# A CHEMICAL AND MINERALOGICAL STUDY OF THE PYROXENES FROM SOME AFRICAN ALKALINE ~~ROCKS~~ COMPLEXES

A Thesis presented for the Degree of

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in the

University of London

by

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# ABSTRACT

The thesis describes a group of pyroxenes belonging to a diopside-hedenbergite-acmite series, which come from the alkaline rocks of East and Southern Africa.

The pyroxenes have been analysed chemically; and two refractive indices and the specific gravity have been determined. Values obtained for the $A' \wedge c$ angle have been included in the study.

The compositions of the pyroxenes depend on the area from which they come and also on the rock types in which they occur; but all the pyroxenes from the African alkaline rocks fall within a well-defined band of composition.

It has been found that differences in content of the minor constituents depend both on composition and the area from which they come.

The $Fe^{+2}/Mg$ ratio in the more diopsidic pyroxenes, and the $Fe^{+3}$ content in those nearer acmite control the physical properties.

## ACKNOWLEDGEMENTS

I should like to thank Professor B.C. King for his help and for giving me the opportunity to start this work.

I also thank Professor J.H. Taylor for his encouragement and for providing facilities to complete the thesis.

Dr. J.P. Riley, of the Department of Oceanography, University of Liverpool, allowed me to work for some time in his laboratories and also gave me much valuable advice on methods of analysis, for which I am most grateful.

In addition I am grateful to Mr. B. Collins of the Department of Geology, Bedford College, who carried out the determinations of the A' c angle used in the thesis, and to the members of the Department of Geology, Bedford College, who provided the specimens.

Finally, I am indebted to my sister, who typed the manuscript.

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# I INTRODUCTION

The pyroxenes studied belong to a diopside-hedenbergite-acmite series. The rocks from which they come are members of the alkaline suite of East and Southern Africa.

Previously, very little work has been carried out on these minerals and it had been assumed that they belonged to the diopside aegirine-augite series. The work forms a contribution to the study of the East African alkaline rocks being made by Professor King and other workers.

The chemistry of the major and some minor constituents is discussed, and certain physical properties, refractive index, specific gravity and the A $\wedge$ c angle (King 1962) have been selected for determination, with the intention of providing graphs for the estimation of the composition of these pyroxenes from values obtained for their physical properties.

Many of the pyroxenes analysed come from the ijolites and associated rocks of Lokupoi (Napak) in Uganda, but pyroxenes have also been analysed from Budeda, Bukusu and Tororo, also in Uganda, and from Semarule in Bechuanaland. The few analyses of pyroxenes from certain of these localities which have been made by other workers have been used; they are one from Napak (King 1949) and one each from Budeda, Napak and Tororo (Sutherland, unpublished data).

A number of pyroxenes from other areas of alkaline rocks, which were analysed by the writer, have been added for comparative purposes. These include two from Loch Borrolan in Scotland and four from Sørøy in Northern Norway, areas that are being studied by members of the Department of Geology at Bedford College. In all, sixty one new analyses have been made (Table I).

Use has also been made of thirty seven published analyses of pyroxenes from other areas of alkaline rocks (Table II). These include seven from Africa, but are mostly from other areas.

## TABLE II

## PUBLISHED ANALYSES OF PYROXENES

| Locality | Number of Analyses | Reference |
|---|---|---|
| Assynt, Sutherland | 1 | Sabine 1950. |
| Brevik, Norway | 1 | Washington & Merwin 1927. |
| Haliburton County, Ontario | 3 | Tilley & Gittins 1961. |
| Homa Bay, Kenya | 1 | Pulfrey 1950. |
| Iivaara, Finland | 3 | Lehijarvi 1960. |
| Ilmen Mountains, U.S.S.R. | 1 | Zavaritsky 1946. |
| Iron Hill, Colorado, U.S.A. | 1 | Larsen 1942. |
| Kangerdluarsuk, Greenland | 1 | W. & M. 1927. |
| Kigom, Nigeria | 1 | Greenwood 1951. |
| Kola Peninsula, U.S.S.R. | 1 | Polkanov 1940. |
| Laven Langesund Fjord, Norway | 1 | W. & M. 1927. |
| Libby Stock, Montana, U.S.A. | 1 | Goransen 1927. |
| Libby Stock, Montana, U.S.A. | 2 | W. & M. 1927. |
| Magnet Cove, Arkansas, U.S.A. | 2 | W. & M. 1927. |
| Morotu, Sakhalin, Japan | 7 | Yagi 1953. |
| Nyamunuka, S.W. Uganda | 1 | Sahama 1952. |
| Nyiragongo, Belgian Congo | 4 | Sahama & Meyer 1958. |
| Quincy, Massachusetts, U.S.A. | 1 | W. & M. 1927. |
| Rockall | 1* | W. & M. 1927. |
| Rocky Boy Stock, Bearpaw Mountains, Montana, U.S.A. | 1 | Pecora 1942. |
| Rundmeyr, Norway | 1 | W. & M. 1927. |
| Salem Neck, Massachusetts, U.S.A. | 1 | W. & M. 1927. |

*Calculated from a rock analysis.

## II PREPARATION OF MINERAL SAMPLES FOR ANALYSIS

During the preparation of the sample for rock analysis, part was retained for a study of the minerals. Whereas the material for rock analysis was crushed to a fine powder in the agate morter, the material for mineral analysis was ground initially so that it passed a 120 mesh sieve and then washed to remove the dust. The magnetite (which was present in a few samples) was extracted with a hand magnet, and the remaining material passed through the magnetic separator set so that a rapid rough separation of light and dark minerals was effected. The portion of light minerals (felspar, nepheline, wollastonite, cancrinite and also apatite and sphene) was set aside, and the dark minerals: pyroxene, usually melanite, and sometimes other iron ores and biotite were examined under the microscope. Almost invariably they were found to consist of composite grains; the typical occurrence of many of the pyroxenes is in crystal intergrowths with melanite.

The dark minerals were further ground, this time to pass a 200 mesh sieve, washed and passed through the separator adjusted to give a more exact separation. This removed the remaining light minerals, including those released from composite grains. Where pyroxene was the only dark mineral present, the material was ready for analysis at this stage.

By altering the setting of the magnetic separator, it was possible to separate the melanite and iron ores from the biotite and pyroxene. Where biotite was present, it always came down with the pyroxene.

The separation was repeated until the pyroxene was as free as possible from melanite. Occasionally, at this stage, the pyroxene was clean enough to be used for analysis. Usually, however, the use of heavy liquids was necessary to obtain really pure samples. The biotite was separated using methylene iodide (s.g. 3.33) in which pyroxenes of almost all compositions sink, as only the most diopsidic varieties have specific gravities of less than 3.33, and in which the biotite floats easily. For removal of the last traces of melanite, Clerici's solution was used. No hand picking was done for the samples analysed by macromethods. For the six samples analysed by micromethods, the sample was entirely hand picked.

The samples were all carefully washed in distilled water and dried at 105°C for 12 hours before analysis.

## III ANALYTICAL METHODS

Most of the pyroxenes were analysed at Bedford College using the methods to be described, but ten were analysed in the Department of Oceanography, University of Liverpool, under the supervision of Dr. J.P. Riley and in accordance with his methods (Riley 1958, 1959). Four analyses were made at King's College, London, using the rapid methods of Riley except for $SiO_2$, CaO and MgO which were determined gravimetrically.

The methods generally employed were adapted by the writer to suit the apparatus available. A Unicam SP 500 or similar instrument was not available, and therefore some colourimetric methods now commonly in use were not practicable. The "rapid" determination of silica as the molybdenum blue complex could not be carried out as the filter spectrophotometer available was not sufficiently sensitive when used at the infra red end of the spectrum.

Since the rapid methods of analysis for calcium and magnesium were not found to be very satisfactory, owing to the large amounts of these constituents in the diopsidic pyroxenes, it was convenient to determine these and the silica in the same portion using gravimetric methods. The lack of apparatus for certain of the rapid methods thus proved not to be disadvantageous.

The eleven principal constituents were determined in the following three groups:-

1. $SiO_2$, total $R_2O_3$, CaO and MgO;
2. $TiO_2$, MnO, $P_2O_5$, $K_2O$, $Na_2O$ and total iron as $Fe_2O_3$;
3. FeO.

Two one gram portions and several (usually three) half gram portions were taken. A sample of not less than about four grams was required in one analysis, and hand picking was therefore not practicable.

## 1. GRAVIMETRIC METHODS

One of the one gram samples was used as a classical "main" portion in which silica, total $R_2O_3$ and calcium and magnesium oxide were determined. The mineral sample was fused with sodium carbonate. The addition of potassium carbonate was not found to be necessary. Some minor modifications of the common classical methods were necessary owing to the unusual proportions in which some of the major constituents are present. In the diopsidic pyroxenes there are large amounts of calcium and magnesium, while the proportion of iron to aluminium in the hydroxide precipitate is very high in all the pyroxenes.

In order to avoid as far as possible the risk of low results for silica, considerable care was taken to ensure its complete precipitation and dehydration, since some silica is liable to be retained in solution. Three evaporations were carried out, and the residue each time was baked for two hours at about 400°C on the hot plate.

