amphibole</th>
<th>Nepheline</th>
</tr>
</thead>
<tbody>
<tr>
<td>U744</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U782</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U783</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U786</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Melilite-pseudomorph carbonatites.

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Calcite</th>
<th>Opaque Oxide</th>
<th>Apatite</th>
<th>Pyrochlore</th>
<th>Biotite</th>
<th>Aegirine</th>
<th>Orthoclase</th>
<th>Fluorite</th>
<th>Barite</th>
<th>Monazite</th>
<th>Limonite</th>
<th>Amphibole</th>
<th>Nepheline</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC396</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC401</td>
<td>M</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC639</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ferruginous alvikites.

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Calcite</th>
<th>Opaque Oxide</th>
<th>Apatite</th>
<th>Pyrochlore</th>
<th>Biotite</th>
<th>Aegirine</th>
<th>Orthoclase</th>
<th>Fluorite</th>
<th>Barite</th>
<th>Monazite</th>
<th>Limonite</th>
<th>Amphibole</th>
<th>Nepheline</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF115</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF199</td>
<td>M</td>
<td>M</td>
<td>a</td>
<td>m</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix Table 2a, (continued). Mineralogy of analysed carbonatites. See key to Table 2 for explanation of symbols.
<table>
<thead>
<tr>
<th></th>
<th>Pyroxene</th>
<th>Nepheline</th>
<th>Feldspar</th>
<th>Garnet</th>
<th>Sphene</th>
<th>Cancrinite</th>
<th>Apatite</th>
<th>Calcite</th>
<th>Magnetite</th>
<th>Mica</th>
<th>Analcime</th>
<th>Wollastonite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HC988</strong></td>
<td>MM</td>
<td>m</td>
<td>a</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>N683</strong></td>
<td>MM</td>
<td>Mm</td>
<td>-</td>
<td>m</td>
<td>a</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>N694</strong></td>
<td>MM</td>
<td>m</td>
<td>-</td>
<td>m</td>
<td>a</td>
<td>a</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>U1999</strong></td>
<td>MM</td>
<td>Mm</td>
<td>am</td>
<td>am</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td><strong>SuB27</strong></td>
<td>MM</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td><strong>SuN35</strong></td>
<td>MM</td>
<td>m</td>
<td>-</td>
<td>m</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td><strong>HC930</strong></td>
<td>Mm</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>SuT0590</strong></td>
<td>M</td>
<td>M</td>
<td>am</td>
<td>am</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td><strong>SuB7a</strong></td>
<td>Mm</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td><strong>SuB266</strong></td>
<td>M</td>
<td>M</td>
<td>am</td>
<td>am</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td><strong>U211</strong></td>
<td>m</td>
<td>MM</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>m</td>
</tr>
<tr>
<td><strong>U1054</strong></td>
<td>m</td>
<td>MM</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Appendix Table 2b(i).* Mineralogy of analysed peralkaline intrusive silicate rocks. See key for explanation of symbols.
<table>
<thead>
<tr>
<th></th>
<th>Pyroxene</th>
<th>Nepheline</th>
<th>Feldspar</th>
<th>Garnet</th>
<th>Sphene</th>
<th>Cancrinite</th>
<th>Apatite</th>
<th>Calcite</th>
<th>Magnetite</th>
<th>Mica</th>
<th>Analcime</th>
<th>Wollastonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1111</td>
<td>m</td>
<td>M</td>
<td>m</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>am</td>
</tr>
<tr>
<td>SuN5</td>
<td>m</td>
<td>M</td>
<td>m</td>
<td>a</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>SuN63</td>
<td>m</td>
<td>M</td>
<td>am</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>HC309</td>
<td>m</td>
<td>M</td>
<td>m</td>
<td>M</td>
<td>am</td>
<td>-</td>
<td>a</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC324</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>am</td>
<td>-</td>
<td>a</td>
<td>a</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC741</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>am</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC993</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>a</td>
<td>am</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>U88</td>
<td>m</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
</tr>
<tr>
<td>U369</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SuN521</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>HC323</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>M</td>
<td>m</td>
<td>-</td>
<td>a</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC934</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>M</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC964</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>M</td>
<td>am</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC999</td>
<td>am</td>
<td>M</td>
<td>m</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SuB232</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>SuB302</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>

Appendix Table 2b(i), (continued). Mineralogy of analysed peralkaline silicate rocks.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Pyroxene</th>
<th>Nepheline</th>
<th>Feldspar</th>
<th>Garnet</th>
<th>Sphene</th>
<th>Cancrinite</th>
<th>Apatite</th>
<th>Calcite</th>
<th>Magnetite</th>
<th>Mica</th>
<th>Analcime</th>
<th>Wollastonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>N225</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N266</td>
<td>m</td>
<td>m</td>
<td>M</td>
<td>am</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N464</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td></td>
<td>-</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N503</td>
<td>M</td>
<td>m</td>
<td>M</td>
<td>am</td>
<td>-</td>
<td>am</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N688</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuTo38</td>
<td>M</td>
<td>m</td>
<td>M</td>
<td></td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuB247</td>
<td>m</td>
<td>m</td>
<td>M</td>
<td>am</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuB262</td>
<td>m</td>
<td>M</td>
<td>M</td>
<td></td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuB265</td>
<td>m</td>
<td>M</td>
<td>M</td>
<td></td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuB311</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>am</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuN106</td>
<td>m</td>
<td>m</td>
<td>M</td>
<td></td>
<td>-</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U149</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td></td>
<td>-</td>
<td>am</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>am</td>
</tr>
<tr>
<td>U207</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U242</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>am</td>
<td>a</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U345</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix Table 2b(i), (continued). Mineralogy of peralkaline intrusive silicate rocks.
<p>| | | | | | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pyroxene</td>
<td>Nepheline</td>
<td>Feldspar</td>
<td>Garnet</td>
<td>Sphene</td>
<td>Cancrinite</td>
<td>Apatite</td>
<td>Calcite</td>
<td>Magnetite</td>
<td>Mica</td>
<td>Analcime</td>
<td>Wollastonite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N593</td>
<td>MM</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N595</td>
<td>MM</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N712</td>
<td>MM</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U156</td>
<td>m</td>
<td>MMM</td>
<td>-</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF89a</td>
<td>m</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC583</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC761b</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC1005</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N85</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>M</td>
<td>a</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U162</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N90</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N185</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U48</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U296</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U301</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U382</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix Table 2b(ii). MINERALOGY OF PHONOLITIC ROCKS. See key to Table 2 for explanation of symbols.
<table>
<thead>
<tr>
<th>Pyroxene</th>
<th>Nepheline</th>
<th>Feldspar</th>
<th>Garnet</th>
<th>Sphene</th>
<th>Cancrinite</th>
<th>Apatite</th>
<th>Calcite</th>
<th>Magnetite</th>
<th>Mica</th>
<th>Analcime</th>
<th>Quartz</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC54</td>
<td>am</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
</tr>
<tr>
<td>HC653</td>
<td>m</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>M</td>
</tr>
<tr>
<td>HC743</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC744</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>m</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC797</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>am</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HC800</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>m</td>
</tr>
<tr>
<td>HC825</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N729</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N734</td>
<td>M</td>
<td>-</td>
<td>M</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Appendix Table 2b(iii). Mineralogy of fenitic 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.

<table>
<thead>
<tr>
<th>Element/oxide</th>
<th>Detection Limit</th>
<th>Upper limit of Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe$_2$O$_3$</td>
<td>0.1%</td>
<td>30%</td>
</tr>
<tr>
<td>MnO</td>
<td>0.1%</td>
<td>3%</td>
</tr>
<tr>
<td>MgO</td>
<td>0.1%</td>
<td>10%</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.1%</td>
<td>5%</td>
</tr>
<tr>
<td>Ba</td>
<td>10ppm</td>
<td>40000ppm</td>
</tr>
<tr>
<td>Li</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Mo</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Nb</td>
<td>50ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Sr</td>
<td>10ppm</td>
<td>40000ppm</td>
</tr>
<tr>
<td>V</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Zn</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Zr</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Ce</td>
<td>50ppm</td>
<td>10000ppm</td>
</tr>
<tr>
<td>La</td>
<td>35ppm</td>
<td>6000ppm</td>
</tr>
<tr>
<td>Y</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Dy</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Cr</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Ni</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Cu</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Pb</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Co</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Specimen Number</td>
<td>( \text{FeO} ) wt. %</td>
<td>( \text{MnO} ) wt. %</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>HFR19</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>HF84</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>HC338</td>
<td>-</td>
<td>0.2</td>
</tr>
<tr>
<td>HCG965</td>
<td>2.1</td>
<td>0.21</td>
</tr>
<tr>
<td>N177</td>
<td>3.7</td>
<td>0.41</td>
</tr>
<tr>
<td>U455</td>
<td>2.2</td>
<td>0.33</td>
</tr>
<tr>
<td>U771</td>
<td>2.7</td>
<td>0.1</td>
</tr>
<tr>
<td>U784</td>
<td>1.7</td>
<td>0.39</td>
</tr>
<tr>
<td>U842</td>
<td>1.0</td>
<td>0.33</td>
</tr>
<tr>
<td>U847</td>
<td>2.7</td>
<td>0.34</td>
</tr>
<tr>
<td>U875</td>
<td>0.4</td>
<td>0.16</td>
</tr>
<tr>
<td>U1229</td>
<td>1.7</td>
<td>0.82</td>
</tr>
<tr>
<td>SUB254</td>
<td>6.7</td>
<td>0.32</td>
</tr>
</tbody>
</table>

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

- element not detected, nd element not determined.

Elements Ge, Ge and Be not detected.
| Specimen | FeO | MnO | MgO | TiO | Ba | Li | Mo | Nb | Sr | V | Zn | ZR | Ce | La | Nd | Dy | Y | Cr | Ni | Cu | Pb | Co |
|----------|-----|-----|-----|-----|----|----|----|----|----|---|----|----|----|----|----|----|---|---|----|----|-----|-----|-----|
| 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 | 3000| 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 | 1200| 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 sersite and alvikite carbonatites from W. Kenya and E. Uganda.

- Element not detected, nd analysis not attempted. Elements Gr, Ge and Bc not detected.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>TiO₂</th>
<th>Be</th>
<th>Li</th>
<th>Mo</th>
<th>Nb</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Ce</th>
<th>La</th>
<th>Nd</th>
<th>Y</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Pb</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt%</td>
<td>wt%</td>
<td>wt%</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td>HC597</td>
<td>6.0</td>
<td>1.9</td>
<td>2.2</td>
<td>-</td>
<td>6400</td>
<td>30</td>
<td>25</td>
<td>700</td>
<td>1620</td>
<td>100</td>
<td>210</td>
<td>215</td>
<td>2933</td>
<td>1831</td>
<td>627</td>
<td>97</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>HF603</td>
<td>5.1</td>
<td>0.75</td>
<td>1.75</td>
<td>-</td>
<td>4460</td>
<td>30</td>
<td>30</td>
<td>675</td>
<td>1150</td>
<td>55</td>
<td>90</td>
<td>40</td>
<td>2295</td>
<td>994</td>
<td>704</td>
<td>112</td>
<td>8</td>
<td>8</td>
<td>-</td>
<td>60</td>
<td>12</td>
</tr>
<tr>
<td>HF609</td>
<td>13.0</td>
<td>2.15</td>
<td>0.3</td>
<td>0.15</td>
<td>4550</td>
<td>20</td>
<td>70</td>
<td>500</td>
<td>940</td>
<td>65</td>
<td>100</td>
<td>35</td>
<td>2750</td>
<td>1234</td>
<td>995</td>
<td>86</td>
<td>10</td>
<td>5</td>
<td>30</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>HC613</td>
<td>5.3</td>
<td>0.95</td>
<td>1.9</td>
<td>0.1</td>
<td>1280</td>
<td>25</td>
<td>20</td>
<td>425</td>
<td>1190</td>
<td>110</td>
<td>465</td>
<td>50</td>
<td>1350</td>
<td>1060</td>
<td>777</td>
<td>89</td>
<td>8</td>
<td>10</td>
<td>5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>HC614</td>
<td>18.4</td>
<td>0.87</td>
<td>-</td>
<td>0.35</td>
<td>680</td>
<td>15</td>
<td>5</td>
<td>850</td>
<td>545</td>
<td>240</td>
<td>50</td>
<td>50</td>
<td>2908</td>
<td>1156</td>
<td>72</td>
<td>50</td>
<td>5</td>
<td>10</td>
<td>-</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>HC629</td>
<td>1.7</td>
<td>0.32</td>
<td>-</td>
<td>-</td>
<td>1520</td>
<td>-</td>
<td>-</td>
<td>350</td>
<td>840</td>
<td>65</td>
<td>35</td>
<td>30</td>
<td>1500</td>
<td>675</td>
<td>560</td>
<td>150</td>
<td>8</td>
<td>20</td>
<td>-</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>HF636</td>
<td>5.5</td>
<td>0.81</td>
<td>-</td>
<td>0.1</td>
<td>1180</td>
<td>25</td>
<td>25</td>
<td>350</td>
<td>1025</td>
<td>150</td>
<td>110</td>
<td>70</td>
<td>1600</td>
<td>907</td>
<td>881</td>
<td>88</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>HF649</td>
<td>6.4</td>
<td>3.2</td>
<td>0.5</td>
<td>0.35</td>
<td>4050</td>
<td>50</td>
<td>5</td>
<td>400</td>
<td>1620</td>
<td>100</td>
<td>75</td>
<td>80</td>
<td>858</td>
<td>263</td>
<td>17</td>
<td>25</td>
<td>10</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC659</td>
<td>1.9</td>
<td>0.76</td>
<td>-</td>
<td>0.15</td>
<td>2450</td>
<td>25</td>
<td>15</td>
<td>200</td>
<td>830</td>
<td>30</td>
<td>50</td>
<td>-</td>
<td>1456</td>
<td>627</td>
<td>559</td>
<td>43</td>
<td>6</td>
<td>5</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC698</td>
<td>18.4</td>
<td>0.89</td>
<td>1.8</td>
<td>0.5</td>
<td>520</td>
<td>15</td>
<td>5</td>
<td>1000</td>
<td>995</td>
<td>260</td>
<td>285</td>
<td>235</td>
<td>1911</td>
<td>732</td>
<td>662</td>
<td>47</td>
<td>16</td>
<td>45</td>
<td>-</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>N24</td>
<td>2.2</td>
<td>&gt; 3.0</td>
<td>-</td>
<td>-</td>
<td>4520</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>1340</td>
<td>215</td>
<td>240</td>
<td>-</td>
<td>7500</td>
<td>3500</td>
<td>1400</td>
<td>360</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>N142</td>
<td>1.3</td>
<td>&gt; 3.0</td>
<td>0.5</td>
<td>-</td>
<td>680</td>
<td>-</td>
<td>35</td>
<td>1000</td>
<td>1200</td>
<td>230</td>
<td>70</td>
<td>65</td>
<td>4900</td>
<td>260</td>
<td>1200</td>
<td>600</td>
<td>6</td>
<td>5</td>
<td>-</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