Owing to the very high proportion of iron in the precipitate formed with ammonia, the colour change in the indicator (methyl red) was masked so that ammonia was necessarily added in large excess. After a double precipitation, therefore, the combined filtrates were acidified, evaporated down to about 200 mls. when a further precipitation with ammonia was carried out. This time the end point was easily seen as the bulk of the precipitate was very small. Unless this procedure was followed, the calcium oxide obtained was discoloured by traces of iron; and aluminium would also be present, but this would not be apparent from the colour.

A double oxalate precipitation was carried out for the determination of calcium. The precipitate was ignited at 900°C to 1000°C to constant weight and thus weighed as $CaO$.

The magnesium was precipitated as the phosphate after addition of nitric acid to the filtrate from the calcium oxalate and evaporation to dryness to decompose the ammonium salts, present at this stage in large amounts. A large excess of ammonium salts present in solution prevents the complete precipitation of magnesium either as phosphate or oxine. The magnesium phosphate was ignited at a low temperature (dull redness only) to constant weight and weighed as the pyrophosphate. The use of vitreosil crucibles for the ignition of the magnesium phosphate was found to be desirable, as these never become too hot over a Bunsen burner flame, thereby preventing the paper from burning and the reduction of the phosphate. It was found that if the paper was allowed to burn, a white precipitate was never obtained.

The precipitation of magnesium as the oxine was never used as there was always sufficient magnesium phosphate for accurate weighing, and the bulk of oxine precipitate formed with the larger amounts of magnesium of the diopsidic pyroxenes was found to be too great.

## 2. COLOURIMETRIC AND OTHER METHODS

Using the other one gram portion, total iron as $Fe_2O_3$, $Na_2O$, $K_2O$, $TiO_2$, $P_2O_5$, and MnO were determined.

The alkalies were determined using the Eel flame photometer making calibration curves each time it was used and following the now well known methods, except that the interfering elements were not removed using the citrate resin but by precipitation with ammonia and filtration.

Of the methods for the remaining constituents, some were the usual colourimetric methods and others different because of the limitations of the Hilger Spectrophotometer.

The methods of Riley were used for MnO and $TiO_2$, and for $Al_2O_3$ when it was determined directly. In most cases, however, the $Al_2O_3$ value was obtained by difference from the value for the total $R_2O_3$. Modifications of the dilutions used by Riley were necessary as the Hilger Spectrophotometer (Spekker) is most sensitive with higher colour concentration than the Unicam SP 500. The Spekker is, however, very reliable for measuring the yellow and violet colours of the $TiO_2$, $Al_2O_3$ and MnO complexes.

Fluoride destroys or prevents the formation of the permanganate colour used in the determination of manganese. Care should be taken to ensure that all the fluoride from the HF is removed in the second fuming down. If there was any doubt, a third fuming was carried out.

When $Al_2O_3$ is determined as the yellow oxine complex, it is extracted with a solution of 8-hydroxyquinoline in chloroform after adjusting the pH to 4.5 and complexing the iron as the dipyridyl complex. If the pH is incorrect, the iron remains in solution, and forms a green oxine.

With the high Fe/Al ratio of these pyroxenes, great care had to be taken to get the correct pH in order to obtain an accurate value for $Al_2O_3$.

The fact that sulphuric acid rather than perchloric acid had been used in dissolving the minerals made it difficult to obtain the correct pH value. The use of sulphuric acid was necessary, because the presence of Ti in appreciable quantities in some of the pyroxenes led to the formation of an insoluble oxychloride with perchloric acid. This meant that all the titanium was not brought into solution.

Using sulphuric acid, the chief difficulty resulted from the relative insolubility of calcium sulphate, which formed in large amounts from the diopsidic pyroxenes. Since, however, calcium was determined gravimetrically in the other portion, any undissolved calcium sulphate was filtered off.

The methods used for total iron and phosphorus were not those commonly in use. The blue molybdenum complex used for the determination of phosphorus could not be measured on the spekker as the instrument is not sufficiently sensitive at the infra red end of the spectrum. In the experience of the writer, the red dipyridyl complex of iron is not very easily measured on the spekker.

For $P_2O_5$, the yellow molybdivanadophosphoric acid complex was used. This is yellow, stable and can be accurately measured.

The total iron was determined using the yellow-brown complex formed by sulphosalicylic acid with ferric iron. This was found in the circumstances to be more satisfactory than the dipyridyl method although the sulphosalicylic acid complex is rather unstable and somewhat sensitive to temperature.

It was found, however, that determinations compare very well with those made in Liverpool using the dipyridyl complex with the same samples.

The following precautions should be taken when using the sulphosalicylic acid method:-

(i) The colour of the solution should be yellow or yellow brown and not reddish brown, i.e. rather dilute. The iron should not exceed 100 µg/ml.

(ii) A large excess of reagent does have some effect on the colour, therefore the same volume of reagent should always be added to each solution.

(iii) Several standards should be run with each batch of samples so that in calculation, standards can be selected which give readings near to those of the samples. This is necessary because the reading/concentration relationship is not exactly rectilinear although at low concentrations it is nearly so.

## 3. DETERMINATION OF FERROUS IRON

For the determination of ferrous iron, a modified Pratt method was used, titrating the solution of the rock with either potassium permanganate (which was not found to be so satisfactory) or with potassium dichromate using sodium diphenylamine sulphonate as indicator.

## 4. DETERMINATION OF WATER AND CARBON DIOXIDE

As was expected, there is little water and no carbon dioxide in the pyroxenes. Only seven determinations of these constituents were made, four using the micromethod of Riley (1959) and three by a method similar to the macrodetermination of Riley (1958).

# IV CALCULATION AND PLOTTING OF THE ANALYSES

Various methods of calculation and plotting of the analyses were tried of which the most instructive are discussed below.

## 1. MOLECULES OF FIXED END MEMBERS

### (1) Diopside, Hedenbergite and Acmite

The molecular proportions of each constituent in the analysis were calculated, and allotted to molecules of diopside, hedenbergite and acmite.

Strict rules were applied in this calculation. First $Fe_2O_3$ was allotted to the alkalies. $Al_2O_3$ was then used if $Fe_2O_3$ was insufficient for all the alkalies. $FeO + MnO$ was allotted to $CaO$ to give hedenbergite and then $MgO$ to $CaO$ to give diopside. (Washington & Merwin 1927.) $Al_2O_3$ and $TiO_2$ were used to make up any deficiency in $SiO_2$.

These three molecules, expressed as percentages of the total molecular proportions of the oxides, were plotted on a diagram as shown in Figure 1. A triangular plot results, the size of which depends on the amount of the constituents which have not been allocated to the main molecules. This is usually $P_2O_5$ and excess $CaSiO_3$, and occasionally $MgSiO_3$, $Al_2O_3$ and $TiO_2$.

In the diopsidic pyroxenes the size of the triangle

Figure 2

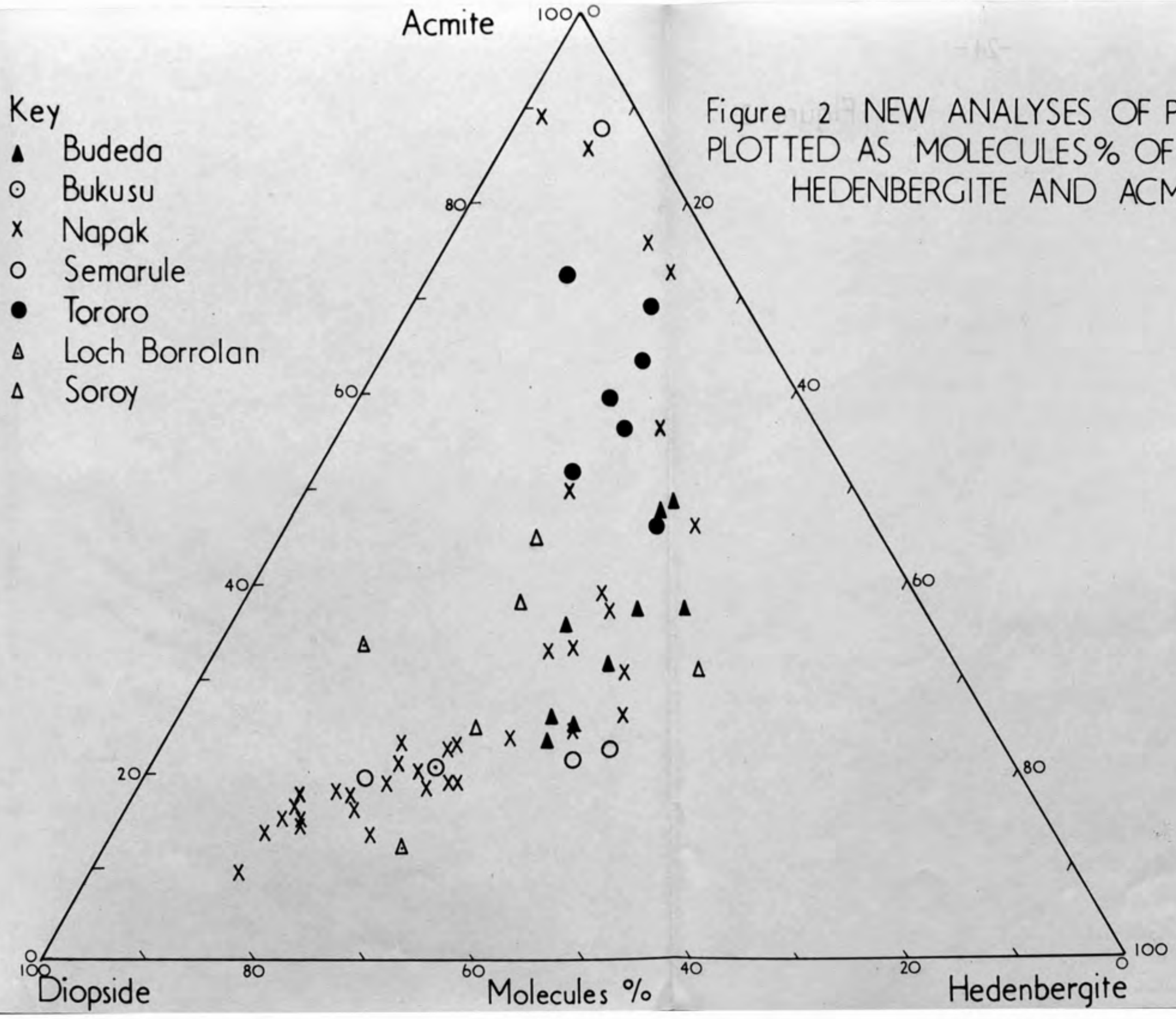


Figure 2 NEW ANALYSES OF PYROXENES PLOTTED AS MOLECULES % OF DIOPSIDE, HEDENBERGITE AND ACMITE

Figure 2a

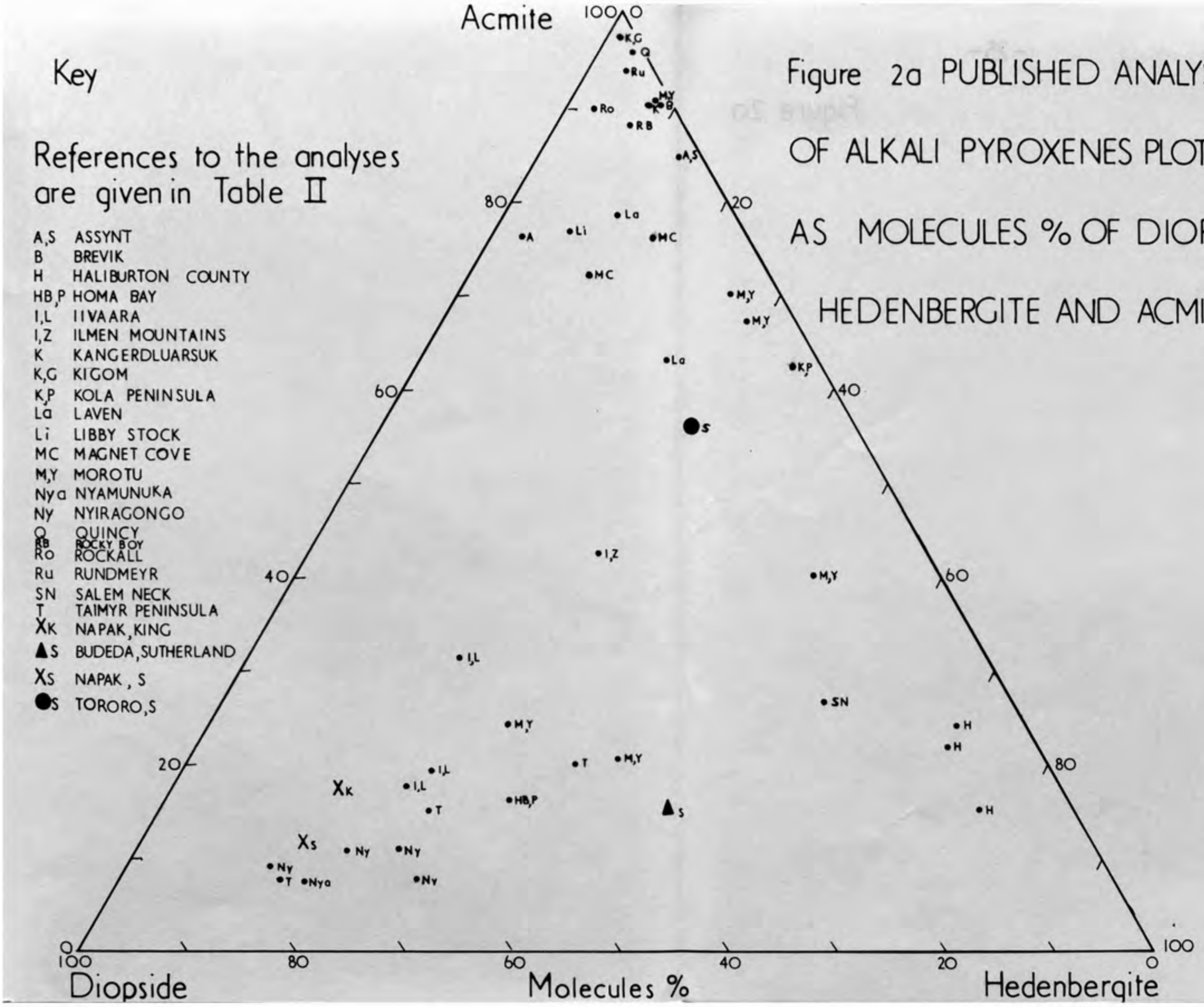


Figure 2a PUBLISHED ANALYSES OF ALKALI PYROXENES PLOTTED AS MOLECULES % OF DIOPSIDE, HEDENBERGITE AND ACMITE

mainly reflects excess $CaSiO_3$. In other cases, the excess consists principally of $MgSiO_3$, $Al_2O_3$ and $TiO_2$. Figure 2 shows the compositions of the pyroxenes in terms of the three main molecules only.

As shown in Figure 2, the great majority of the pyroxenes, including all of those from African localities, fall within a curved band, which extends from a composition near diopside initially trending in a direction representing predominant enrichment in hedenbergite, and then, when acmite reaches 25%, swings sharply to trend directly towards acmite.

Figures 1a and 2a show plots of all previous analyses, calculated in the same way. Most of these pyroxenes, including all those from rocks which are alkaline in the strictly accepted sense, fall within the band.

Of the newly analysed pyroxenes, only one falls outside the band. This is from a xenolith in borolanite and shows enrichment in MgO. Of the previously analysed samples, those from the nepheline rocks of Ontario, Canada show a distinctive enrichment in FeO.

The distribution of pyroxenes from different areas in different groups within the pyroxenes band suggests that individual areas show chemical peculiarities (Figure 3).