Appendix_table_3a (continued). Analyses of olivikite carbonatites from W. Kenya and E. Uganda, element not detected nd analysis not attempted. Elements Dy, Er, Ce and Be not detected.
| Specimen | FeO | MnO | MgO | TiO₂ | Ba | Li | Mo | Nb | Sr | V | Zn | Zr | Ce | La | Nd | Y | Cr | Ni | Cu | Pb | Co |
|----------|-----|-----|-----|------|----|----|----|----|----|---|----|----|----|----|----|---|---|---|---|---|---|---|
| Number   | wt. % | wt. % | wt. % | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | 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 | 1250 | 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  | 4.4 | 0.93 | 1.6 | 0.5 | 520 | - | - | 1090 | 165 | 270 | - | 940 | 580 | 317 | 70 | - | 10 | 10 | - | - |

Appendix Table 3e (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 | Fe₂O₃ | MnO | MgO | TiO₂ | Ba | Li | Mo | Nb | Sr | V | Zn | Zr | Ce | La | Nd | Y | Cr | Ni | Cu | Pb | Co |
|----------|-------|-----|-----|------|----|----|----|----|----|---|----|----|----|----|----|---|---|---|----|----|----|----|
| Number   | wt. % | wt. % | wt. % | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm |
| 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 | 5 | 55 |

**Melilite-pseudomorph carbonatites.**

**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 | 10 | 40 | 150 |
| HF490    | 2.0   | >3.0 | 0.8 | - | >40000 | 25 | 10 | 700 | 800 | 180 | 330 | 300 | 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.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>TiO₂</th>
<th>Be</th>
<th>Li</th>
<th>Mo</th>
<th>Nb</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Ce</th>
<th>La</th>
<th>Nd</th>
<th>Y</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Pb</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N339</td>
<td>10.0</td>
<td>3.08</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>-</td>
<td>1300</td>
<td>110</td>
<td>220</td>
<td>-</td>
<td>&gt;10000</td>
<td>&gt;6000</td>
<td>900</td>
<td>220</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U416</td>
<td>3.0</td>
<td>&gt;3.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td>240</td>
<td>860</td>
<td>90</td>
<td>180</td>
<td>60</td>
<td>5720</td>
<td>5250</td>
<td>260</td>
<td>130</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U595</td>
<td>&gt;30.0</td>
<td>3.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1220</td>
<td>35</td>
<td>20</td>
<td>550</td>
<td>710</td>
<td>60</td>
<td>130</td>
<td>40</td>
<td>4583</td>
<td>1339</td>
<td>463</td>
<td>ND</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>U788</td>
<td>5.8</td>
<td>1.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2280</td>
<td>-</td>
<td>-</td>
<td>230</td>
<td>180</td>
<td>140</td>
<td>-</td>
<td>821</td>
<td>111</td>
<td>372</td>
<td>nd</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U839</td>
<td>20.2</td>
<td>1.7</td>
<td>0.4</td>
<td>0.4</td>
<td>-</td>
<td>2240</td>
<td>-</td>
<td>-</td>
<td>1150</td>
<td>860</td>
<td>940</td>
<td>480</td>
<td>30</td>
<td>4313</td>
<td>1230</td>
<td>1230</td>
<td>80</td>
<td>-</td>
<td>25</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>U954</td>
<td>4.6</td>
<td>2.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2640</td>
<td>-</td>
<td>10</td>
<td>980</td>
<td>170</td>
<td>110</td>
<td>20</td>
<td>3380</td>
<td>1560</td>
<td>884</td>
<td>110</td>
<td>15</td>
<td>30</td>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Carbonatitic Breccias.**

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>TiO₂</th>
<th>Be</th>
<th>Li</th>
<th>Mo</th>
<th>Nb</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Ce</th>
<th>La</th>
<th>Nd</th>
<th>Y</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Pb</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td>HF160</td>
<td>9.4</td>
<td>0.6</td>
<td>0.5</td>
<td>1.9</td>
<td>2000</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td>180</td>
<td>140</td>
<td>60</td>
<td>125</td>
<td>590</td>
<td>350</td>
<td>40</td>
<td>nd</td>
<td>nd</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HF195</td>
<td>7.0</td>
<td>0.6</td>
<td>2.2</td>
<td>1.3</td>
<td>4900</td>
<td>25</td>
<td>5200</td>
<td>1015</td>
<td>120</td>
<td>185</td>
<td>80</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>15</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>HF230</td>
<td>5.6</td>
<td>2.7</td>
<td>1.3</td>
<td>1.0</td>
<td>660</td>
<td>15</td>
<td>-</td>
<td>240</td>
<td>70</td>
<td>110</td>
<td>100</td>
<td>500</td>
<td>295</td>
<td>118</td>
<td>25</td>
<td>nd</td>
<td>nd</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>HF377</td>
<td>13.7</td>
<td>2.3</td>
<td>0.5</td>
<td>0.4</td>
<td>5360</td>
<td>-</td>
<td>10</td>
<td>480</td>
<td>620</td>
<td>170</td>
<td>240</td>
<td>40</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>HF384</td>
<td>9.5</td>
<td>0.2</td>
<td>0.9</td>
<td>1.6</td>
<td>960</td>
<td>45</td>
<td>-</td>
<td>65</td>
<td>95</td>
<td>255</td>
<td>50</td>
<td>125</td>
<td>-</td>
<td>100</td>
<td>nd</td>
<td>nd</td>
<td>30</td>
<td>20</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF621</td>
<td>9.6</td>
<td>0.9</td>
<td>0.7</td>
<td>2.2</td>
<td>2800</td>
<td>-</td>
<td>-</td>
<td>350</td>
<td>170</td>
<td>200</td>
<td>80</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>10</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

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

Elements Ge, Dy, Ge, and Be not detected in these samples.*
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO₂</th>
<th>MgO</th>
<th>TiO₂</th>
<th>MnO</th>
<th>Be</th>
<th>B</th>
<th>Co</th>
<th>Cu</th>
<th>Mo</th>
<th>Pb</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>岩相</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>---</td>
</tr>
<tr>
<td>HC258</td>
<td>&lt; 0.05</td>
<td>0.35</td>
<td>2.2</td>
<td>1.0</td>
<td>190</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>3720</td>
<td>1600</td>
<td>70</td>
<td>Alvikite</td>
</tr>
<tr>
<td>HF462</td>
<td>&lt; 0.05</td>
<td>0.1</td>
<td>2.4</td>
<td>0.6</td>
<td>1250</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>130</td>
<td>270</td>
<td>4720</td>
<td>1050</td>
<td>20</td>
</tr>
<tr>
<td>HC613</td>
<td>&lt; 0.05</td>
<td>0.1</td>
<td>1.9</td>
<td>0.8</td>
<td>660</td>
<td>20</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>58</td>
<td>155</td>
<td>4600</td>
<td>1800</td>
<td>20</td>
</tr>
<tr>
<td>HC614</td>
<td>&lt; 0.05</td>
<td>0.1</td>
<td>2.1</td>
<td>0.7</td>
<td>410</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>40</td>
<td>70</td>
<td>4560</td>
<td>1250</td>
<td>10</td>
</tr>
<tr>
<td>HC629</td>
<td>&lt; 0.05</td>
<td>0.2</td>
<td>1.4</td>
<td>1.0</td>
<td>1200</td>
<td>30</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>45</td>
<td>275</td>
<td>3730</td>
<td>1080</td>
<td>40</td>
</tr>
<tr>
<td>HC649</td>
<td>&lt; 0.05</td>
<td>0.5</td>
<td>&gt;5.0</td>
<td>0.6</td>
<td>1750</td>
<td>20</td>
<td>35</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>250</td>
<td>2700</td>
<td>780</td>
<td>55</td>
<td>Alvikite</td>
</tr>
<tr>
<td>U389</td>
<td>&lt; 0.05</td>
<td>0.1</td>
<td>1.1</td>
<td>0.4</td>
<td>680</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>50</td>
<td>6500</td>
<td>950</td>
<td>10</td>
<td>Alvikite</td>
</tr>
<tr>
<td>U783</td>
<td>&lt; 0.05</td>
<td>0.4</td>
<td>1.0</td>
<td>1.9</td>
<td>2250</td>
<td>20</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>120</td>
<td>490</td>
<td>6200</td>
<td>1900</td>
<td>20</td>
<td>Alvikite</td>
</tr>
<tr>
<td>N348</td>
<td>&lt; 0.05</td>
<td>0.1</td>
<td>4.3</td>
<td>0.8</td>
<td>370</td>
<td>10</td>
<td>20</td>
<td>5</td>
<td>5</td>
<td>170</td>
<td>25</td>
<td>1800</td>
<td>1940</td>
<td>10</td>
<td>Alvikite</td>
</tr>
<tr>
<td>N427</td>
<td>&lt; 0.05</td>
<td>1.6</td>
<td>0.1</td>
<td>1.5</td>
<td>2000</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>110</td>
<td>300</td>
<td>900</td>
<td>250</td>
<td>1380</td>
<td>25</td>
<td>Alvikite</td>
</tr>
</tbody>
</table>

Appendix Table 3b(i). Spectrometric analyses of magnetite from carbonatites. The elements Cr, Bi, Ge, Ni, Sn, Ag, Li, and Ge were below the limits of detection.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>$\text{Fe}_2\text{O}_3$</th>
<th>MgO</th>
<th>MnO</th>
<th>Be</th>
<th>Pb</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Rock</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF84</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>460</td>
<td>2200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Sovite</td>
<td></td>
</tr>
<tr>
<td>HC338</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
<td>810</td>
<td>4000</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Sovite</td>
<td></td>
</tr>
<tr>
<td>HC965</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>460</td>
<td>4000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Sovite</td>
<td></td>
</tr>
<tr>
<td>U771</td>
<td>-</td>
<td>0.3</td>
<td>0.2</td>
<td>250</td>
<td>2440</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Sovite</td>
<td></td>
</tr>
<tr>
<td>HC258</td>
<td>0.55</td>
<td>0.3</td>
<td>0.1</td>
<td>3000</td>
<td>890</td>
<td>65</td>
<td>95</td>
<td></td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
<tr>
<td>HC366</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>1660</td>
<td>1290</td>
<td>55</td>
<td>15</td>
<td>13</td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
<tr>
<td>HF462</td>
<td>0.9</td>
<td>1.6</td>
<td>0.3</td>
<td>2560</td>
<td>1390</td>
<td>-</td>
<td>20</td>
<td>-</td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
<tr>
<td>HF508</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>800</td>
<td>1620</td>
<td>-</td>
<td>70</td>
<td>-</td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
<tr>
<td>HC509</td>
<td>-</td>
<td>0.2</td>
<td>0.3</td>
<td>560</td>
<td>2480</td>
<td>20</td>
<td>10</td>
<td>-</td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
<tr>
<td>HC613</td>
<td>-</td>
<td>0.2</td>
<td>0.2</td>
<td>400</td>
<td>1580</td>
<td>40</td>
<td>120</td>
<td>-</td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
<tr>
<td>HC629</td>
<td>-</td>
<td>0.2</td>
<td>0.2</td>
<td>940</td>
<td>1250</td>
<td>20</td>
<td>25</td>
<td>15</td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
<tr>
<td>HC649</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>860</td>
<td>2400</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Alvikite</td>
<td></td>
</tr>
</tbody>
</table>

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.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>Fe$_2$O$_3$</th>
<th>MgO</th>
<th>MnO</th>
<th>Ba</th>
<th>Pb</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>Type</td>
</tr>
<tr>
<td>u783</td>
<td>2.4</td>
<td>0.7</td>
<td>0.7</td>
<td>450</td>
<td>10</td>
<td>1140</td>
<td>15</td>
<td>340</td>
<td>35</td>
<td>Alvikite</td>
</tr>
<tr>
<td>u786</td>
<td>0.9</td>
<td>0.4</td>
<td>0.4</td>
<td>260</td>
<td>-</td>
<td>1480</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>Alvikite</td>
</tr>
<tr>
<td>u842</td>
<td>0.5</td>
<td>-</td>
<td>0.1</td>
<td>1050</td>
<td>-</td>
<td>1040</td>
<td>-</td>
<td>45</td>
<td>-</td>
<td>Alvikite</td>
</tr>
<tr>
<td>u786</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
<td>410</td>
<td>-</td>
<td>2800</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Alvikite</td>
</tr>
<tr>
<td>N348</td>
<td>0.8</td>
<td>-</td>
<td>0.6</td>
<td>960</td>
<td>-</td>
<td>1480</td>
<td>-</td>
<td>78</td>
<td>-</td>
<td>Alvikite</td>
</tr>
</tbody>
</table>

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.
| \( \text{Al}_2\text{O}_3 \) | \( \text{CaO} \) | \( \text{Fe}_2\text{O}_3 \cdot \text{K}_2\text{O} \) | \( \text{Mg} \) | \( \text{MnO} \) | \( \text{TiO}_2 \) | \( \text{Ba} \) | \( \text{Co} \) | \( \text{Cr} \) | \( \text{Cu} \) | \( \text{Ga} \) | \( \text{Li} \) | \( \text{Mo} \) | \( \text{Ni} \) | \( \text{Pb} \) | \( \text{Sr} \) | \( \text{V} \) | \( \text{Zn} \) | \( \text{Zr} \) | \( \text{Specimen} \) |
| 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 |

**PYROXENE.**

| 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 |

**MICA.**

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 | Fe₂O₃ | MnO | TiO₂ | CaO | Ba | Be | Co | Cr | Cu | Ga | Li | Nb | Ni | Pb | Sn | Sr | V | Zn | Zr | Ce | Y | La |
|----------|------|-----|------|-----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|----|----|
| Number   | wt.%| wt.%| wt.%| ppm | ppm| ppm| ppm| ppm| 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|
| SuT134   | 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.
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 and 7a-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.