Figure 3

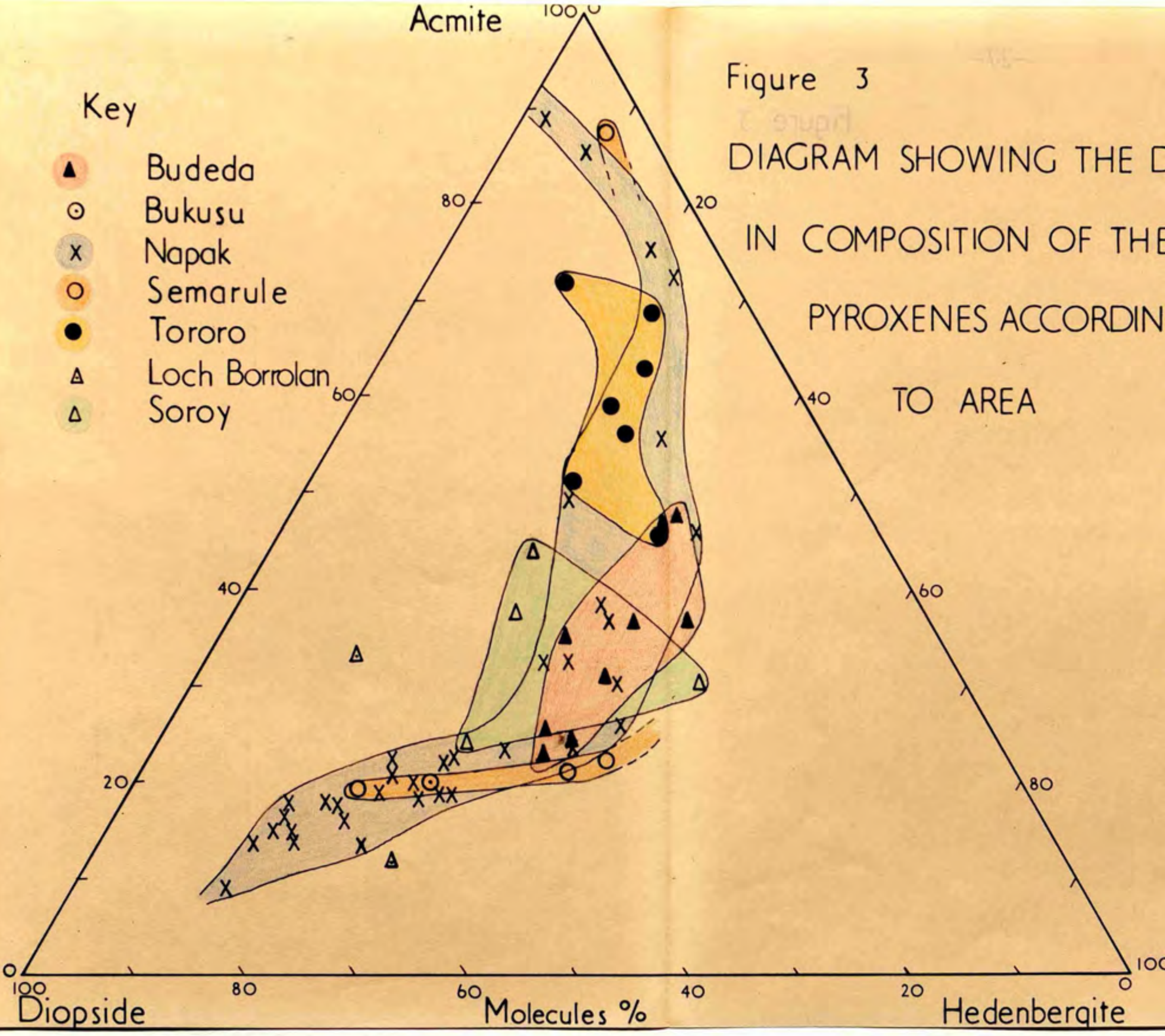


Figure 3

DIAGRAM SHOWING THE DIFFERENCE IN COMPOSITION OF THE PYROXENES ACCORDING TO AREA

The pyroxenes from the melteigites and ijolites of Budeda generally contain more hedenbergite and acmite than those from corresponding rocks of Napak. The restricted range of pyroxene compositions represented in some of the areas is due to the limited range of rock types from which pyroxenes have been analysed. The Tororo pyroxenes are all either from carbonatites, including mixed carbonate-silicate rocks, or fenites.

### (2) Wollastonite, Enstatite and Ferrosilite

The results of plotting the molecular percentage of these three end members is shown in Figure 4. Other components cannot be represented as "triangles of error", since, owing to the exclusion of acmite, the triangles would be very large in the case of the pyroxenes rich in this molecule.

The plot shows a tendency for the diopsidic pyroxenes to show an excess of $CaSiO_3$, while those nearer to acmite become somewhat deficient in this component.

Many of the pyroxenes appear to fall in the field of fassaite (Troger 1951), but it should be noted that the described fassaites, unlike these pyroxenes, contain between 10 and 20% of $Al_2O_3 + Fe_2O_3$.

Figure 4

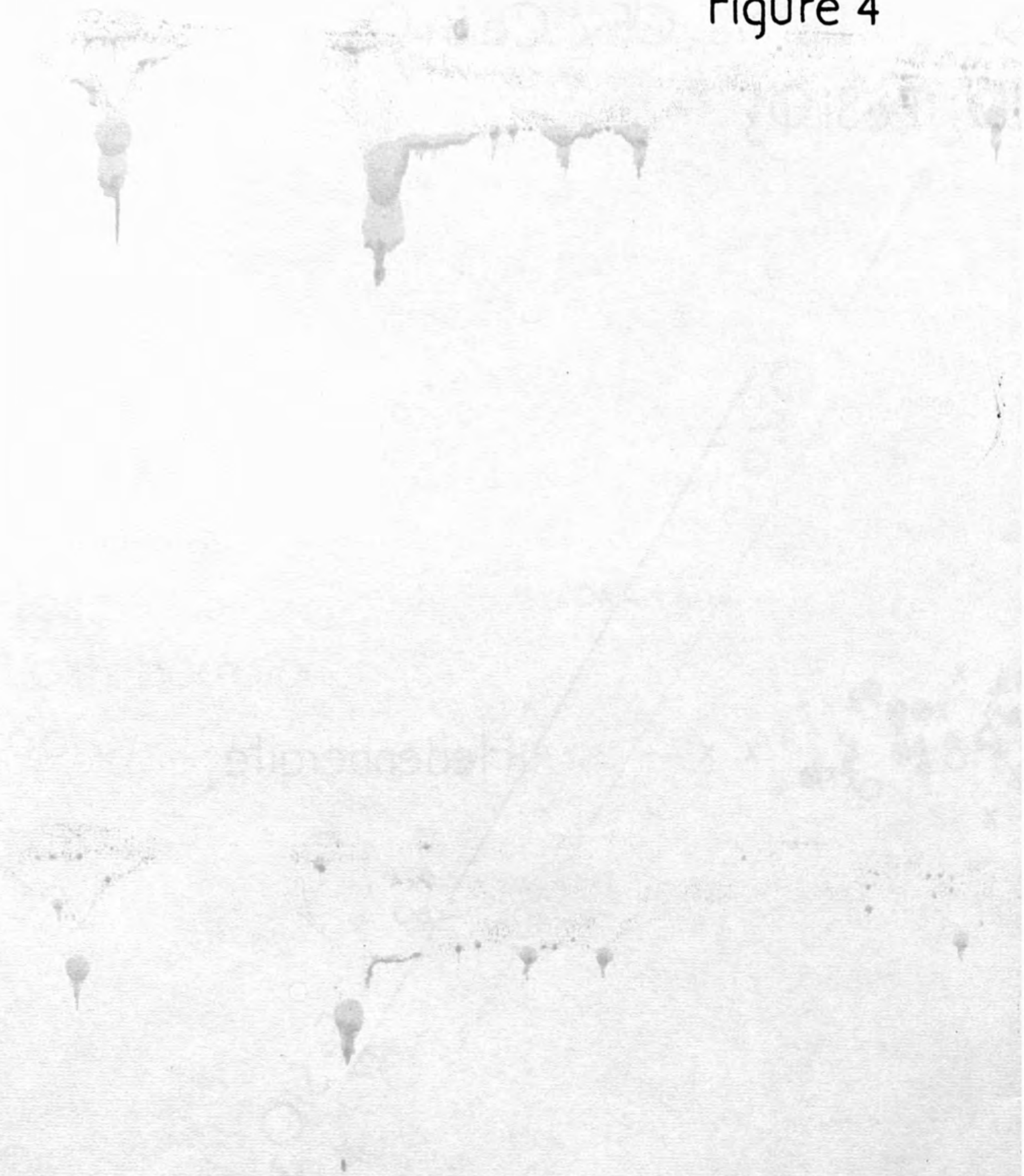
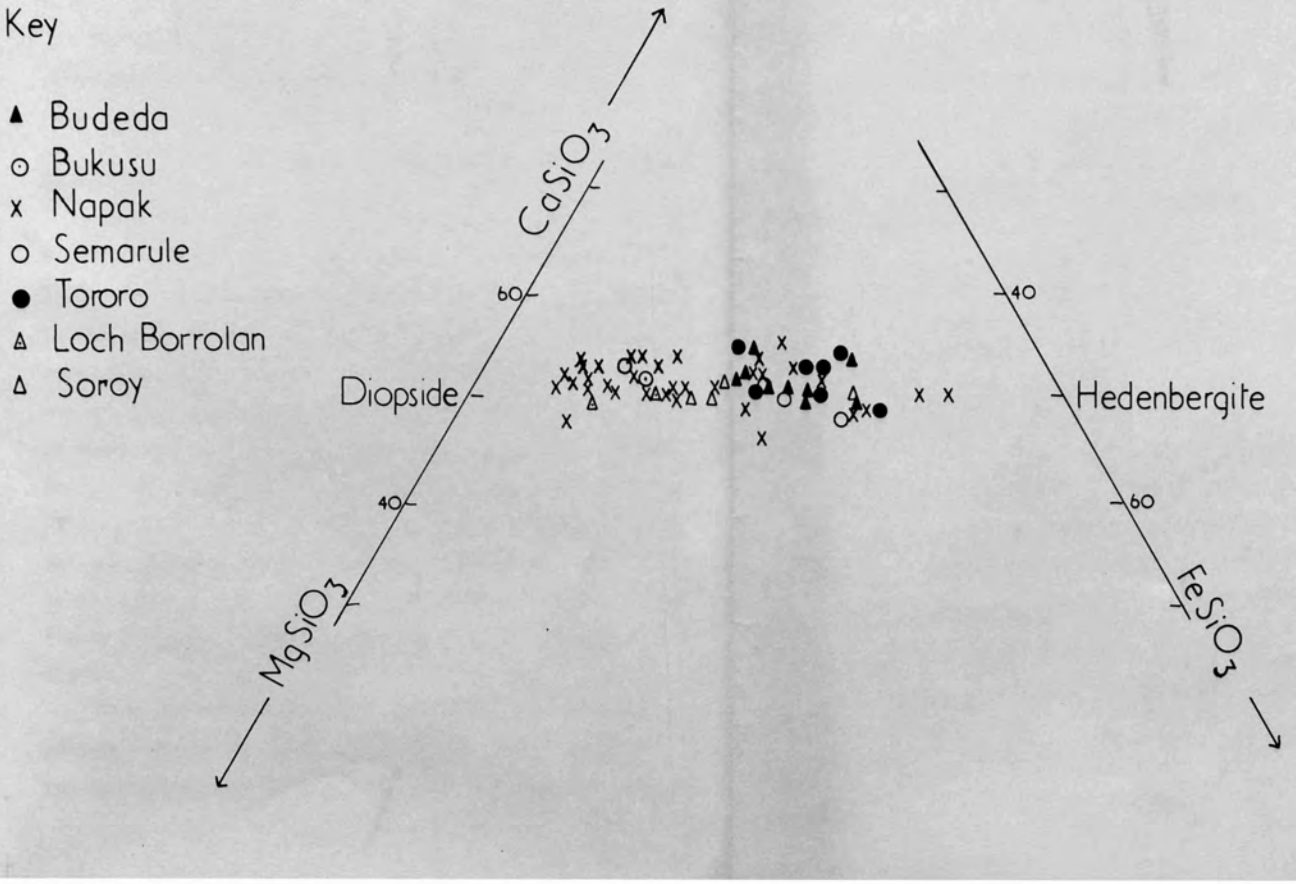


Figure 4 ANALYSES PLOTTED AS MOLECULES % OF $CaSiO_3$, $MgSiO_3$ AND $FeSiO_3$.



## 2. CALCULATION ACCORDING TO THE PYROXENE STRUCTURAL FORMULA

In Table I, the results of recalculating the analyses on the basis $O = 6$ and allotting the constituents according to the structural formula: $X_1 Y_1 Z_2 O_6$ are shown.

Using the usual procedure, sufficient Al Ti and sometimes $Fe^{+3}$ are added to Si to fill the Z position (Hess 1949).

### Na + K, $Fe^{+3}$ + Ti + Al and Ca + Mg + $Fe^{+2}$ + Mn as vertices of a triangle

On Figure 5, the atomic proportions are grouped as Na + K, $Fe^{+3}$ + Ti + Al (of the Y position) and Ca + Mg + $Fe^{+2}$ + Mn, and plotted on a triangular diagram according to the method adopted by Sabine (1950) for the acmitic pyroxenes. Ideally, the plots lie on an altitude of the triangle since, in using triangular coordinates, it is necessary to assume that the summation of the cations is 2. The plots make small triangles, the size of which is an indication of the departure of the summation of the cations from 2. In a few cases, the size of the triangles casts doubt upon the correctness of the analysis. Figure 5a shows published analyses plotted on the same system.

This method of plotting is of value in assessing patterns of atomic substitution but it cannot be used for indicating variations in the more diopsidic pyroxenes under consideration since Mg and $Fe^{+2}$ are not expressed separately. The ratio of these two constituents has an important influence on physical properties (Section V).

It can be seen that in all the methods of plotting discussed above, the problem was encountered of representing more than three molecules or groups of constituents on a diagram which must of necessity be in two dimensions. The small triangles show by their size an approximate value for a fourth constituent, but the representation is not entirely satisfactory. A three dimensional diagram could show much more but it is impractical for general use.

## 3. RELATIONSHIP OF MAJOR CONSTITUENTS

### (1) General

Figure 2 shows that in the majority of the alkali pyroxenes, where acmite is 25% or less, diopside exceeds hedenbergite, but where acmite is above 25%, hedenbergite almost always exceeds diopside until very large amounts of the acmite molecule are present, when diopside may, but not necessarily, exceed hedenbergite (Figure 2).

### (2) Ratio of Mg + $Fe^{+2}$ + Mn/Ca, Na + K/Ca and Na + K/$Fe^{+3}$ + Ti + Al

Plots of these ratios are shown in Figures 6, 7 and 8. Instead of being equal in atomic proportions, the line in Figure 6 shows that in the acmitic pyroxenes, Mg + $Fe^{+2}$ + Mn