<table>
<thead>
<tr>
<th>Element</th>
<th>Detection Limit</th>
<th>Upper limit of Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba</td>
<td>10ppm</td>
<td>5000ppm</td>
</tr>
<tr>
<td>Be</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Co</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Cr</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Cu</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Ga</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Li</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Nb</td>
<td>50ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Ni</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Pb</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Sn</td>
<td>5ppm</td>
<td>4000ppm</td>
</tr>
<tr>
<td>Sr</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>V</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Zn</td>
<td>10ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Zr</td>
<td>5ppm</td>
<td>1000ppm</td>
</tr>
<tr>
<td>Ce</td>
<td>50ppm</td>
<td>10000ppm</td>
</tr>
<tr>
<td>La</td>
<td>35ppm</td>
<td>6000ppm</td>
</tr>
<tr>
<td>Nd</td>
<td>10ppm</td>
<td>6000ppm</td>
</tr>
<tr>
<td>Y</td>
<td>5ppm</td>
<td>10000ppm</td>
</tr>
<tr>
<td></td>
<td>U1099</td>
<td>SuB27</td>
</tr>
<tr>
<td>--------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>SiO₂</td>
<td>44.80</td>
<td>45.68</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.96</td>
<td>0.64</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.21</td>
<td>3.33</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.64</td>
<td>6.71</td>
</tr>
<tr>
<td>Fe O</td>
<td>9.38</td>
<td>9.50</td>
</tr>
<tr>
<td>MnO</td>
<td>0.19</td>
<td>0.41</td>
</tr>
<tr>
<td>MgO</td>
<td>5.16</td>
<td>6.89</td>
</tr>
<tr>
<td>CrO</td>
<td>15.88</td>
<td>20.28</td>
</tr>
<tr>
<td>Na₂O</td>
<td>5.26</td>
<td>2.86</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.75</td>
<td>0.10</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.17</td>
<td>2.10</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O⁻</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>0.44</td>
<td>0.11</td>
</tr>
<tr>
<td>Total</td>
<td>100.05</td>
<td>99.07</td>
</tr>
</tbody>
</table>

Appendix Table 4a. Chemical analyses of intrusive peralkaline silicate rocks from W. Kenya and E. Uganda.
### Chemical Analyses of Intrusive Peralkaline Silicate Rocks from W. Kenya and E. Uganda

<table>
<thead>
<tr>
<th></th>
<th>SuN5</th>
<th>SuN63</th>
<th>HC309</th>
<th>HC741</th>
<th>U369</th>
<th>HC964</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>41.69</td>
<td>40.79</td>
<td>39.80</td>
<td>44.52</td>
<td>38.98</td>
<td>42.04</td>
</tr>
<tr>
<td>TiO₂</td>
<td>-</td>
<td>-</td>
<td>2.54</td>
<td>1.36</td>
<td>3.29</td>
<td>0.44</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.59</td>
<td>2.27</td>
<td>6.08</td>
<td>11.88</td>
<td>5.87</td>
<td>4.34</td>
</tr>
<tr>
<td>FeO</td>
<td>0.97</td>
<td>0.52</td>
<td>2.73</td>
<td>1.72</td>
<td>2.75</td>
<td>1.20</td>
</tr>
<tr>
<td>MnO</td>
<td>0.14</td>
<td>0.13</td>
<td>0.19</td>
<td>0.24</td>
<td>0.16</td>
<td>0.20</td>
</tr>
<tr>
<td>MgO</td>
<td>1.64</td>
<td>1.58</td>
<td>4.02</td>
<td>0.51</td>
<td>3.65</td>
<td>3.11</td>
</tr>
<tr>
<td>CaO</td>
<td>13.97</td>
<td>12.44</td>
<td>14.72</td>
<td>17.50</td>
<td>14.77</td>
<td>10.11</td>
</tr>
<tr>
<td>Na₂O</td>
<td>11.33</td>
<td>12.98</td>
<td>7.15</td>
<td>2.11</td>
<td>7.09</td>
<td>11.41</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.14</td>
<td>5.34</td>
<td>3.60</td>
<td>4.03</td>
<td>2.94</td>
<td>4.60</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.46</td>
<td>0.21</td>
<td>0.61</td>
<td>0.14</td>
<td>0.04</td>
<td>0.32</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>-</td>
<td>-</td>
<td>0.88</td>
<td>1.49</td>
<td>0.27</td>
<td>1.64</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td></td>
<td></td>
<td></td>
<td>0.56</td>
<td>0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.25</td>
<td>0.50</td>
<td>0.98</td>
<td>3.28</td>
<td>0.32</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>100.62</td>
<td>100.02</td>
<td>98.29</td>
<td>99.66</td>
<td>100.52</td>
<td>100.12</td>
</tr>
</tbody>
</table>

**Appendix Table 4a (continued)**
<table>
<thead>
<tr>
<th></th>
<th>SuB247</th>
<th>SuB262</th>
<th>SuB265</th>
<th>SuB311</th>
<th>SuN106</th>
<th>SuTo38</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>48.18</td>
<td>47.70</td>
<td>50.25</td>
<td>53.93</td>
<td>54.38</td>
<td>43.34</td>
</tr>
<tr>
<td>TiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.60</td>
<td>0.49</td>
<td>0.62</td>
<td>0.32</td>
<td>0.58</td>
<td>0.59</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>17.24</td>
<td>13.65</td>
<td>19.50</td>
<td>18.27</td>
<td>17.02</td>
<td>13.95</td>
</tr>
<tr>
<td>Fe&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>2.84</td>
<td>3.27</td>
<td>2.42</td>
<td>1.54</td>
<td>4.67</td>
<td>5.69</td>
</tr>
<tr>
<td>FeO</td>
<td>3.16</td>
<td>3.10</td>
<td>2.51</td>
<td>2.15</td>
<td>2.57</td>
<td>3.96</td>
</tr>
<tr>
<td>MnO</td>
<td>0.16</td>
<td>0.25</td>
<td>0.20</td>
<td>0.11</td>
<td>0.12</td>
<td>0.27</td>
</tr>
<tr>
<td>MgO</td>
<td>1.34</td>
<td>0.43</td>
<td>0.41</td>
<td>1.08</td>
<td>1.09</td>
<td>1.58</td>
</tr>
<tr>
<td>CaO</td>
<td>8.26</td>
<td>11.23</td>
<td>5.67</td>
<td>5.15</td>
<td>3.79</td>
<td>12.40</td>
</tr>
<tr>
<td>Na&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>6.91</td>
<td>4.93</td>
<td>6.90</td>
<td>7.94</td>
<td>5.55</td>
<td>3.97</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>5.64</td>
<td>6.04</td>
<td>6.50</td>
<td>5.66</td>
<td>9.54</td>
<td>5.89</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>0.49</td>
<td>0.55</td>
<td>0.32</td>
<td>0.26</td>
<td>0.35</td>
<td>0.01</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;O+</td>
<td>2.14</td>
<td>1.58</td>
<td>2.87</td>
<td>0.72</td>
<td>-</td>
<td>2.62</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;O-</td>
<td>5.2</td>
<td>1.86</td>
<td>1.96</td>
<td>-</td>
<td>4.40</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>99.65</td>
<td>98.42</td>
<td>100.23</td>
<td>99.09</td>
<td>99.66</td>
<td>99.67</td>
</tr>
</tbody>
</table>

Analyst: DSS DSS DSS DSS DSS MB

Appendix Table 4a (continued). Chemical analyses of intrusive peralkaline silicate rocks from W. Kenya and E. Uganda.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>FeO</th>
<th>Fe$_2$O$_3$</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>TiO$_2$</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>Type</td>
</tr>
<tr>
<td>HC988</td>
<td>39</td>
<td>5.4</td>
<td>2.9</td>
<td>9.2</td>
<td>7.8</td>
<td>0.4</td>
<td>&gt;20.0</td>
<td>2.6</td>
<td>1.1</td>
<td>1.1</td>
<td>Pyroxenite</td>
</tr>
<tr>
<td>N683</td>
<td>40</td>
<td>6.0</td>
<td>6.4</td>
<td>6.7</td>
<td>7.6</td>
<td>0.2</td>
<td>&gt;20.0</td>
<td>2.04</td>
<td>0.6</td>
<td>1.6</td>
<td>do.</td>
</tr>
<tr>
<td>U1099</td>
<td>55</td>
<td>13.5</td>
<td>8.8</td>
<td>4.5</td>
<td>9.6</td>
<td>0.2</td>
<td>13.6</td>
<td>4.96</td>
<td>1.7</td>
<td>0.9</td>
<td>do.</td>
</tr>
<tr>
<td>Su827</td>
<td>47</td>
<td>3.2</td>
<td>9.5</td>
<td>6.7</td>
<td>6.7</td>
<td>0.5</td>
<td>&gt;20.0</td>
<td>2.9</td>
<td>0.1</td>
<td>0.6</td>
<td>do.</td>
</tr>
<tr>
<td>SuN35</td>
<td>42</td>
<td>7.4</td>
<td>5.8</td>
<td>16.1</td>
<td>9.0</td>
<td>0.2</td>
<td>18.0</td>
<td>3.7</td>
<td>1.6</td>
<td>2.3</td>
<td>do.</td>
</tr>
<tr>
<td>N694</td>
<td>45</td>
<td>5.4</td>
<td>6.0</td>
<td>10.8</td>
<td>5.8</td>
<td>0.5</td>
<td>&gt;20.0</td>
<td>2.8</td>
<td>4.0</td>
<td>0.9</td>
<td>do.</td>
</tr>
<tr>
<td>HC312</td>
<td>42</td>
<td>5.1</td>
<td>2.6</td>
<td>5.8</td>
<td>5.8</td>
<td>0.5</td>
<td>&gt;20.0</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>Iholite</td>
</tr>
<tr>
<td>HC930</td>
<td>49</td>
<td>9.8</td>
<td>5.3</td>
<td>7.8</td>
<td>5.7</td>
<td>0.6</td>
<td>19.6</td>
<td>5.0</td>
<td>1.6</td>
<td>0.5</td>
<td>do.</td>
</tr>
<tr>
<td>SuB78</td>
<td>47</td>
<td>11.6</td>
<td>6.5</td>
<td>7.1</td>
<td>2.9</td>
<td>0.4</td>
<td>10.7</td>
<td>5.5</td>
<td>1.4</td>
<td>0.4</td>
<td>do.</td>
</tr>
<tr>
<td>SuB266</td>
<td>49</td>
<td>14.9</td>
<td>4.7</td>
<td>5.1</td>
<td>2.4</td>
<td>0.3</td>
<td>7.9</td>
<td>8.4</td>
<td>3.3</td>
<td>1.1</td>
<td>do.</td>
</tr>
<tr>
<td>SuTo590</td>
<td>43</td>
<td>12.8</td>
<td>4.7</td>
<td>16.2</td>
<td>1.0</td>
<td>0.3</td>
<td>14.8</td>
<td>6.9</td>
<td>3.1</td>
<td>2.0</td>
<td>do.</td>
</tr>
<tr>
<td>U211</td>
<td>47</td>
<td>14.8</td>
<td>2.2</td>
<td>5.8</td>
<td>2.7</td>
<td>0.2</td>
<td>16.8</td>
<td>7.8</td>
<td>3.4</td>
<td>0.8</td>
<td>Urtite</td>
</tr>
<tr>
<td>U1054</td>
<td>43</td>
<td>16.2</td>
<td>0.5</td>
<td>1.1</td>
<td>0.2</td>
<td>0.2</td>
<td>&gt;10.0</td>
<td>9.8</td>
<td>4.6</td>
<td>0.2</td>
<td>do.</td>
</tr>
</tbody>
</table>

Appendix Table 4b. Spectrometric analyses for major elements in peralkaline intrusive silicate rocks from W. Kenya and E. Uganda. — analysis not attempted.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>TiO₂</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td></td>
</tr>
<tr>
<td>U1111</td>
<td>45</td>
<td>19.7</td>
<td>0.4</td>
<td>-</td>
<td>0.2</td>
<td>0.1</td>
<td>10.8</td>
<td>11.3</td>
<td>4.7</td>
<td>0.1</td>
<td>Urtite</td>
</tr>
<tr>
<td>SuN5</td>
<td>36</td>
<td>14.6</td>
<td>0.3</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1</td>
<td>16.0</td>
<td>11.4</td>
<td>4.3</td>
<td>0.1</td>
<td>do</td>
</tr>
<tr>
<td>SuN63</td>
<td>35</td>
<td>11.3</td>
<td>0.1</td>
<td>-</td>
<td>0.1</td>
<td>0.7</td>
<td>10.8</td>
<td>13.0</td>
<td>4.1</td>
<td>0.1</td>
<td>do</td>
</tr>
<tr>
<td>HC309</td>
<td>43</td>
<td>13.9</td>
<td>1.5</td>
<td>6.3</td>
<td>1.9</td>
<td>0.1</td>
<td>11.0</td>
<td>8.0</td>
<td>4.0</td>
<td>4.0</td>
<td>Melanite iolite</td>
</tr>
<tr>
<td>HC324</td>
<td>39</td>
<td>12.6</td>
<td>2.4</td>
<td>6.2</td>
<td>2.9</td>
<td>0.2</td>
<td>12.6</td>
<td>7.2</td>
<td>3.1</td>
<td>2.8</td>
<td>do</td>
</tr>
<tr>
<td>HC741</td>
<td>45</td>
<td>11.8</td>
<td>1.0</td>
<td>13.9</td>
<td>0.2</td>
<td>0.2</td>
<td>17.6</td>
<td>2.0</td>
<td>5.3</td>
<td>1.7</td>
<td>do</td>
</tr>
<tr>
<td>HC993</td>
<td>38</td>
<td>9.7</td>
<td>1.7</td>
<td>10.2</td>
<td>2.3</td>
<td>0.3</td>
<td>&gt;20.0</td>
<td>4.4</td>
<td>2.1</td>
<td>2.6</td>
<td>do</td>
</tr>
<tr>
<td>U88</td>
<td>48</td>
<td>11.9</td>
<td>1.4</td>
<td>7.2</td>
<td>2.4</td>
<td>6.3</td>
<td>&gt;20.0</td>
<td>7.3</td>
<td>3.2</td>
<td>0.8</td>
<td>do</td>
</tr>
<tr>
<td>U202</td>
<td>46</td>
<td>13.4</td>
<td>2.5</td>
<td>8.7</td>
<td>5.3</td>
<td>0.2</td>
<td>11.2</td>
<td>6.0</td>
<td>2.4</td>
<td>4.2</td>
<td>do</td>
</tr>
<tr>
<td>SuN521</td>
<td>40</td>
<td>7.4</td>
<td>4.4</td>
<td>9.0</td>
<td>4.2</td>
<td>0.3</td>
<td>&gt;20.0</td>
<td>2.4</td>
<td>0.6</td>
<td>0.8</td>
<td>do</td>
</tr>
<tr>
<td>HC323</td>
<td>43</td>
<td>13.7</td>
<td>1.7</td>
<td>6.5</td>
<td>2.8</td>
<td>0.2</td>
<td>15.9</td>
<td>7.6</td>
<td>3.0</td>
<td>2.2</td>
<td>Feldspathic iolite</td>
</tr>
<tr>
<td>HC934</td>
<td>40</td>
<td>14.0</td>
<td>1.8</td>
<td>6.3</td>
<td>2.2</td>
<td>0.2</td>
<td>9.2</td>
<td>7.4</td>
<td>3.3</td>
<td>1.8</td>
<td>do</td>
</tr>
<tr>
<td>HC964</td>
<td>42</td>
<td>20.6</td>
<td>1.2</td>
<td>4.3</td>
<td>3.1</td>
<td>0.2</td>
<td>10.1</td>
<td>11.41</td>
<td>4.6</td>
<td>0.4</td>
<td>do</td>
</tr>
<tr>
<td>HC999</td>
<td>40</td>
<td>12.1</td>
<td>1.6</td>
<td>7.4</td>
<td>1.0</td>
<td>0.2</td>
<td>15.6</td>
<td>5.3</td>
<td>2.7</td>
<td>3.8</td>
<td>do</td>
</tr>
</tbody>
</table>

Appendix Table 4b (continued). Spectrometric analyses for major element in peralkaline intrusive silicate rocks from W. Kenya and E. Uganda. - ELEMENT not detected.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>FeO</th>
<th>FeO</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>TiO$_2$</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>Type</td>
</tr>
<tr>
<td>SuB247</td>
<td>48</td>
<td>15.7</td>
<td>3.2</td>
<td>2.8</td>
<td>0.7</td>
<td>0.2</td>
<td>8.1</td>
<td>6.9</td>
<td>5.6</td>
<td>0.8</td>
<td>Nepheline-syenite</td>
</tr>
<tr>
<td>SuB262</td>
<td>53</td>
<td>11.8</td>
<td>3.1</td>
<td>3.3</td>
<td>0.8</td>
<td>0.3</td>
<td>10.3</td>
<td>4.8</td>
<td>6.1</td>
<td>0.4</td>
<td>do.</td>
</tr>
<tr>
<td>SuB265</td>
<td>51</td>
<td>17.9</td>
<td>2.5</td>
<td>2.4</td>
<td>0.3</td>
<td>0.2</td>
<td>5.6</td>
<td>6.9</td>
<td>6.5</td>
<td>0.7</td>
<td>do.</td>
</tr>
<tr>
<td>SuB311</td>
<td>51</td>
<td>16.3</td>
<td>2.2</td>
<td>1.5</td>
<td>0.5</td>
<td>0.1</td>
<td>4.9</td>
<td>7.9</td>
<td>5.7</td>
<td>0.3</td>
<td>do.</td>
</tr>
<tr>
<td>SuN106</td>
<td>49</td>
<td>16.7</td>
<td>1.6</td>
<td>4.3</td>
<td>0.3</td>
<td>0.1</td>
<td>1.8</td>
<td>4.6</td>
<td>8.7</td>
<td>0.3</td>
<td>do.</td>
</tr>
<tr>
<td>SuTb38</td>
<td>48</td>
<td>12.1</td>
<td>4.0</td>
<td>5.7</td>
<td>0.6</td>
<td>0.2</td>
<td>11.0</td>
<td>4.0</td>
<td>5.9</td>
<td>0.7</td>
<td>do.</td>
</tr>
<tr>
<td>N225</td>
<td>40</td>
<td>15.1</td>
<td>3.6</td>
<td>1.0</td>
<td>0.2</td>
<td>0.1</td>
<td>&gt;10.0</td>
<td>8.9</td>
<td>3.1</td>
<td>0.4</td>
<td>do.</td>
</tr>
<tr>
<td>N266</td>
<td>42</td>
<td>15.5</td>
<td>1.3</td>
<td>3.0</td>
<td>0.6</td>
<td>0.2</td>
<td>9.7</td>
<td>9.8</td>
<td>5.0</td>
<td>0.5</td>
<td>do.</td>
</tr>
<tr>
<td>N464</td>
<td>47</td>
<td>17.0</td>
<td>1.4</td>
<td>3.8</td>
<td>0.5</td>
<td>0.2</td>
<td>5.1</td>
<td>9.9</td>
<td>3.3</td>
<td>0.5</td>
<td>do.</td>
</tr>
<tr>
<td>N503</td>
<td>50</td>
<td>16.4</td>
<td>0.6</td>
<td>4.8</td>
<td>0.4</td>
<td>0.2</td>
<td>5.1</td>
<td>9.8</td>
<td>6.1</td>
<td>0.5</td>
<td>do.</td>
</tr>
<tr>
<td>N688</td>
<td>49</td>
<td>10.0</td>
<td>3.3</td>
<td>5.8</td>
<td>3.9</td>
<td>3.8</td>
<td>&gt;20.0</td>
<td>5.9</td>
<td>2.0</td>
<td>0.5</td>
<td>do.</td>
</tr>
</tbody>
</table>

Appendix Table 4b (continued). Spectrometric analyses for major elements peralkaline intrusive silicate rocks from W. Kenya and E. Uganda.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>FeO</th>
<th>Fe$_2$O$_3$</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>TiO$_2$</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC865</td>
<td>41</td>
<td>12.7</td>
<td>2.0</td>
<td>7.0</td>
<td>5.0</td>
<td>0.2</td>
<td>nd</td>
<td>nd</td>
<td>11.4</td>
<td>nd</td>
<td>1.5</td>
</tr>
<tr>
<td>HC912</td>
<td>42</td>
<td>12.0</td>
<td>2.6</td>
<td>5.5</td>
<td>4.6</td>
<td>0.3</td>
<td>12.4</td>
<td>7.1</td>
<td>3.2</td>
<td>1.1</td>
<td>do</td>
</tr>
<tr>
<td>U149</td>
<td>41</td>
<td>17.0</td>
<td>1.7</td>
<td>4.0</td>
<td>0.5</td>
<td>0.2</td>
<td>7.2</td>
<td>8.6</td>
<td>5.2</td>
<td>0.6</td>
<td>do</td>
</tr>
<tr>
<td>U207</td>
<td>49</td>
<td>15.8</td>
<td>10.2</td>
<td>1.7</td>
<td>0.3</td>
<td>9.6</td>
<td>3.4</td>
<td>3.7</td>
<td>1.0</td>
<td></td>
<td>do</td>
</tr>
<tr>
<td>U242</td>
<td>47</td>
<td>17.0</td>
<td>2.9</td>
<td>8.5</td>
<td>1.2</td>
<td>0.3</td>
<td>5.7</td>
<td>8.3</td>
<td>4.7</td>
<td>0.4</td>
<td>do</td>
</tr>
<tr>
<td>U345</td>
<td>47</td>
<td>17.4</td>
<td>1.9</td>
<td>4.6</td>
<td>0.5</td>
<td>0.2</td>
<td>4.2</td>
<td>8.4</td>
<td>6.1</td>
<td>0.8</td>
<td>do</td>
</tr>
</tbody>
</table>

Appendix Table 4b (continued). Spectrometric analyses for major elements in peralkaline silicate intrusive rocks from W. Kenya and E. Uganda.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>Ba</th>
<th>Be</th>
<th>Co</th>
<th>Cr</th>
<th>Cu</th>
<th>Ga</th>
<th>Li</th>
<th>Nb</th>
<th>Ni</th>
<th>Pb</th>
<th>Sn</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Ce</th>
<th>Y</th>
<th>La</th>
<th>Nd</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td>HC988</td>
<td>240</td>
<td>10</td>
<td>30</td>
<td>5</td>
<td>14</td>
<td>24</td>
<td>25</td>
<td>330</td>
<td>15</td>
<td>10</td>
<td>28</td>
<td>760</td>
<td>380</td>
<td>160</td>
<td>480</td>
<td>610</td>
<td>20</td>
<td>140</td>
<td>-</td>
<td>Pyroxenite</td>
</tr>
<tr>
<td>N683</td>
<td>300</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>25</td>
<td>10</td>
<td>30</td>
<td>500</td>
<td>-</td>
<td>50</td>
<td>25</td>
<td>750</td>
<td>190</td>
<td>140</td>
<td>600</td>
<td>800</td>
<td>25</td>
<td>100</td>
<td>-</td>
<td>Pyroxenite</td>
</tr>
<tr>
<td>N694</td>
<td>1600</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>U1099</td>
<td>340</td>
<td>10</td>
<td>79</td>
<td>354</td>
<td>80</td>
<td>25</td>
<td>-</td>
<td>185</td>
<td>184</td>
<td>15</td>
<td>30</td>
<td>430</td>
<td>275</td>
<td>160</td>
<td>100</td>
<td>130</td>
<td>9</td>
<td>100</td>
<td>-</td>
<td>Pyroxenite</td>
</tr>
<tr>
<td>SuB27</td>
<td>150</td>
<td>20</td>
<td>31</td>
<td>98</td>
<td>22</td>
<td>18</td>
<td>20</td>
<td>370</td>
<td>28</td>
<td>38</td>
<td>30</td>
<td>440</td>
<td>130</td>
<td>145</td>
<td>540</td>
<td>400</td>
<td>-</td>
<td>250</td>
<td>-</td>
<td>Pyroxenite</td>
</tr>
<tr>
<td>SuN35</td>
<td>230</td>
<td>-</td>
<td>35</td>
<td>-</td>
<td>10</td>
<td>30</td>
<td>-</td>
<td>400</td>
<td>15</td>
<td>50</td>
<td>30</td>
<td>300</td>
<td>260</td>
<td>300</td>
<td>270</td>
<td>250</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>Pyroxenite</td>
</tr>
<tr>
<td>HC312</td>
<td>1220</td>
<td>-</td>
<td>30</td>
<td>75</td>
<td>25</td>
<td>-</td>
<td>-</td>
<td>130</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1680</td>
<td>165</td>
<td>100</td>
<td>170</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>Ijolite</td>
</tr>
<tr>
<td>HC930</td>
<td>970</td>
<td>30</td>
<td>30</td>
<td>5</td>
<td>32</td>
<td>38</td>
<td>440</td>
<td>15</td>
<td>18</td>
<td>30</td>
<td>870</td>
<td>310</td>
<td>250</td>
<td>420</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>Ijolite</td>
<td></td>
</tr>
<tr>
<td>SuB7a</td>
<td>1500</td>
<td>30</td>
<td>22</td>
<td>20</td>
<td>25</td>
<td>10</td>
<td>170</td>
<td>10</td>
<td>15</td>
<td>10</td>
<td>630</td>
<td>100</td>
<td>230</td>
<td>840</td>
<td>-</td>
<td>-</td>
<td>250</td>
<td>-</td>
<td>Ijolite</td>
<td></td>
</tr>
<tr>
<td>SuB266</td>
<td>1030</td>
<td>30</td>
<td>22</td>
<td>26</td>
<td>38</td>
<td>-</td>
<td>280</td>
<td>20</td>
<td>15</td>
<td>15</td>
<td>650</td>
<td>125</td>
<td>355</td>
<td>600</td>
<td>370</td>
<td>14</td>
<td>135</td>
<td>-</td>
<td>Ijolite</td>
<td></td>
</tr>
<tr>
<td>SuTo590</td>
<td>960</td>
<td>30</td>
<td>33</td>
<td>-</td>
<td>12</td>
<td>50</td>
<td>33</td>
<td>1350</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>1160</td>
<td>325</td>
<td>140</td>
<td>770</td>
<td>200</td>
<td>5</td>
<td>170</td>
<td>-</td>
<td>Ijolite</td>
</tr>
<tr>
<td>U211</td>
<td>280</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>42</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>680</td>
<td>250</td>
<td>200</td>
<td>350</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td>-</td>
<td>-</td>
<td>Urtilte</td>
<td></td>
</tr>
<tr>
<td>U1054</td>
<td>180</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>60</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td>690</td>
<td>140</td>
<td>260</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>210</td>
<td>-</td>
<td>-</td>
<td>Urtilte</td>
<td></td>
</tr>
</tbody>
</table>