Figure 6

Figure 6 PLOT OF $Mg + Fe^{+2} + Mn$ AGAINST Ca

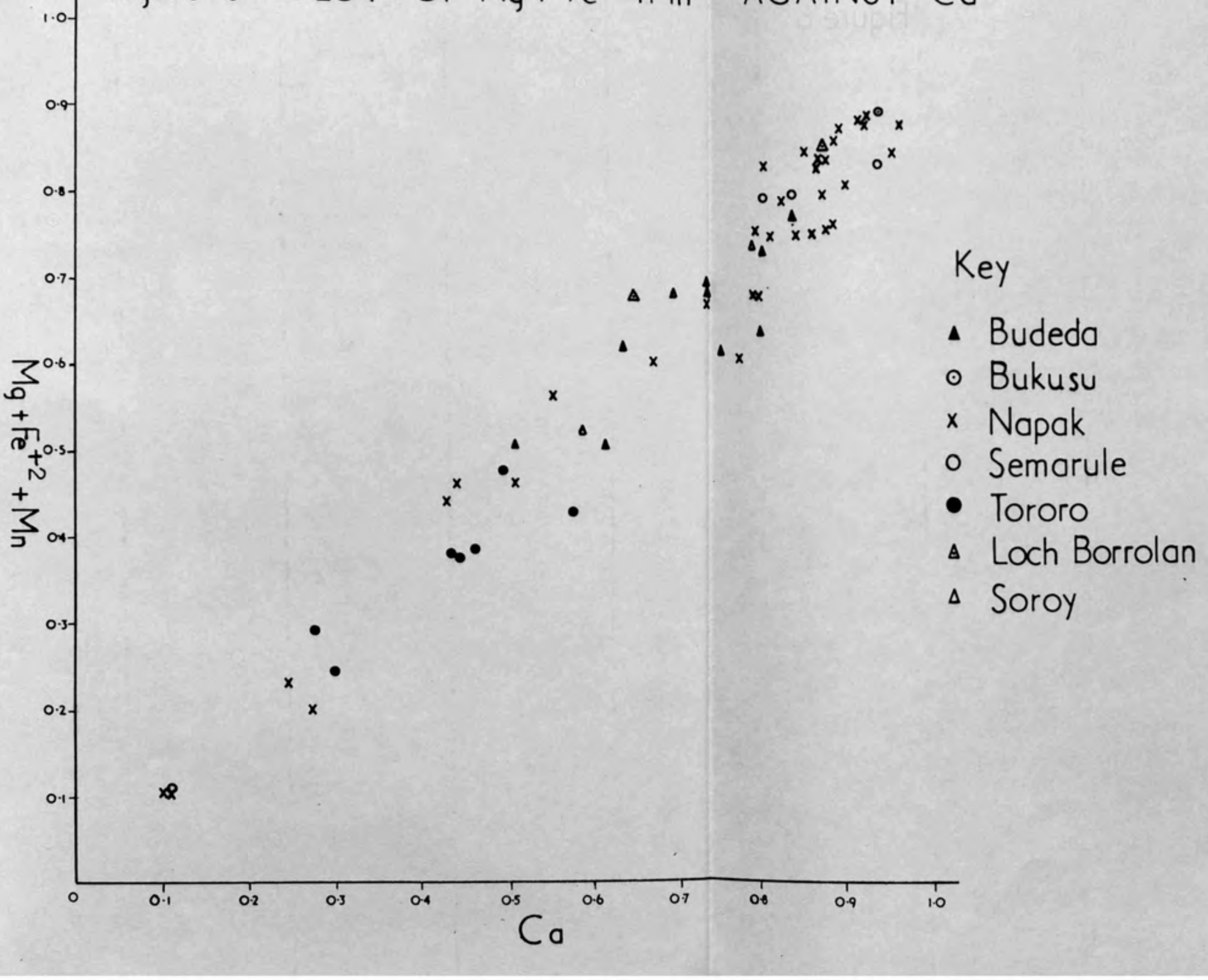


Figure 6a

Figure 6a PLOT OF Mg + $Fe^{+2}$ + Mn AGAINST Ca

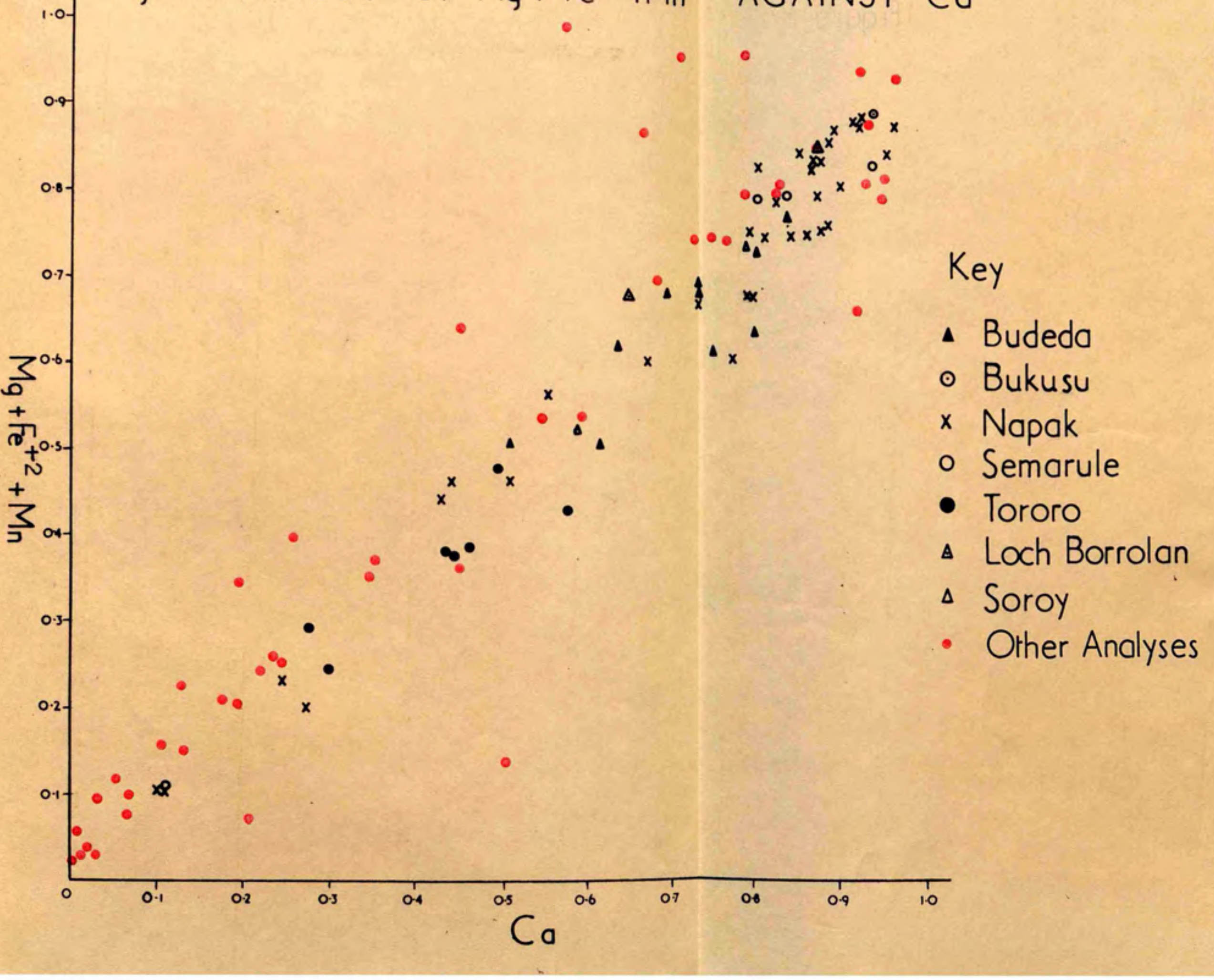


Figure 7

Figure 7 PLOT OF Na + K AGAINST Ca

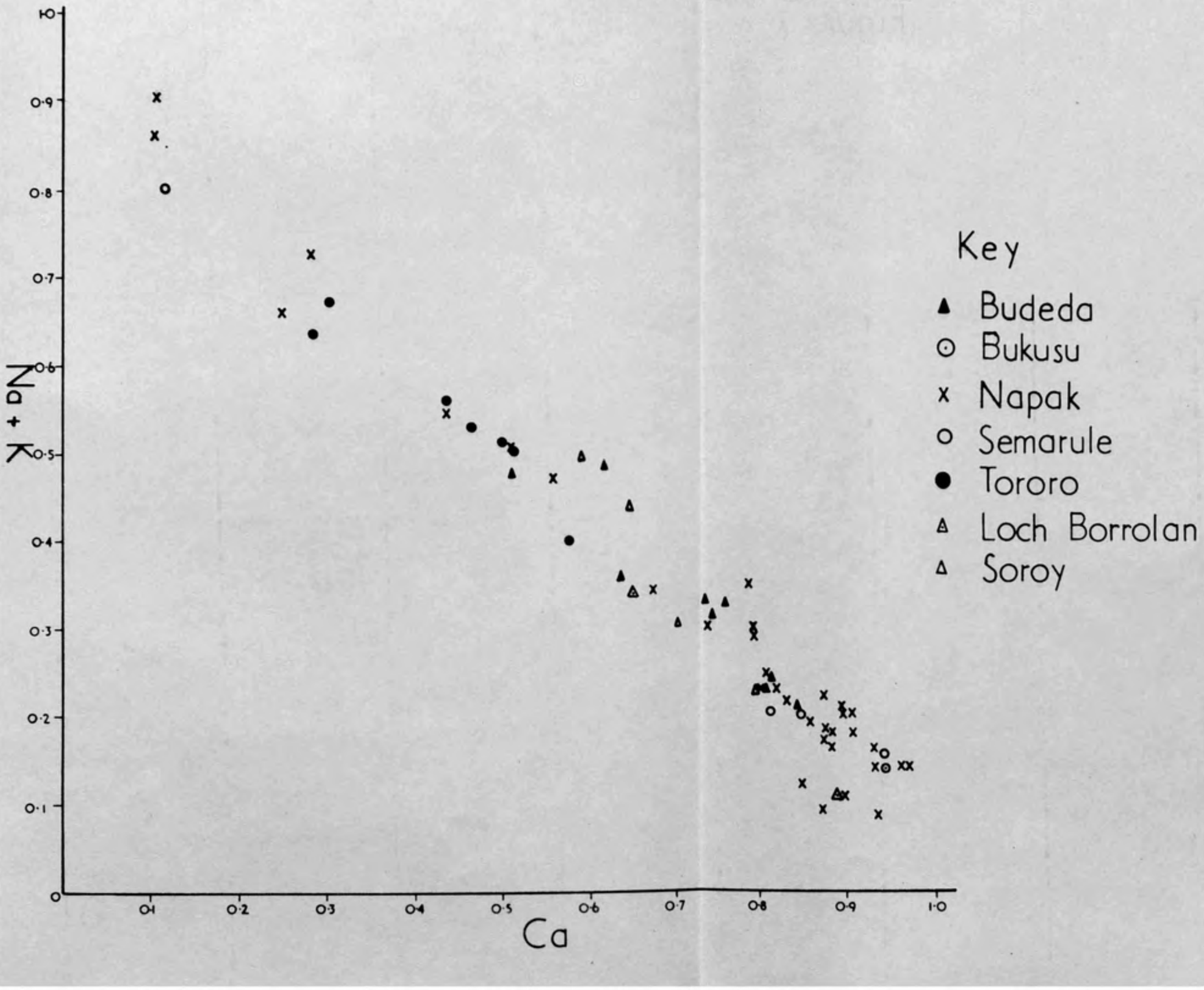


Figure 7a

Figure 7a PLOT OF Na + K AGAINST Ca

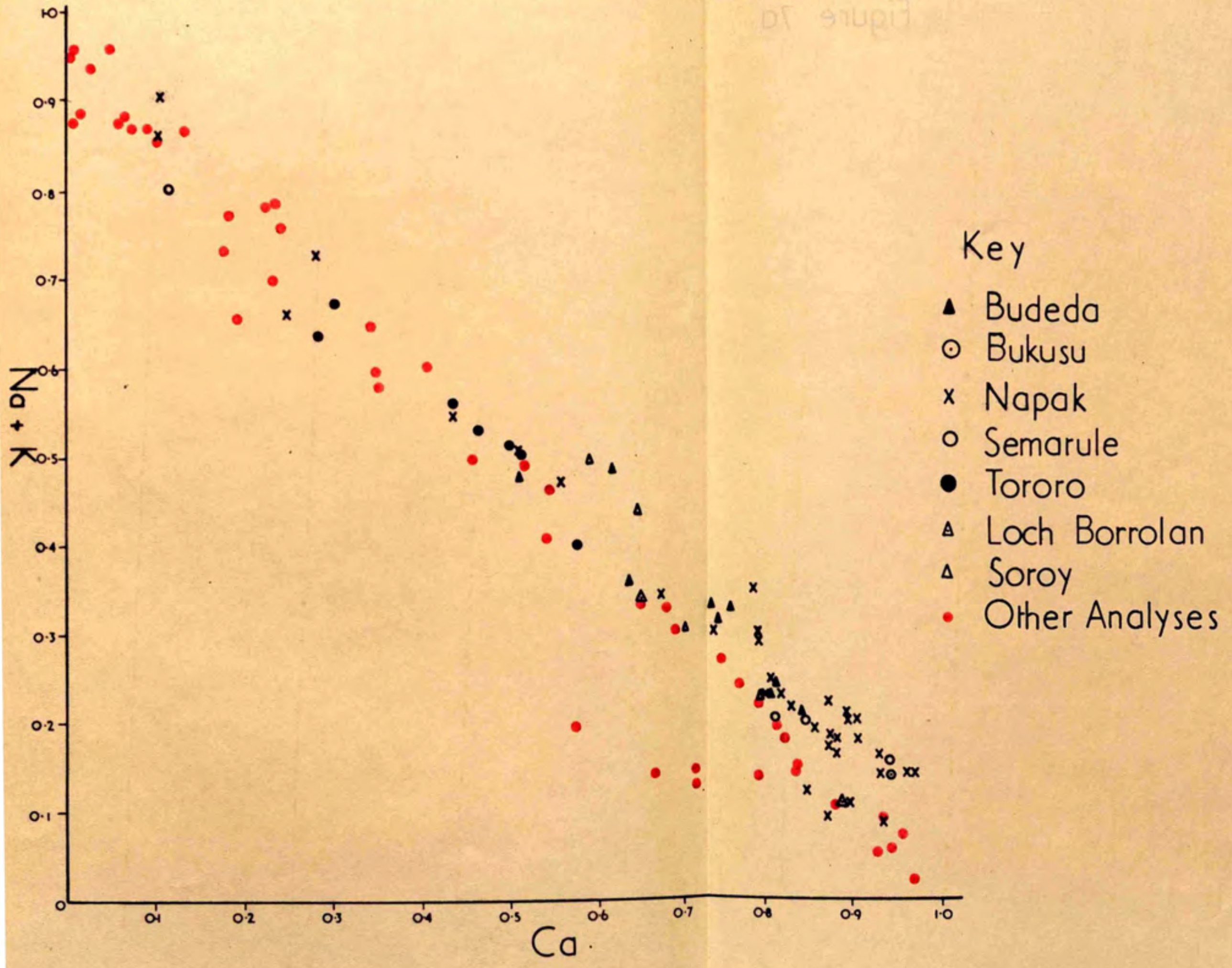


Figure 8

Figure 8 PLOT OF Na + K AGAINST Fe$^{+3}$ + Ti + Al

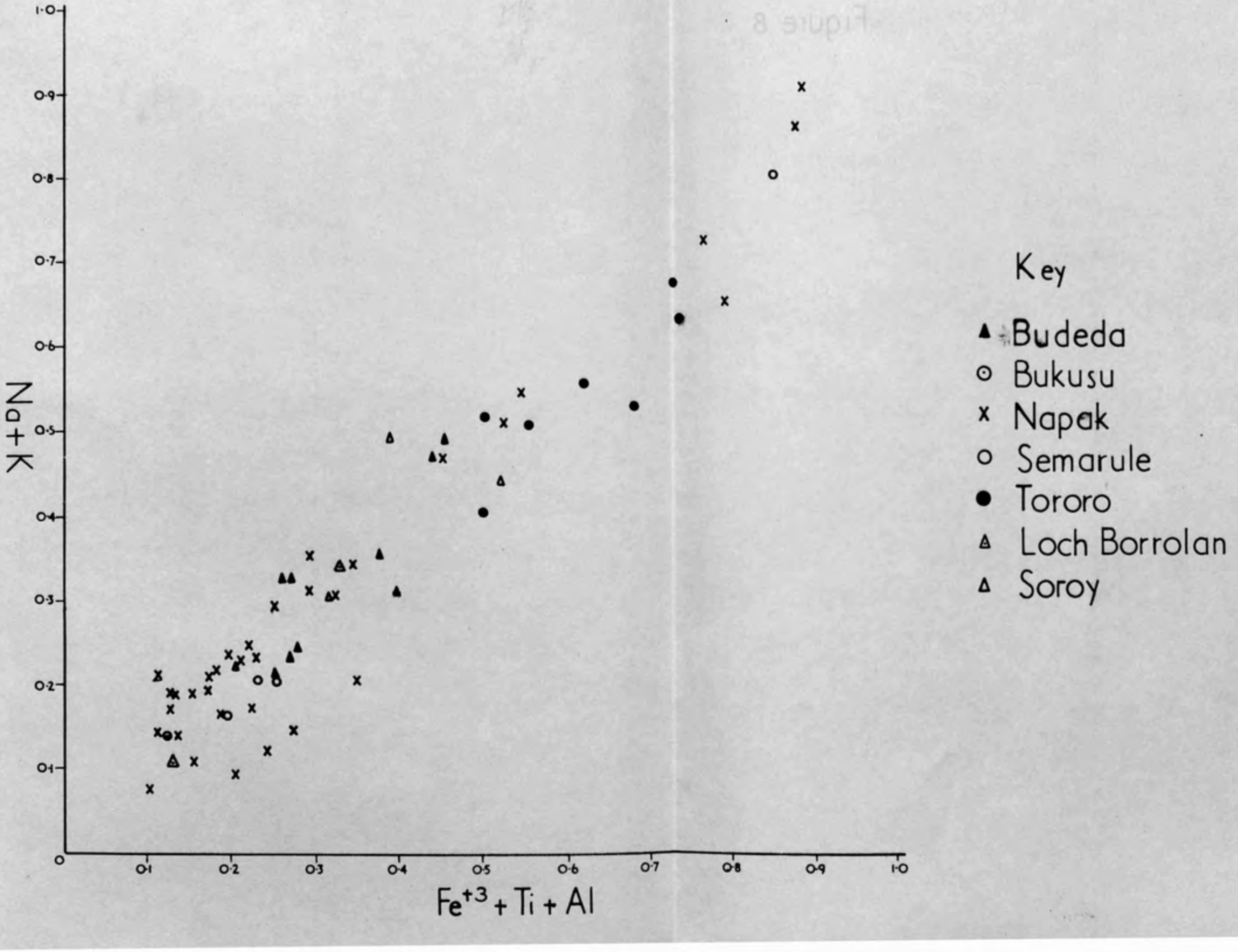