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 | Specimen | 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 |
|----------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| U1111          |         | 380     | 5       | -       | -       | -       | -       | -       | -       | -       | -       | -       | -       | 600     | 20      | 250     | -       | 80      | 180     | Urtite   |
| SuN5           |         | 340     | -       | -       | -       | -       | -       | -       | -       | -       | -       | -       | -       | 210     | 100     | -       | -       | 330     | -       | Urtite   |
| SuN63          |         | 290     | -       | -       | -       | -       | -       | -       | -       | -       | -       | -       | -       | 210     | 100     | -       | -       | -       | 200     | Urtite   |
| HC309          |         | 100     | 20      | 26      | -       | 44      | 36      | 15      | 330     | 10      | 8       | 20      | 500     | 275     | 65      | 1350    | 250     | 147     | 200     | Melanite ijolite |
| HC324          |         | 300     | 30      | 22      | -       | 8       | 35      | 20      | 440     | 10      | 15     | 18      | 1070    | 310     | 200     | 750     | 760     | 52      | -       | Melanite ijolite |
| HC741          |         | 3080    | 30      | 15      | -       | 25      | 55      | 33      | 620     | 10      | 20     | 15      | 1100    | 660     | 100     | 1200    | 900     | 83      | 105     | Melanite ijolite |
| HC993          |         | 2200    | 30      | 22      | -       | 40      | 35      | 38      | 640     | 10      | 15     | 15      | 790     | 460     | 100     | 340     | 125     | 37      | 110     | Melanite ijolite |
| v88            |         | 430     | -       | 15      | -       | 25      | 35      | 30      | 250     | 30      | -      | 10      | 830     | 380     | 120     | 450     | 250     | -       | 160     | Melanite ijolite |
| U369           |         | 200     | 10      | 10      | -       | -       | 30      | 15      | 250     | 40      | -      | -       | 390     | 420     | 180     | 920     | -       | 103     | -       | Melanite ijolite |
| SuN521         |         | 110     | -       | 30      | -       | -       | 20      | 45      | 220     | 25      | 25     | 10      | 300     | 240     | 100     | 320     | -       | 150     | -       | Melanite ijolite |
| HC323          |         | 410     | 30      | 25      | 25      | 5       | 30      | 32      | 830     | 25      | 15     | 20      | 1090    | 475     | 185     | 1150    | 500     | 30      | 45      | Feldspathic ijolite |
| HC934          |         | 780     | 10      | 30      | 30      | 30      | 38      | 5       | 410     | 62      | 15     | 15      | 980     | 230     | 90      | 500     | 580     | -       | 110     | Feldspathic ijolite |
| HC964          |         | 200     | 10      | 22      | -       | 70      | 30      | -       | -       | -       | 5      | -       | 730     | 120300  | 180     | 880     | 32      | nd      | -       | Feldspathic ijolite |
| HC999          |         | 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 | Ba   | Be  | Co  | Cr  | Cu  | Ga  | Li  | Nb  | Ni  | Pb  | Sn  | Sr  | V   | Zn  | Zr  | Ce  | Y   | La  | Nd  | Rock Type |
|-----------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
| SuB247          | 3240 | 30  | 12  | -   | 5   | 46  | 20  | 330 | -   | 5   | 5   | 1420 | 125 | 120 | 750 | 300 | 9   | 600    | Nephefine-syenite |
| SuB262          | 4480 | 30  | 12  | 12  | -   | 35  | 16  | 250 | 10  | 10  | 12  | 1100 | 75  | 60  | 880 | 400 | -   | 350    | do.                 |
| SuB265          | 1840 | 10  | -   | -   | -   | 44  | -   | -   | -   | 10  | -   | 1050 | 60  | 230 | 350 | 300 | 25  | 250    | do.                 |
| SuB311          | 2100 | 10  | -   | 10  | -   | 46  | -   | -   | -   | -   | 970 | 90   | 220 | 470 | -   | 42  | 200 | -      | do.                 |
| SuN106          | 3400 | -   | -   | -   | -   | 35  | -   | -   | -   | -   | 215 | 75   | 275 | 110 | -   | 18  | 200 | -      | do.                 |
| SuTo38          | 4600 | 30  | 12  | -   | 5   | 46  | 20  | 330 | -   | 10  | 5   | 1300 | 275 | 145 | 590 | 400 | 12  | 350    | do.                 |
| N225            | 1800 | 10  | -   | -   | -   | 45  | -   | -   | -   | -   | 440 | 100  | 220 | 140 | 200 | 14  | 180 | -      | do.                 |
| N266            | 1800 | 10  | -   | -   | -   | 40  | -   | -   | -   | 20  | 1000 | 75  | 270 | 700 | 700 | 20  | 1000   | do.                 |
| N464            | 1100 | 10  | -   | -   | -   | 50  | -   | -   | -   | 60  | -   | 700  | 20  | 460 | 900 | 150 | 49  | 350    | do.                 |
| N503            | 2400 | 15  | -   | -   | 80  | -   | -   | -   | 200 | 50  | 1150 | 160 | 370 | 1900| 1100| 48  | 450    | do.                 |
| N688            | 1700 | 10  | -   | -   | 10  | 30  | 200 | -   | 25  | 1100| 220 | 80   | 550 | 1000| 80  | 80  | -   | -      | do.                 |

Appendix Table 4c (continued). Trace elements in peralkaline intrusive silicate rocks from W. Kenya and E. Uganda. - element below detection limit, nd analysis not attempted.
| Specimen | B* | Be | Co | Cr | Cu | Ga | Li | Nb | Ni | Pb | Sn | Sr | V | Zn | Zr | Ce | Y | La | Nd | Rock       |
|----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|         |
| Number   | ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| Type       |
| HC865    | 3200| -  | 5  | -  | 5  | 35 | -  | -  | -  | -  | -  | -  | 1040| 700| 60 | 510| nd | nd | nd | Microjolite |
| HC912    | 960 | -  | 5  | 10 | 20 | 35 | -  | -  | -  | -  | -  | -  | 700 | 660| 70 | 430| 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 | 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. - element below detection limit, nd analysis not attempted.
Appendix Table 5a, Chemical analyses of peralkaline silicate rocks.

<table>
<thead>
<tr>
<th></th>
<th>N595</th>
<th>U890</th>
<th>U926</th>
<th>HF329</th>
<th>U156</th>
<th>U162</th>
<th>HF89A</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>40.47</td>
<td>43.86</td>
<td>43.79</td>
<td>44.94</td>
<td>50.76</td>
<td>51.39</td>
<td>45.64</td>
</tr>
<tr>
<td>TiO₂</td>
<td>3.25</td>
<td>2.51</td>
<td>2.65</td>
<td>1.49</td>
<td>0.56</td>
<td>0.58</td>
<td>1.50</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>8.75</td>
<td>11.51</td>
<td>13.27</td>
<td>16.64</td>
<td>20.42</td>
<td>20.10</td>
<td>15.44</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>11.86</td>
<td>6.66</td>
<td>8.50</td>
<td>5.54</td>
<td>5.14</td>
<td>3.74</td>
<td>4.86</td>
</tr>
<tr>
<td>FeO</td>
<td>2.80</td>
<td>5.80</td>
<td>5.00</td>
<td>2.06</td>
<td>0.62</td>
<td>1.61</td>
<td>2.73</td>
</tr>
<tr>
<td>MgO</td>
<td>0.17</td>
<td>0.20</td>
<td>0.20</td>
<td>0.21</td>
<td>0.26</td>
<td>0.27</td>
<td>0.23</td>
</tr>
<tr>
<td>MgO</td>
<td>9.77</td>
<td>7.96</td>
<td>6.25</td>
<td>2.87</td>
<td>0.52</td>
<td>0.21</td>
<td>1.85</td>
</tr>
<tr>
<td>CaO</td>
<td>14.33</td>
<td>10.91</td>
<td>9.70</td>
<td>8.75</td>
<td>2.04</td>
<td>4.71</td>
<td>9.81</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.24</td>
<td>4.00</td>
<td>3.33</td>
<td>6.39</td>
<td>8.92</td>
<td>10.31</td>
<td>6.30</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.14</td>
<td>2.00</td>
<td>2.42</td>
<td>3.88</td>
<td>6.75</td>
<td>5.09</td>
<td>2.93</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.5</td>
<td>0.25</td>
<td>0.25</td>
<td>0.48</td>
<td>0.14</td>
<td>0.13</td>
<td>0.50</td>
</tr>
<tr>
<td>H₂O+</td>
<td>3.6</td>
<td>3.57</td>
<td>3.14</td>
<td>2.02</td>
<td>1.48</td>
<td>2.47</td>
<td>4.15</td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.73</td>
<td>0.90</td>
<td>1.96</td>
<td>1.90</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>0.32</td>
<td></td>
<td></td>
<td>0.69</td>
<td>0.10</td>
<td></td>
<td>3.74</td>
</tr>
<tr>
<td>TOTAL</td>
<td>99.48</td>
<td>99.96</td>
<td>99.40</td>
<td>97.92</td>
<td>99.97</td>
<td>100.61</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Appendix Table 5a (continued). Chemical analyses of phonolitic rocks from W. Kenya and E. Uganda.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>FeO</th>
<th>Fe$_2$O$_3$</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>TiO$_2$</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>wt. %</td>
<td>Type</td>
</tr>
<tr>
<td>N593</td>
<td>46</td>
<td>11.6</td>
<td>2.0</td>
<td>12.8</td>
<td>7.8</td>
<td>0.3</td>
<td>15.2</td>
<td>3.0</td>
<td>1.7</td>
<td>1.7</td>
<td>Melanephelinite</td>
</tr>
<tr>
<td>N595</td>
<td>43</td>
<td>8.9</td>
<td>3.2</td>
<td>14.8</td>
<td>10.2</td>
<td>0.2</td>
<td>15.2</td>
<td>2.5</td>
<td>1.3</td>
<td>3.5</td>
<td>do.</td>
</tr>
<tr>
<td>N712</td>
<td>50</td>
<td>11.5</td>
<td>4.0</td>
<td>10.4</td>
<td>9.6</td>
<td>0.3</td>
<td>16.0</td>
<td>2.0</td>
<td>0.8</td>
<td>0.8</td>
<td>do.</td>
</tr>
<tr>
<td>U890</td>
<td>44</td>
<td>9.7</td>
<td>6.1</td>
<td>5.4</td>
<td>6.3</td>
<td>0.2</td>
<td>10.1</td>
<td>4.2</td>
<td>2.0</td>
<td>1.8</td>
<td>do.</td>
</tr>
<tr>
<td>U926</td>
<td>45</td>
<td>13.2</td>
<td>4.8</td>
<td>8.0</td>
<td>6.0</td>
<td>0.3</td>
<td>11.4</td>
<td>3.4</td>
<td>2.3</td>
<td>3.0</td>
<td>do.</td>
</tr>
<tr>
<td>HF329</td>
<td>46</td>
<td>14.4</td>
<td>1.8</td>
<td>4.8</td>
<td>4.0</td>
<td>0.2</td>
<td>8.5</td>
<td>6.9</td>
<td>3.2</td>
<td>1.6</td>
<td>Nephelinite</td>
</tr>
<tr>
<td>SUT125</td>
<td>44</td>
<td>13.0</td>
<td>4.4</td>
<td>5.9</td>
<td>2.4</td>
<td>0.4</td>
<td>16.8</td>
<td>5.3</td>
<td>3.7</td>
<td>1.1</td>
<td>do.</td>
</tr>
<tr>
<td>U156</td>
<td>49</td>
<td>19.0</td>
<td>6.3</td>
<td>2.9</td>
<td>2.9</td>
<td>0.3</td>
<td>1.6</td>
<td>8.6</td>
<td>6.3</td>
<td>0.6</td>
<td>do.</td>
</tr>
<tr>
<td>U162</td>
<td>49</td>
<td>17.8</td>
<td>1.6</td>
<td>1.1</td>
<td>0.3</td>
<td>0.2</td>
<td>3.5</td>
<td>4.9</td>
<td>2.5</td>
<td>0.7</td>
<td>Phonolitic nephelinite</td>
</tr>
<tr>
<td>HF89a</td>
<td>48</td>
<td>15.9</td>
<td>2.5</td>
<td>6.4</td>
<td>4.3</td>
<td>0.3</td>
<td>8.9</td>
<td>6.3</td>
<td>3.6</td>
<td>1.6</td>
<td>do.</td>
</tr>
<tr>
<td>HC583</td>
<td>46</td>
<td>16.3</td>
<td>0.6</td>
<td>3.5</td>
<td>4.1</td>
<td>0.1</td>
<td>4.0</td>
<td>8.1</td>
<td>4.7</td>
<td>0.8</td>
<td>do.</td>
</tr>
<tr>
<td>HC761b</td>
<td>55</td>
<td>16.8</td>
<td>1.6</td>
<td>7.5</td>
<td>2.1</td>
<td>0.3</td>
<td>7.5</td>
<td>8.0</td>
<td>3.8</td>
<td>1.0</td>
<td>do.</td>
</tr>
</tbody>
</table>

Appendix Table 5b. Spectrometric and other analyses for major elements in phonolite rocks from W. Kenya and E. Uganda.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</th>
<th>FeO</th>
<th>Fe&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na&lt;sub&gt;2&lt;/sub&gt;O</th>
<th>K&lt;sub&gt;2&lt;/sub&gt;O</th>
<th>TiO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td></td>
</tr>
<tr>
<td>HC1005</td>
<td>41</td>
<td>13.4</td>
<td>2.7</td>
<td>5.4</td>
<td>1.3</td>
<td>0.3</td>
<td>8.1</td>
<td>8.4</td>
<td>3.6</td>
<td>1.5</td>
<td>Phonolitic nephelinite</td>
</tr>
<tr>
<td>N85</td>
<td>49</td>
<td>15.5</td>
<td>1.8</td>
<td>6.4</td>
<td>2.1</td>
<td>0.2</td>
<td>6.2</td>
<td>7.1</td>
<td>4.6</td>
<td>1.3</td>
<td>do.</td>
</tr>
<tr>
<td>U48</td>
<td>54</td>
<td>15.8</td>
<td>2.8</td>
<td>6.4</td>
<td>1.7</td>
<td>0.2</td>
<td>nd</td>
<td>4.4</td>
<td>3.6</td>
<td>1.9</td>
<td>Analcime phonolite</td>
</tr>
<tr>
<td>U278</td>
<td>55</td>
<td>18.6</td>
<td>2.4</td>
<td>4.2</td>
<td>0.3</td>
<td>0.3</td>
<td>1.1</td>
<td>8.0</td>
<td>2.0</td>
<td>0.5</td>
<td>do.</td>
</tr>
<tr>
<td>U296</td>
<td>56</td>
<td>19.1</td>
<td>0.2</td>
<td>3.7</td>
<td>0.4</td>
<td>0.2</td>
<td>1.9</td>
<td>8.9</td>
<td>4.4</td>
<td>0.4</td>
<td>do.</td>
</tr>
<tr>
<td>U301</td>
<td>59</td>
<td>19.7</td>
<td>0.5</td>
<td>4.6</td>
<td>0.5</td>
<td>0.2</td>
<td>1.3</td>
<td>7.6</td>
<td>5.4</td>
<td>0.6</td>
<td>do.</td>
</tr>
<tr>
<td>U382</td>
<td>57</td>
<td>20.5</td>
<td>2.0</td>
<td>1.9</td>
<td>0.5</td>
<td>0.2</td>
<td>1.45</td>
<td>6.7</td>
<td>5.4</td>
<td>0.5</td>
<td>do.</td>
</tr>
<tr>
<td>N90</td>
<td>48</td>
<td>16.2</td>
<td>2.1</td>
<td>5.7</td>
<td>0.5</td>
<td>0.2</td>
<td>4.6</td>
<td>8.9</td>
<td>4.5</td>
<td>1.1</td>
<td>do.</td>
</tr>
<tr>
<td>N158</td>
<td>50</td>
<td>17.0</td>
<td>0.9</td>
<td>4.1</td>
<td>0.2</td>
<td>0.2</td>
<td>2.8</td>
<td>8.4</td>
<td>6.4</td>
<td>0.4</td>
<td>do.</td>
</tr>
</tbody>
</table>

Appendix Table 5b (continued). Spectrometric and other analyses for major elements in phonolitic rocks from W. Kenya and E. Uganda. ND analysis not attempted.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>Ba (ppm)</th>
<th>Be (ppm)</th>
<th>Co (ppm)</th>
<th>Cr (ppm)</th>
<th>Cu (ppm)</th>
<th>Ga (ppm)</th>
<th>Li (ppm)</th>
<th>Nb (ppm)</th>
<th>Ni (ppm)</th>
<th>Pb (ppm)</th>
<th>Sn (ppm)</th>
<th>Sr (ppm)</th>
<th>V (ppm)</th>
<th>Zn (ppm)</th>
<th>Zr (ppm)</th>
<th>Ce (ppm)</th>
<th>Y (ppm)</th>
<th>La (ppm)</th>
<th>Nd (ppm)</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>N593</td>
<td>3200</td>
<td>15</td>
<td>50</td>
<td>50</td>
<td>210</td>
<td>35</td>
<td>30</td>
<td>400</td>
<td>50</td>
<td>40</td>
<td>25</td>
<td>880</td>
<td>550</td>
<td>150</td>
<td>790</td>
<td>500</td>
<td>25</td>
<td>-</td>
<td>-</td>
<td>Melanephelinite</td>
</tr>
<tr>
<td>N595</td>
<td>1700</td>
<td>10</td>
<td>60</td>
<td>410</td>
<td>215</td>
<td>10</td>
<td>15</td>
<td>200</td>
<td>120</td>
<td>40</td>
<td>25</td>
<td>720</td>
<td>310</td>
<td>260</td>
<td>300</td>
<td>350</td>
<td>19</td>
<td>-</td>
<td>-</td>
<td>do.</td>
</tr>
<tr>
<td>N712</td>
<td>6000</td>
<td>15</td>
<td>60</td>
<td>250</td>
<td>180</td>
<td>40</td>
<td>45</td>
<td>250</td>
<td>110</td>
<td>50</td>
<td>10</td>
<td>1300</td>
<td>220</td>
<td>360</td>
<td>510</td>
<td>580</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>do.</td>
</tr>
<tr>
<td>U920</td>
<td>950</td>
<td>-</td>
<td>60</td>
<td>350</td>
<td>155</td>
<td>25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>105</td>
<td>-</td>
<td>-</td>
<td>1050</td>
<td>675</td>
<td>100</td>
<td>310</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>do.</td>
</tr>
<tr>
<td>U926</td>
<td>1300</td>
<td>-</td>
<td>50</td>
<td>65</td>
<td>110</td>
<td>28</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>1700</td>
<td>750</td>
<td>125</td>
<td>450</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>do.</td>
</tr>
<tr>
<td>HF329</td>
<td>7280</td>
<td>30</td>
<td>30</td>
<td>236</td>
<td>44</td>
<td>45</td>
<td>-</td>
<td>560</td>
<td>54</td>
<td>30</td>
<td>20</td>
<td>1230</td>
<td>80</td>
<td>185</td>
<td>820</td>
<td>1100</td>
<td>7</td>
<td>240</td>
<td>-</td>
<td>Nephelinite</td>
</tr>
<tr>
<td>SuT125</td>
<td>3000</td>
<td>-</td>
<td>15</td>
<td>-</td>
<td>110</td>
<td>35</td>
<td>60</td>
<td>300</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>1000</td>
<td>130</td>
<td>360</td>
<td>590</td>
<td>400</td>
<td>45</td>
<td>250</td>
<td>-</td>
<td>do.</td>
</tr>
<tr>
<td>U156</td>
<td>1000</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1150</td>
<td>600</td>
<td>140</td>
<td>1500</td>
<td>300</td>
<td>35</td>
<td>500</td>
<td>-</td>
<td>do.</td>
</tr>
<tr>
<td>U162</td>
<td>2560</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>80</td>
<td>-</td>
<td>-</td>
<td>1250</td>
<td>200</td>
<td>400</td>
<td>950</td>
<td>1000</td>
<td>38</td>
<td>500</td>
<td>-</td>
<td>Phonolitic nephe</td>
</tr>
<tr>
<td>HF89a</td>
<td>2050</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>35</td>
<td>35</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>25</td>
<td>-</td>
<td>1820</td>
<td>675</td>
<td>120</td>
<td>550</td>
<td>700</td>
<td>28</td>
<td>180</td>
<td>-</td>
<td>nephelinite do.</td>
</tr>
<tr>
<td>HC583</td>
<td>&gt;4000</td>
<td>-</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>45</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>1550</td>
<td>630</td>
<td>160</td>
<td>1500</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd do.</td>
</tr>
<tr>
<td>HC761b</td>
<td>1800</td>
<td>40</td>
<td>22</td>
<td>32</td>
<td>102</td>
<td>50</td>
<td>25</td>
<td>950</td>
<td>38</td>
<td>55</td>
<td>15</td>
<td>1450</td>
<td>220</td>
<td>390</td>
<td>1210</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd do.</td>
<td></td>
</tr>
</tbody>
</table>

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

- element not detected, nd analysis not attempted.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Ba (ppm)</th>
<th>Be (ppm)</th>
<th>Co (ppm)</th>
<th>Cr (ppm)</th>
<th>Cu (ppm)</th>
<th>Ga (ppm)</th>
<th>Li (ppm)</th>
<th>Nb (ppm)</th>
<th>Ni (ppm)</th>
<th>Pb (ppm)</th>
<th>Sn (ppm)</th>
<th>Sr (ppm)</th>
<th>V (ppm)</th>
<th>Zn (ppm)</th>
<th>Zr (ppm)</th>
<th>Ce (ppm)</th>
<th>Y (ppm)</th>
<th>La (ppm)</th>
<th>Nd (ppm)</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>N85</td>
<td>1350</td>
<td>10</td>
<td>-</td>
<td>40</td>
<td>45</td>
<td>40</td>
<td>5</td>
<td>200</td>
<td>-</td>
<td>60</td>
<td>-</td>
<td>880</td>
<td>130</td>
<td>410</td>
<td>1000</td>
<td>600</td>
<td>9</td>
<td>350</td>
<td>-</td>
<td>do.</td>
</tr>
<tr>
<td>U296</td>
<td>550</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>80</td>
<td>200</td>
<td>-</td>
<td>75</td>
<td>-</td>
<td>830</td>
<td>60</td>
<td>460</td>
<td>1600</td>
<td>320</td>
<td>18</td>
<td>300</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U301</td>
<td>480</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>80</td>
<td>200</td>
<td>-</td>
<td>95</td>
<td>-</td>
<td>570</td>
<td>150</td>
<td>470</td>
<td>1000</td>
<td>-</td>
<td>7</td>
<td>300</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U382</td>
<td>680</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>15</td>
<td>-</td>
<td>150</td>
<td>20</td>
<td>400</td>
<td>1140</td>
<td>700</td>
<td>58</td>
<td>700</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N90</td>
<td>2500</td>
<td>10</td>
<td>-</td>
<td>10</td>
<td>40</td>
<td>-</td>
<td>200</td>
<td>-</td>
<td>75</td>
<td>1400</td>
<td>150</td>
<td>400</td>
<td>800</td>
<td>1300</td>
<td>270</td>
<td>500</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N158</td>
<td>960</td>
<td>15</td>
<td>-</td>
<td>60</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>1000</td>
<td>75</td>
<td>250</td>
<td>1000</td>
<td>700</td>
<td>53</td>
<td>450</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuB269</td>
<td>970</td>
<td>30</td>
<td>-</td>
<td>12</td>
<td>58</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>1150</td>
<td>60</td>
<td>160</td>
<td>1680</td>
<td>-</td>
<td>19</td>
<td>300</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

- element not detected, nd - analysis not attempted.
<table>
<thead>
<tr>
<th></th>
<th>Sub218</th>
<th>Sub223</th>
<th>Sub242</th>
<th>Sub279</th>
<th>SuTo509</th>
<th>SuTo510</th>
<th>SuTo514</th>
<th>SuTo536</th>
<th>SuTo598</th>
<th>HC54</th>
<th>HC744</th>
<th>HC825</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>55.85</td>
<td>64.79</td>
<td>59.36</td>
<td>57.61</td>
<td>63.86</td>
<td>72.99</td>
<td>67.01</td>
<td>51.14</td>
<td>54.56</td>
<td>71.54</td>
<td>54.08</td>
<td>56.38</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.98</td>
<td>0.43</td>
<td>0.41</td>
<td>0.68</td>
<td>0.72</td>
<td>0.18</td>
<td>0.79</td>
<td>0.44</td>
<td>0.36</td>
<td>0.48</td>
<td>0.50</td>
<td>0.51</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>4.42</td>
<td>2.05</td>
<td>2.43</td>
<td>2.36</td>
<td>4.05</td>
<td>1.26</td>
<td>3.54</td>
<td>1.12</td>
<td>6.93</td>
<td>1.19</td>
<td>4.90</td>
<td>5.91</td>
</tr>
<tr>
<td>FeO</td>
<td>3.79</td>
<td>0.88</td>
<td>2.24</td>
<td>3.03</td>
<td>0.49</td>
<td>0.66</td>
<td>0.54</td>
<td>2.33</td>
<td>0.49</td>
<td>3.12</td>
<td>2.59</td>
<td>0.83</td>
</tr>
<tr>
<td>MnO</td>
<td>0.19</td>
<td>0.09</td>
<td>0.09</td>
<td>0.19</td>
<td>0.35</td>
<td>0.10</td>
<td>0.23</td>
<td>0.16</td>
<td>0.50</td>
<td>0.08</td>
<td>0.22</td>
<td>0.16</td>
</tr>
<tr>
<td>MgO</td>
<td>1.82</td>
<td>0.40</td>
<td>1.00</td>
<td>1.64</td>
<td>0.54</td>
<td>0.01</td>
<td>0.95</td>
<td>0.04</td>
<td>0.08</td>
<td>2.26</td>
<td>0.68</td>
<td>0.87</td>
</tr>
<tr>
<td>CaO</td>
<td>7.47</td>
<td>2.21</td>
<td>4.43</td>
<td>5.38</td>
<td>1.59</td>
<td>1.11</td>
<td>0.81</td>
<td>8.68</td>
<td>8.01</td>
<td>0.77</td>
<td>3.50</td>
<td>4.00</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.48</td>
<td>8.42</td>
<td>3.59</td>
<td>7.71</td>
<td>5.16</td>
<td>4.09</td>
<td>6.06</td>
<td>1.08</td>
<td>3.77</td>
<td>5.21</td>
<td>5.96</td>
<td>3.31</td>
</tr>
<tr>
<td>K₂O</td>
<td>4.38</td>
<td>3.19</td>
<td>9.17</td>
<td>4.05</td>
<td>5.53</td>
<td>5.63</td>
<td>5.19</td>
<td>10.43</td>
<td>6.86</td>
<td>0.60</td>
<td>6.10</td>
<td>11.44</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>1.11</td>
<td>0.19</td>
<td>0.25</td>
<td>0.54</td>
<td>0.07</td>
<td>0.08</td>
<td>0.05</td>
<td>1.03</td>
<td>0.17</td>
<td>0.10</td>
<td>-</td>
<td>0.04</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>0.92</td>
<td>0.33</td>
<td>0.33</td>
<td>1.00</td>
<td>0.88</td>
<td>0.20</td>
<td>1.81</td>
<td>1.83</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.09</td>
<td>0.43</td>
<td>0.03</td>
<td>0.52</td>
<td>0.91</td>
<td>0.09</td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>0.07</td>
<td>0.08</td>
<td>7.00</td>
<td>4.91</td>
<td>0.24</td>
<td>1.27</td>
<td>2.03</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>97.52</td>
<td>100.76</td>
<td>100.51</td>
<td>99.89</td>
<td>100.32</td>
<td>100.66</td>
<td>100.11</td>
<td>97.68</td>
<td>99.50</td>
<td>99.91</td>
<td>98.89</td>
<td>100.82</td>
</tr>
</tbody>
</table>

APPENDIX TABLE 6a. Chemical analyses of fenitic rocks from W. Kenya and E. Uganda.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>FeO</th>
<th>Fe$_2$O$_3$</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>TiO$_2$</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>Type</td>
</tr>
<tr>
<td>SuB218</td>
<td>57</td>
<td>13.4</td>
<td>3.8</td>
<td>4.4</td>
<td>1.9</td>
<td>0.2</td>
<td>8.5</td>
<td>4.5</td>
<td>4.4</td>
<td>1.4</td>
<td>Syenitic feniite</td>
</tr>
<tr>
<td>SuB223</td>
<td>68</td>
<td>20.0</td>
<td>0.9</td>
<td>2.1</td>
<td>0.8</td>
<td>0.1</td>
<td>2.6</td>
<td>8.4</td>
<td>3.2</td>
<td>0.6</td>
<td>do</td>
</tr>
<tr>
<td>SuB242</td>
<td>57</td>
<td>14.9</td>
<td>2.2</td>
<td>2.4</td>
<td>0.9</td>
<td>0.1</td>
<td>3.8</td>
<td>3.6</td>
<td>9.2</td>
<td>0.6</td>
<td>do with nepheline</td>
</tr>
<tr>
<td>SuB279</td>
<td>55</td>
<td>15.1</td>
<td>3.0</td>
<td>2.4</td>
<td>0.9</td>
<td>0.1</td>
<td>5.1</td>
<td>7.7</td>
<td>4.1</td>
<td>0.6</td>
<td>do</td>
</tr>
<tr>
<td>SuTo509</td>
<td>60</td>
<td>15.8</td>
<td>0.5</td>
<td>4.1</td>
<td>0.5</td>
<td>0.2</td>
<td>1.0</td>
<td>5.2</td>
<td>5.5</td>
<td>0.4</td>
<td>Feniite</td>
</tr>
<tr>
<td>SuTo510</td>
<td>73</td>
<td>18.0</td>
<td>0.1</td>
<td>1.3</td>
<td>-</td>
<td>0.1</td>
<td>4.1</td>
<td>5.6</td>
<td>0.4</td>
<td></td>
<td>do</td>
</tr>
<tr>
<td>SuTo514</td>
<td>65</td>
<td>17.9</td>
<td>0.5</td>
<td>3.5</td>
<td>0.8</td>
<td>0.2</td>
<td>0.5</td>
<td>6.1</td>
<td>5.2</td>
<td>0.5</td>
<td>do</td>
</tr>
<tr>
<td>SuTo536</td>
<td>47</td>
<td>14.3</td>
<td>2.4</td>
<td>1.1</td>
<td>0.3</td>
<td>0.1</td>
<td>8.2</td>
<td>1.1</td>
<td>10.4</td>
<td>0.5</td>
<td>Syenitic feniite</td>
</tr>
<tr>
<td>SuTo598</td>
<td>55</td>
<td>12.1</td>
<td>0.5</td>
<td>6.9</td>
<td>0.8</td>
<td>0.4</td>
<td>8.5</td>
<td>3.8</td>
<td>6.9</td>
<td>0.6</td>
<td>do</td>
</tr>
</tbody>
</table>