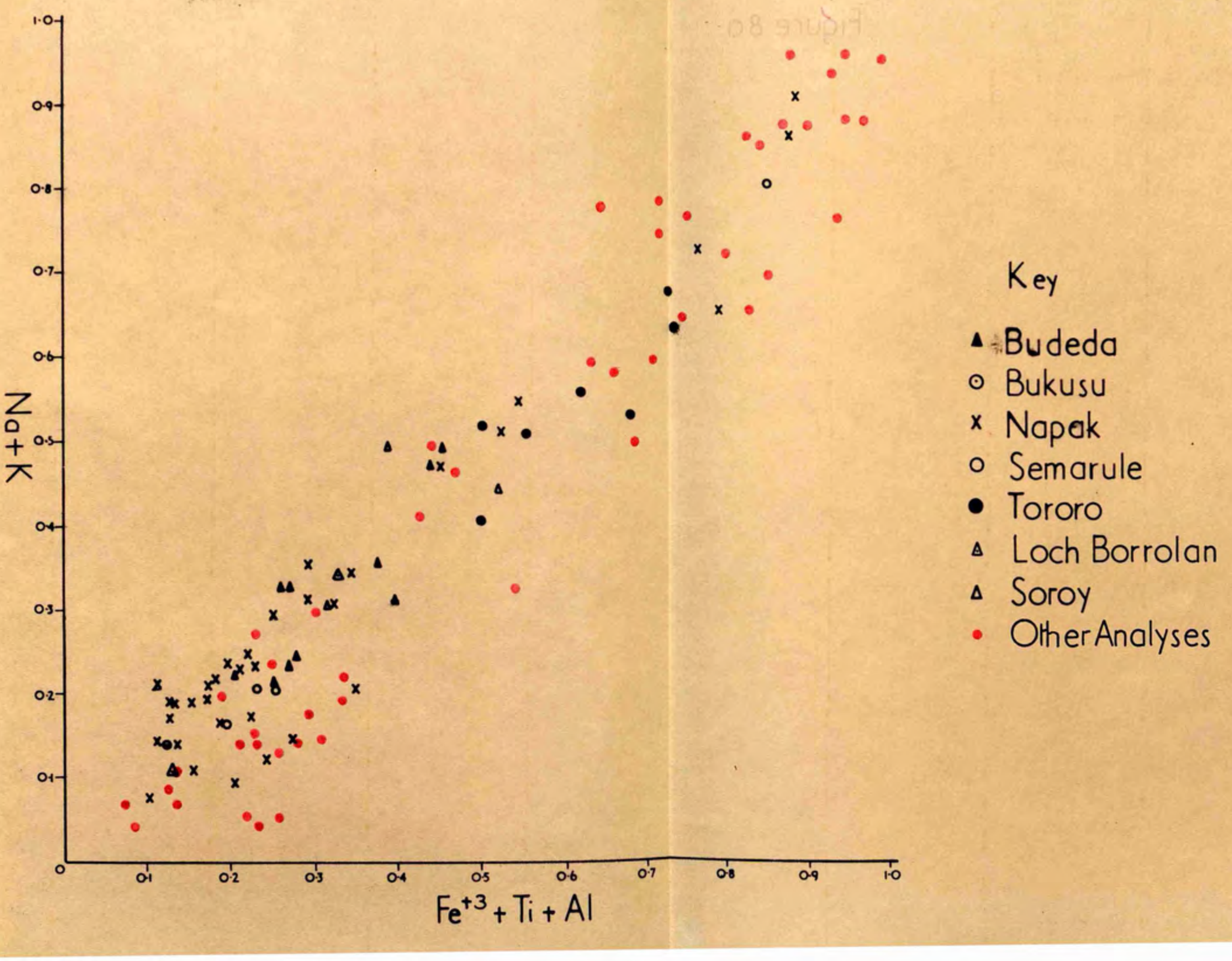


Figure 8a

Figure 8a PLOT OF Na + K AGAINST $Fe^{+3}$ + Ti + Al



is greater than Ca, and in diopsidic pyroxenes Ca is greater than Mg + $Fe^{+2}$ + Mn.

Analyses already published when plotted in this way show the same characteristic but it has apparently escaped attention earlier, probably owing to the small number of analyses of diopsidic pyroxenes. On Figure 6a all available analyses of alkali pyroxenes have been plotted together.