Appendix Table 6b. Spectrometric and other analyses for major elements in feniitic rocks from carbonatitic complexes in W. Kenya and E. Uganda. - element not detected.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>TiO₂</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>wt.%</td>
<td>Type</td>
</tr>
<tr>
<td>HC54</td>
<td>69</td>
<td>12.6</td>
<td>8.6</td>
<td>2.5</td>
<td>0.1</td>
<td>0.6</td>
<td>7.3</td>
<td>0.6</td>
<td>0.8</td>
<td></td>
<td>Fenite</td>
</tr>
<tr>
<td>HC653</td>
<td>69</td>
<td>12.1</td>
<td>1.4</td>
<td>8.0</td>
<td>0.6</td>
<td>0.9</td>
<td>8.0</td>
<td>6.3</td>
<td>4.1</td>
<td>1.4</td>
<td>do.</td>
</tr>
<tr>
<td>HC743</td>
<td>45</td>
<td>15.7</td>
<td>1.5</td>
<td>3.4</td>
<td>0.6</td>
<td>0.2</td>
<td>6.9</td>
<td>5.0</td>
<td>5.1</td>
<td>0.7</td>
<td>do.</td>
</tr>
<tr>
<td>HC744</td>
<td>45</td>
<td>13.1</td>
<td>1.6</td>
<td>11.2</td>
<td>0.1</td>
<td>0.2</td>
<td>3.6</td>
<td>7.1</td>
<td>7.32</td>
<td>0.7</td>
<td>do.</td>
</tr>
<tr>
<td>HC800</td>
<td>61</td>
<td>12.1</td>
<td>1.2</td>
<td>&gt;15.0</td>
<td>2.2</td>
<td>0.1</td>
<td>6.6</td>
<td>9.8</td>
<td>0.2</td>
<td>0.7</td>
<td>do.</td>
</tr>
<tr>
<td>HC825</td>
<td>50</td>
<td>12.8</td>
<td>0.4</td>
<td>5.8</td>
<td>0.3</td>
<td>0.2</td>
<td>4.3</td>
<td>2.5</td>
<td>11.75</td>
<td>0.7</td>
<td>do.</td>
</tr>
<tr>
<td>N729</td>
<td>57</td>
<td>15.1</td>
<td>1.2</td>
<td>8.3</td>
<td>0.9</td>
<td></td>
<td>5.7</td>
<td>3.8</td>
<td>7.1</td>
<td>0.6</td>
<td>do.</td>
</tr>
<tr>
<td>N734</td>
<td>56</td>
<td>12.7</td>
<td>2.2</td>
<td>11.2</td>
<td>0.3</td>
<td>0.3</td>
<td>3.0</td>
<td>5.9</td>
<td>5.2</td>
<td>1.0</td>
<td>do.</td>
</tr>
</tbody>
</table>

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

Appendix Table 6c. Trace elements in fennite rocks from W. Kenya and E. Uganda.
- element not detected, nd analysis not attempted.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Ba</th>
<th>Be</th>
<th>Co</th>
<th>Cr</th>
<th>Cu</th>
<th>Ga</th>
<th>Li</th>
<th>Nb</th>
<th>Ni</th>
<th>Pb</th>
<th>Sn</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Ce</th>
<th>Y</th>
<th>La</th>
<th>Nd</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>Type</td>
</tr>
<tr>
<td>HC54</td>
<td>300</td>
<td>8</td>
<td>12</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12</td>
<td>15</td>
<td>90</td>
<td>-</td>
<td>190</td>
<td>520</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>Fenite</td>
</tr>
<tr>
<td>HC653</td>
<td>2800</td>
<td>40</td>
<td>22</td>
<td>5</td>
<td>14</td>
<td>150</td>
<td>5</td>
<td>295</td>
<td>27</td>
<td>300</td>
<td>20</td>
<td>1520</td>
<td>230</td>
<td>90</td>
<td>1160</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>do.</td>
</tr>
<tr>
<td>HC743</td>
<td>1250</td>
<td>10</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>100</td>
<td>5</td>
<td>-</td>
<td>940</td>
<td>55</td>
<td>240</td>
<td>880</td>
<td>580</td>
<td>5</td>
<td>170</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC744</td>
<td>1930</td>
<td>10</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>170</td>
<td>5</td>
<td>-</td>
<td>1050</td>
<td>90</td>
<td>90</td>
<td>1750</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>do.</td>
<td></td>
</tr>
<tr>
<td>HC800</td>
<td>180</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>34</td>
<td>170</td>
<td>14</td>
<td>30</td>
<td>380</td>
<td>260</td>
<td>90</td>
<td>540</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>do.</td>
<td></td>
</tr>
<tr>
<td>HC825</td>
<td>5040</td>
<td>10</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>85</td>
<td>50</td>
<td>330</td>
<td>10</td>
<td>680</td>
<td>125</td>
<td>185</td>
<td>1420</td>
<td>700</td>
<td>35</td>
<td>180</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N729</td>
<td>4000</td>
<td>30</td>
<td>-</td>
<td>25</td>
<td>40</td>
<td>70</td>
<td>410</td>
<td>-</td>
<td>440</td>
<td>605</td>
<td>75</td>
<td>1000</td>
<td>1900</td>
<td>650</td>
<td>57</td>
<td>650</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N744</td>
<td>3050</td>
<td>25</td>
<td>-</td>
<td>10</td>
<td>70</td>
<td>10</td>
<td>600</td>
<td>30</td>
<td>85</td>
<td>505</td>
<td>40</td>
<td>640</td>
<td>2000</td>
<td>400</td>
<td>49</td>
<td>50</td>
<td>-</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

- element not detected, nd element not analysed.
| Specimen | Al₂O₃ | CaO | Fe₂O₃ | K₂O | MgO | MnO | TiO₂ | Ba | Be | Co | Cr | Cu | Ga | Li | Mo | Ni | Pb | Sr | V | Zn | Zr | Rock       |
|----------|------|-----|-------|-----|-----|-----|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----| Type       |
| Number   | wt. %| wt. %| wt. %| wt. %| ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | Type       |
| SuB27    | 1.6  | 15.5| >20.0 | 0.2 | 6.3 | 0.6 | 0.3 | 70 | -   | 20 | 115| 10 | 20 | -   | 35 | -   | -   | 320| 500| 100| 470| Pyroxenite |
| HC309    | 6.8  | >20.0| 18.6  | 1.0 | 12.5| 0.6 | 1.3 | 200| -   | 50 | 25 | 19 | -   | -   | -   | 1000| 250| 200| 650| Ijolite    |
| HC323    | 5.0  | >20.0| 20.0  | 1.5 | 11.0| 0.9 | 1.6 | 500| -   | 40 | 20 | 20 | -   | -   | -   | 1160| 1550| 200| 650| do.         |
| U351     | 2.4  | 9.4  | >20.0  | 0.7 | 2.2 | 0.1 | 0.6 | 110| -   | 20 | 20 | 40 | 60 | -   | 130| 420  | 300| 1300| 2060| do.         |
| SuTo590  | 1.4  | 17.6 | >20.0  | 0.5 | 2.5 | 1.0 | 0.8 | 120| -   | 10 | 80 | 25 | -   | 20 | -   | 460 | 1500| 350| 1180| do.         |
| U149     | 1.4  | 16.8 | >20.0  | 0.7 | 4.4 | -   | 0.2 | 50 | -   | 20 | 50 | -   | -   | 20 | 320 | 660 | 780 | 550| 280| Microijolite |
| U207     | 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| do.         |
| U242     | 2.2  | >20.0| >20.0  | 0.9 | 5.6 | -   | 0.3 | 260| -   | 20 | - | -   | -   | -   | 130 | 750 | 750| 550| 280| do.         |
| U345     | 5.2  | >20.0| >20.0  | 1.1 | 3.1 | 1.0 | 2.2 | 260| -   | 15 | 20 | 20 | 20 | -   | 70 | 720 | 800 | 220| 680| do.         |
| SuTo38   | 2.8  | 16.4 | >20.0  | 1.2 | 5.5 | 0.8 | 0.5 | 300| 20  | 15 | - | 15 | 30 | -   | 35 | -   | 860| 1450| 240| 1150| Nepheline-syenite |
| SuB265   | 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| do.         |
| RR16     | 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| Fenite      |
| RR6      | 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| do.         |
| RR201    | 3.0  | 8.4  | >20.0  | 2.2 | 3.0 | 0.9 | 1.6 | 700| -   | 10 | nd | 80 | 10 | -   | -   | 540| 900 | 300| 520| do.         |
| HC797    | 3.2  | 4.0  | >20.0  | 2.8 | 3.2 | 0.6 | 1.8 | 800| 10  | - | nd | - | 50 | -   | 35 | 40  | 820 | 1000| 460| 1700| do.         |
| HC825    | 2.5  | 12.8 | >20.0  | 2.8 | 2.2 | 1.0 | 1.4 | 640| -   | 15 | nd | 20 | 35 | -   | -   | 1050| 1620| 350| 1740| do.         |

Appendix Table 7a. Spectrometric analyses of pyroxenes from peralkaline rocks and fenites. - element not detected nd analysis not attempted.
| Specimen | Al₂O₃ | CaO | Fe₂O₃ | K₂O | MgO | MnO | TiO₂ | Ba | Be | Co | Cr | Cu | Ga | Li | Mo | Ni | Pb | Sr | V | Zn | Zr | Rock   |
|----------|-------|-----|-------|-----|-----|-----|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|     |
| Number   | wt.% | wt.% | wt.% | wt.% | wt.% | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | 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 | 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 | 25  | 22  | 10  | 45  | 5   | -   | 670 | 725 | 125 | 1140| Melanepheline |
| 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.**

| 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| 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 carbonatite complexes in W. Kenya and E. Uganda. - element not detected.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Specimen</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>Fe₂O₃</th>
<th>K₂O</th>
<th>MgO</th>
<th>MnO</th>
<th>TiO₂</th>
<th>Ba</th>
<th>Co</th>
<th>Cr</th>
<th>Cu</th>
<th>Ga</th>
<th>Li</th>
<th>Mo</th>
<th>Ni</th>
<th>Pb</th>
<th>Sr</th>
<th>V</th>
<th>Zn</th>
<th>Zr</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1054</td>
<td>nd</td>
<td>0.9</td>
<td>1.4</td>
<td>6.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>120</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>65</td>
<td>-</td>
<td>-</td>
<td>250</td>
<td>-</td>
<td>35</td>
<td>10</td>
<td>Urtite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U1111</td>
<td>nd</td>
<td>1.7</td>
<td>1.6</td>
<td>6.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>65</td>
<td>5</td>
<td>35</td>
<td>260</td>
<td>35</td>
<td>25</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U211</td>
<td>nd</td>
<td>3.2</td>
<td>1.2</td>
<td>5.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>5</td>
<td>10</td>
<td>580</td>
<td>70</td>
<td>25</td>
<td>10</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC324</td>
<td>nd</td>
<td>2.8</td>
<td>1.3</td>
<td>5.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1050</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>5</td>
<td>-</td>
<td>1400</td>
<td>20</td>
<td>55</td>
<td>160</td>
<td>Ijolite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC309</td>
<td>nd</td>
<td>1.1</td>
<td>1.7</td>
<td>6.5</td>
<td>0.1</td>
<td>0.1</td>
<td>640</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>5</td>
<td>-</td>
<td>5</td>
<td>775</td>
<td>50</td>
<td>50</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC323</td>
<td>nd</td>
<td>3.8</td>
<td>1.7</td>
<td>5.3</td>
<td>-</td>
<td>-</td>
<td>0.7</td>
<td>720</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>10</td>
<td>-</td>
<td>5</td>
<td>2100</td>
<td>30</td>
<td>140</td>
<td>do.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.
| Specimen | Al$_2$O$_3$ | CaO | Fe$_2$O$_3$ | K$_2$O | MgO | MnO | TiO$_2$ | Ba | Be | Co | Cr | Cu | Ga | Li | Mo | Ni | Pb | Sr | V | Zn | Zr | Rock       |
|----------|-----------|-----|-------------|-------|-----|-----|--------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|    |
| Number   | wt.%      | wt.%| wt.%        | wt.%  | wt.%| ppm | ppm    | ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| ppm| Type                  |
| SuB247   | nd        | 0.5 | 0.2         | 11.3  | -   | 8   | 6000   | -  | -  | -  | 45 | 5  | -  | 15  | 1025 | -  | 50 | 180 | Nepheline-syenite |
| SuB265   | nd        | -   | 0.1         | 12.3  | -   | 2   | 6000   | -  | -  | -  | 45 | -  | -  | 710 | -   | -  | 50 | do. |
| SuB266   | nd        | 0.2 | 0.3         | 12.3  | -   | 0.1 | 6000   | 5  | 60 | -  | 870| 10 | 10 | 140 | do.  |
| SuB266   | nd        | 0.7 | 1.8         | 11.5  | -   | 0.8 | 6000   | -  | -  | 80 | 20 | -  | 5  | 550 | 125 | 50 | 315 | do.  |
| SuN106   | nd        | -   | 0.6         | 12.0  | -   | 0.1 | 6000   | -  | -  | -  | 40 | -  | -  | 580 | -   | -  | 10 | do. |
| N464     | nd        | -   | 0.5         | nd    | -   | 0.2 | 4400   | -  | -  | -  | 40 | -  | -  | 360 | -   | 50 | 225 | do.  |
| N266     | nd        | 1.0 | 1.8         | 8.0   | -   | 1.2 | 6000   | -  | -  | -  | 25 | -  | -  | 440 | 45  | 15 | 610 | do.  |
| N225     | nd        | 0.1 | 0.6         | 11.0  | -   | 0.2 | 6000   | -  | -  | -  | 30 | -  | -  | 675 | 70  | 10 | 65  | do.  |
| N503     | nd        | 0.1 | 1.4         | nd    | -   | 4   | 6000   | -  | 10 | 40 | -  | 10 | 190| 45  | 30  | 480 | do.  |
| U149     | nd        | -   | 0.8         | 9.0   | -   | 0.1 | 6000   | -  | 45 | -  | -  | 5  | 380| -   | 15  | 90  | do.  |
| U207     | nd        | 1.8 | 4.5         | nd    | -   | 0.1 | 6000   | -  | -  | 20 | 30 | 10 | -  | 5   | 550 | 110 | 30 | 135 | Microijolite |
| U242     | nd        | 1.6 | 2.3         | 9.4   | -   | 1.3 | 6000   | -  | -  | 50 | 10 | -  | 10 | 875 | 55  | 45 | 350 | do.  |
| U345     | nd        | 0.3 | 0.9         | nd    | -   | 0.2 | 6000   | -  | 10 | 35 | -  | -  | 5  | 1250| 30  | 15 | 60  | do.  |
| HC320    | nd        | 0.7 | 0.8         | 8.2   | -   | 0.1 | 1920   | -  | -  | -  | 210| -  | -  | 15  | 290 | -  | 50 | 1000| Fenite |
| HC825    | nd        | 1.1 | 14.3        | -     | -   | 0.2 | 6000   | -  | -  | -  | 135| -  | -  | 475 | 20  | 20 | 790 | do.  |
| HC790    | nd        | 1.8 | 12.8        | -     | -   | 0.2 | 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 | Al₂O₃ | CaO | Fe₂O₃ | K₂O | MgO | MnO | TiO₂ | Ba  | Bo  | Co  | Cr  | Cu  | Ga  | Li  | Mo  | Ni  | Pb  | Sr  | V  | Zn | Zr | Rock   |
|----------------|------|-----|------|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|----|----|-------|
| 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.    |
| 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.
<table>
<thead>
<tr>
<th></th>
<th>Mica</th>
<th>Garnet HC324</th>
<th>Garnet HC323</th>
<th>Dark Garnet HC741</th>
<th>Light Garnet HC741</th>
<th>Garnet HC805</th>
<th>Garnet HC805</th>
<th>Sphene HC324</th>
<th>Sphene HC323</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>50.44</td>
<td>39.85</td>
<td>33.49</td>
<td>34.25</td>
<td>36.59</td>
<td>34.75</td>
<td>35.29</td>
<td>31.74</td>
<td>31.15</td>
</tr>
<tr>
<td>A1O2</td>
<td>35.60</td>
<td>0.66</td>
<td>0.63</td>
<td>0.69</td>
<td>0.98</td>
<td>1.62</td>
<td>0.83</td>
<td>0.95</td>
<td>0.68</td>
</tr>
<tr>
<td>CaO</td>
<td>0.03</td>
<td>32.31</td>
<td>32.74</td>
<td>33.32</td>
<td>33.71</td>
<td>32.70</td>
<td>34.62</td>
<td>25.25</td>
<td>27.69</td>
</tr>
<tr>
<td>FeO</td>
<td>1.78</td>
<td>25.90</td>
<td>24.78</td>
<td>23.69</td>
<td>25.53</td>
<td>22.92</td>
<td>24.40</td>
<td>2.00</td>
<td>2.30</td>
</tr>
<tr>
<td>MgO</td>
<td>*</td>
<td>0.29</td>
<td>0.46</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>MnO</td>
<td>*</td>
<td>0.47</td>
<td>0.52</td>
<td>0.51</td>
<td>0.47</td>
<td>0.49</td>
<td>0.45</td>
<td>0.03</td>
<td>*</td>
</tr>
<tr>
<td>TiO2</td>
<td>*</td>
<td>5.18</td>
<td>7.24</td>
<td>7.49</td>
<td>2.73</td>
<td>7.44</td>
<td>4.31</td>
<td>40.03</td>
<td>38.15</td>
</tr>
<tr>
<td>K2O</td>
<td>12.10</td>
<td>0.06</td>
<td>0.09</td>
<td>*</td>
<td>*</td>
<td>0.03</td>
<td>0.04</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Appendix Table 8a. Electron microprobe analyses of mica, melanite garnet and sphene from several ijolites from W. Kenya and E. Uganda.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Cerium wt.p.c.</th>
<th>Lanthanum wt.p.c</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC741</td>
<td>Ijolite</td>
<td>0.07</td>
<td>0.1</td>
</tr>
<tr>
<td>HC805</td>
<td>Ijolite</td>
<td>0.05</td>
<td>*</td>
</tr>
<tr>
<td>HC324</td>
<td>Melanite</td>
<td>0.11</td>
<td>0.05</td>
</tr>
<tr>
<td>U242</td>
<td>Ijolite</td>
<td>0.05</td>
<td>*</td>
</tr>
<tr>
<td>HC964</td>
<td>Ijolite</td>
<td>0.32</td>
<td>0.15</td>
</tr>
<tr>
<td>HC323</td>
<td>Ijolite</td>
<td>0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>N684</td>
<td>Nepheline-syenite</td>
<td>0.18</td>
<td>0.11</td>
</tr>
<tr>
<td>N688</td>
<td>Nepheline-syenite</td>
<td>0.19</td>
<td>0.08</td>
</tr>
<tr>
<td>N266</td>
<td>Nepheline-syenite</td>
<td>0.17</td>
<td>*</td>
</tr>
<tr>
<td>HC338</td>
<td>Sovite</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>HF508</td>
<td>Alvikite</td>
<td>0.11</td>
<td>*</td>
</tr>
<tr>
<td>HC649</td>
<td>Alvikite</td>
<td>0.07</td>
<td>*</td>
</tr>
<tr>
<td>HC367</td>
<td>Alvikite</td>
<td>0.16</td>
<td>*</td>
</tr>
</tbody>
</table>

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.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Cerium wt.p.c.</th>
<th>Lanthanum wt.p.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR482</td>
<td>Fenite</td>
<td>0.12</td>
<td>0.05</td>
</tr>
<tr>
<td>RR516</td>
<td>Fenite</td>
<td>0.11</td>
<td>*</td>
</tr>
<tr>
<td>RR201</td>
<td>Fenite</td>
<td>0.05</td>
<td>*</td>
</tr>
</tbody>
</table>

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.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Rock Type</th>
<th>Cerium wt. p.c.</th>
<th>Lanthanum wt. p.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC338</td>
<td>Sovite</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>HF508</td>
<td>Alvikite</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>HC649</td>
<td>Alvikite</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>HC367</td>
<td>Alvikite</td>
<td>0.06</td>
<td>*</td>
</tr>
<tr>
<td>HF661</td>
<td>Ferruginous Alvikite</td>
<td>0.21</td>
<td>*</td>
</tr>
<tr>
<td>HF666</td>
<td>Ferruginous Alvikite</td>
<td>0.13</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CALCITE.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MONAZITE.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appendix Table 8b, (continued). Electron microprobe analyses for Ce and La in calcite, pyrochlore, and monazite from carbonatites, from W. Kenya and E. Uganda.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* element not detected.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specimen Number</td>
<td>Rock Type</td>
<td>Fe₂O₃</td>
<td>MnO</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------</td>
<td>-------</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>CALCITE.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC338</td>
<td>Sovite</td>
<td>0.13</td>
<td>0.25</td>
</tr>
<tr>
<td>HF508</td>
<td>Alvikite</td>
<td>0.15</td>
<td>0.04</td>
</tr>
<tr>
<td>HC649</td>
<td>Alvikite</td>
<td>0.13</td>
<td>0.19</td>
</tr>
<tr>
<td>HC258</td>
<td>Alvikite</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>HF666</td>
<td>Ferruginous Alvikite</td>
<td>0.92</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>MAGNETITE.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF508</td>
<td>Alvikite</td>
<td></td>
<td>0.70</td>
</tr>
<tr>
<td>HC258</td>
<td>Alvikite</td>
<td></td>
<td>1.30</td>
</tr>
<tr>
<td>HC649</td>
<td>Alvikite</td>
<td></td>
<td>1.28</td>
</tr>
<tr>
<td><strong>PYROCHLORIE.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC649</td>
<td>Alvikite</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>HF666</td>
<td>Ferruginous Alvikite</td>
<td>0.36</td>
<td></td>
</tr>
</tbody>
</table>

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.
<table>
<thead>
<tr>
<th></th>
<th>FeO</th>
<th>MnO</th>
<th>Zr</th>
<th>Zn</th>
<th>V</th>
<th>Mo</th>
<th>Li</th>
<th>Y</th>
<th>Nd</th>
<th>La</th>
<th>Ce</th>
<th>Sr</th>
<th>Nb</th>
<th>Ba</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>0.53</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zr</td>
<td>0.21</td>
<td>-0.11</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>0.71</td>
<td>0.63</td>
<td>0.11</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0.75</td>
<td>0.46</td>
<td>0.34</td>
<td>0.62</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td>0.04</td>
<td>0.15</td>
<td>0.22</td>
<td>0.03</td>
<td>-0.21</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li</td>
<td>-0.11</td>
<td>-0.28</td>
<td>0.20</td>
<td>-0.15</td>
<td>-0.35</td>
<td>0.52</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>0.39</td>
<td>0.43</td>
<td>0.15</td>
<td>0.39</td>
<td>0.28</td>
<td>0.02</td>
<td>-0.04</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nd</td>
<td>0.28</td>
<td>0.62</td>
<td>-0.05</td>
<td>0.36</td>
<td>0.34</td>
<td>0.17</td>
<td>-0.11</td>
<td>0.39</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>La</td>
<td>0.19</td>
<td>0.53</td>
<td>0.11</td>
<td>0.28</td>
<td>0.30</td>
<td>0.09</td>
<td>-0.18</td>
<td>0.36</td>
<td>0.73</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ce</td>
<td>0.38</td>
<td>0.73</td>
<td>0.00</td>
<td>0.51</td>
<td>0.44</td>
<td>0.13</td>
<td>-0.18</td>
<td>0.42</td>
<td>0.79</td>
<td>0.88</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr</td>
<td>-0.17</td>
<td>-0.01</td>
<td>-0.04</td>
<td>-0.25</td>
<td>-0.20</td>
<td>0.28</td>
<td>0.15</td>
<td>-0.09</td>
<td>0.06</td>
<td>0.19</td>
<td>0.07</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nb</td>
<td>0.14</td>
<td>0.03</td>
<td>0.48</td>
<td>0.15</td>
<td>0.27</td>
<td>0.19</td>
<td>0.36</td>
<td>0.21</td>
<td>0.34</td>
<td>0.43</td>
<td>0.37</td>
<td>0.13</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ba</td>
<td>0.42</td>
<td>0.72</td>
<td>-0.07</td>
<td>0.55</td>
<td>0.25</td>
<td>0.33</td>
<td>-0.10</td>
<td>0.39</td>
<td>0.34</td>
<td>0.41</td>
<td>0.61</td>
<td>0.04</td>
<td>-0.06</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>0.51</td>
<td>0.17</td>
<td>0.28</td>
<td>0.33</td>
<td>0.35</td>
<td>-0.01</td>
<td>0.19</td>
<td>0.38</td>
<td>0.31</td>
<td>0.22</td>
<td>0.27</td>
<td>-0.07</td>
<td>0.39</td>
<td>0.12</td>
<td>1.0</td>
</tr>
<tr>
<td>TlO</td>
<td>0.47</td>
<td>-0.03</td>
<td>0.25</td>
<td>0.22</td>
<td>0.40</td>
<td>-0.16</td>
<td>0.17</td>
<td>0.29</td>
<td>0.07</td>
<td>0.01</td>
<td>0.04</td>
<td>-0.19</td>
<td>0.32</td>
<td>-0.22</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Appendix Table 9a. Correlation matrix for major and trace elements in carbonatites from W. Kenya and E. Uganda.
| Element | FeO  | FeO$_2$ | MnO | MgO | CaO | Na$_2$O | K$_2$O | TiO$_2$ | Ba | Be | Co | Ga | Li | Nb | Sr | V | Zn | Zr | Ce | Y |
|---------|------|---------|-----|-----|-----|---------|--------|---------|----|----|----|----|----|----|----|---|----|----|----|----|----|
| FeO     | 1.00 |         |     |     |     |         |        |         |    |    |    |    |    |    |    |   |    |    |    |    |    |
| FeO$_2$ | 0.54 | 1.00    |     |     |     |         |        |         |    |    |    |    |    |    |    |   |    |    |    |    |    |
| MnO     | 0.51 | 0.61    | 1.00|     |     |         |        |         |    |    |    |    |    |    |    |   |    |    |    |    |    |
| MgO     | 0.64 | 0.49    | 0.41| 1.00|     |         |        |         |    |    |    |    |    |    |    |   |    |    |    |    |    |
| CaO     | 0.57 | 0.37    | 0.64| 1.00|     |         |        |         |    |    |    |    |    |    |    |   |    |    |    |    |    |
| Na$_2$O | -0.30| -0.40   | -0.27| -0.30| -0.24| 1.00    |         |         |    |    |    |    |    |    |    |   |    |    |    |    |    |
| K$_2$O  | -0.46| -0.25   | -0.39| -0.60| -0.44| 0.31    | 1.00    |         |    |    |    |    |    |    |    |   |    |    |    |    |    |
| TiO$_2$ | 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| 0.00| 1.00|    |    |    |   |    |    |    |    |    |
| Ga      | -0.34| -0.22   | -0.15| -0.58| -0.31| 0.42    | 0.60    | -0.35   | 0.15| -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| 0.23| 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| 0.01|    |

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.
BIBLIOGRAPHY.


_______ 1964 Element distribution in igneous rocks, VII.

_______ 1966 Element distributions in specific igneous rocks, VIII. Geochim. cosmochim. Acta v. 30


_______ and Schairer J.F. 1966. The system Na$_2$O-Al$_2$O$_3$-FeO$_3$-SiO$_2$ at latmosphere, and the petrogenesis of the alkaline rocks. J. Petrology v. 7 No. 1 pp. 114-170.


Biggar G.M. 1967. The system Ca(OH)$_2$-CaF$_2$ - Ca$_3$(PO$_4$)$_2$ - H$_2$O. Mineralog. Mag. v. 36.


____ 1965 Petrogenesis of the alkaline igneous rock suites of volcanic and intrusive centres of E. Uganda. J.Pet. v.6, No.1


<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Title</th>
</tr>
</thead>
</table>


Wahstedt W.C. and Davis J.C. 1968. Fortran IV program for computation and display of Principal components. Computer contribution 21, State geol. Survey, Univ. of Kansas, U.S.A.


1965 Melting relations in the system CaO-MgO-CO$_2$-H$_2$O and its petrological applications. J.Pet. v.6, pp.101-123.

and Haas J.L. 1965. The system CaO-SiO$_2$-CO$_2$-H$_2$O, melting relations with excess vapour at 1kb pressure. Geochim.cosmochim Acta v.29, pp.871-893.


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.

Abstract.

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 Budda, 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 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 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.