Again reflecting the presence of an apparent excess of Ca in the diopsidic pyroxenes, Ca and Na + K are not in exact inverse proportion (see Figure 7). Figure 7a, where all the analyses are plotted together, shows that the previously published analyses also exhibit this trend.

Figures 8 and 8a show that Na + K vary proportionately with the $Fe^{+3}$ + Ti + Al of the Y position.

(3) Presence of extra Calcium

It has been shown that Ca is present in the diopsidic pyroxenes in atomic proportions or molecules % of $CaSiO_3$ exceeding those of the combined $Fe^{+2}$ + Mn + Mg or $FeSiO_3$ + $MnSiO_3$ + $MgSiO_3$. In these pyroxenes, there is an excess of Ca, whereas in others, including the common pyroxenes, there is an excess of Mg or $Fe^{+2}$ + Mn. $MgSiO_3$ and (Fe,Mn) $SiO_3$ have the normal pyroxene structure and can easily be accounted for in the molecules. All forms of $CaSiO_3$ have a different structure from the pyroxenes. Although a monoclinic $CaSiO_3$ is known to exist, it has not a pyroxene structure (Peacock 1935 and Deer, Howie and Zussman 1963 vol. 2).

It is possible that the extra Ca may represent $CaSiO_3$ in solid solution in the pyroxene which could perhaps be comparable with the solid solution series between $FeSiO_3$ and $CaSiO_3$ (Deer, Howie and Zussman 1963 vol. 2).

If the Ca is not present in solid solution, the Ca ions must enter the Y positions in the pyroxene structure as well as the X positions. As the $Ca^{+2}$ ion has a large ionic radius (1.06Å), compared with those of $Fe^{+2}$ and $Mn^{+2}$ (0.83Å and 0.78Å respectively), the presence of the large Ca ion would distort the lattice.

## (4) Apparent Deficiency of Silica

Many of the analyses show apparent deficiencies in $SiO_2$ when calculated as molecules of acmite, diopside and hedenbergite since allowance cannot be made for the substitution of aluminium and titanium for silicon.

In calculating them according to the pyroxene structural formula, the deficiency of $Si^{+4}$ in the Z position can be offset by adding $Al^{+3}$ and $Ti^{+4}$ to $Si^{+4}$. In some cases, however, notably B 101 and N 114, even after the addition of all the $Al^{+3}$ and $Ti^{+4}$ , the value of Z is still less than 2, and some $Fe^{+3}$ has to be added.

It is suspected that in such cases, the $SiO_2$ value obtained by analysis is probably too low, since all methods of determination of silica, both colourimetric and gravimetric have a tendency to give low results.

## 4. MINOR CONSTITUENTS

### (1) $P_2O_5$

This is usually present in insignificant amounts, never greater than 0.5% and rarely more than 0.1 to 0.2%. No allowance is made for it in the calculations. There is no apparent place for substitution by phosphorus in a pyroxene. Apatite is often an abundant accessory in the rocks and the presence of $P_2O_5$ is considered due to this mineral, which occurs as minute crystals in the pyroxenes.

### (2) $Al_2O_3$

The analysed pyroxenes rarely contain more than 3% $Al_2O_3$. N 35C, N 62, N 102 and N 529 have more than 4% but the great majority of the minerals contain less than 2%. The aluminium is considered to replace $Si^{+4}$ and $Fe^{+3}$ in the Z and Y positions respectively. Figure 8 includes Al of the Y position with $Fe^{+3}$ and Ti of the Y position.

Figure 9a shows that $Al_2O_3$ tends to be higher both in the diopsidic and acmitic pyroxenes, but it is lower in

Figure 9a

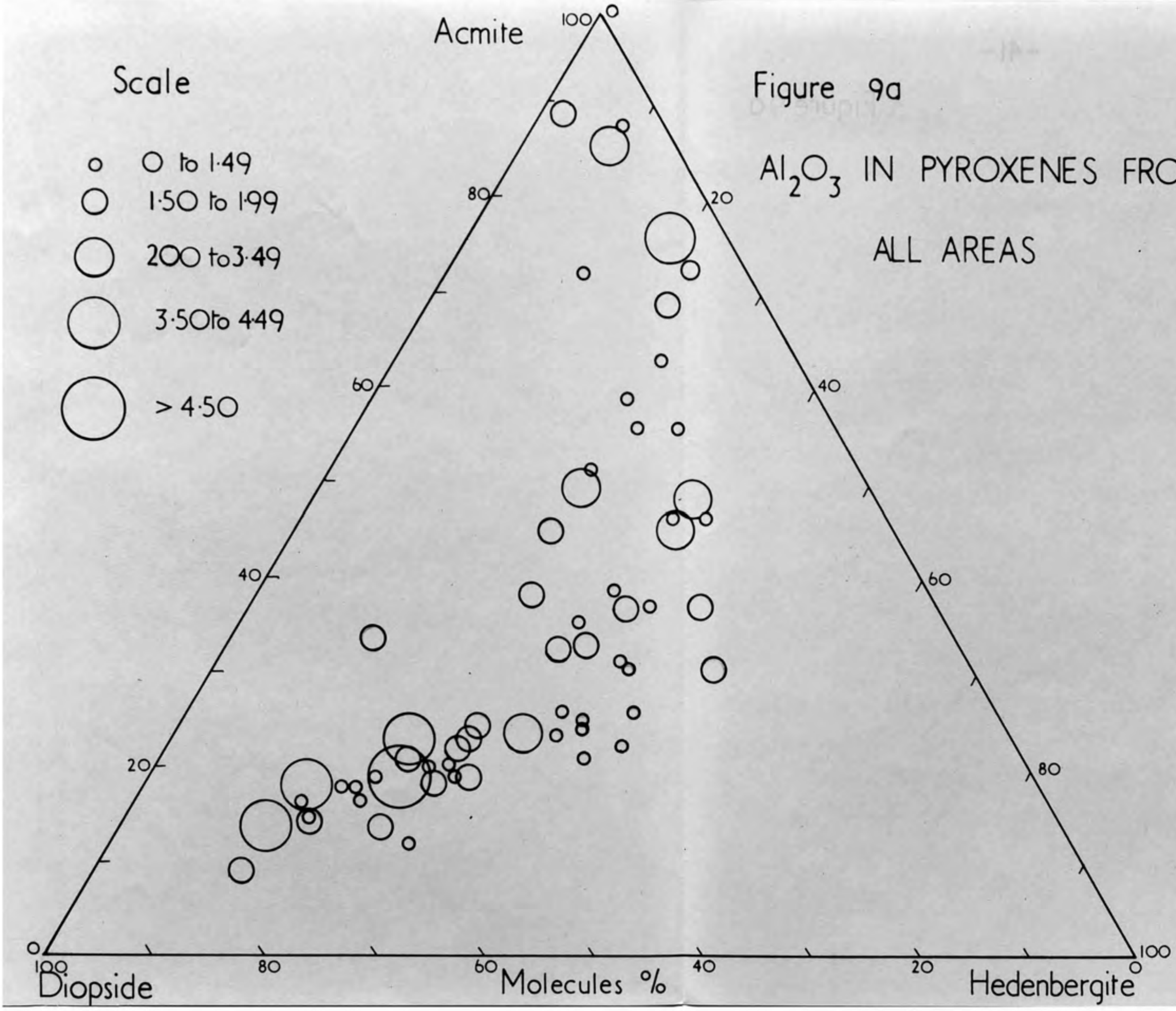


Figure 9a

$Al_2O_3$ IN PYROXENES FROM ALL AREAS

the intermediate members of the series. When $Al^{+3}$ enters the Y position, substitution of Si by Al (or other trivalent element) is necessary unless a monovalent element substitutes for a divalent in X. The following substitutions can occur:

1. $Ca^{+2}\ Mg^{+2}\ Si_2\ O_6 - Ca^{+2}\ Al^{+3}\ (Al^{+3}, Si)\ O_6$
2. $Ca\ Mg\ Si_2\ O_6 - Na\ Al\ Si_2\ O_6$

The first substitution applies to the diopsidic pyroxenes and the second to the acmitic ones.

$Al_2O_3$ also shows regional variation. The pyroxenes from Semarule have very little $Al_2O_3$ (never more than 0.5%), while the pyroxenes from Sørøy contain between 1.5 and 2% $Al_2O_3$. The Napak pyroxenes usually contain between 1 and 3% $Al_2O_3$ although five have less than 1% and four more than 4%. Those with more than 4% $Al_2O_3$ are diopsidic, with the exception of N 102 which is acmitic, and this suggests the presence of the tschermakite molecule and jadeite molecule.

A plot of $TiO_2$ against $Al_2O_3$ is shown in Figure 9b. The pyroxenes of Sørøy contain little $TiO_2$ (less than 0.5%) and larger amounts of $Al_2O_3$ (between 1.5 and 2%). The pyroxenes from Semarule have little $TiO_2$ as well as little $Al_2O_3$, but these, as a group, have higher $SiO_2$. A plot of $Al_2O_3$ against $SiO_2$ is shown in figure 9c.

Figure 9b

Figure 9b PLOT OF $Al_2O_3$ AGAINST $TiO_2$

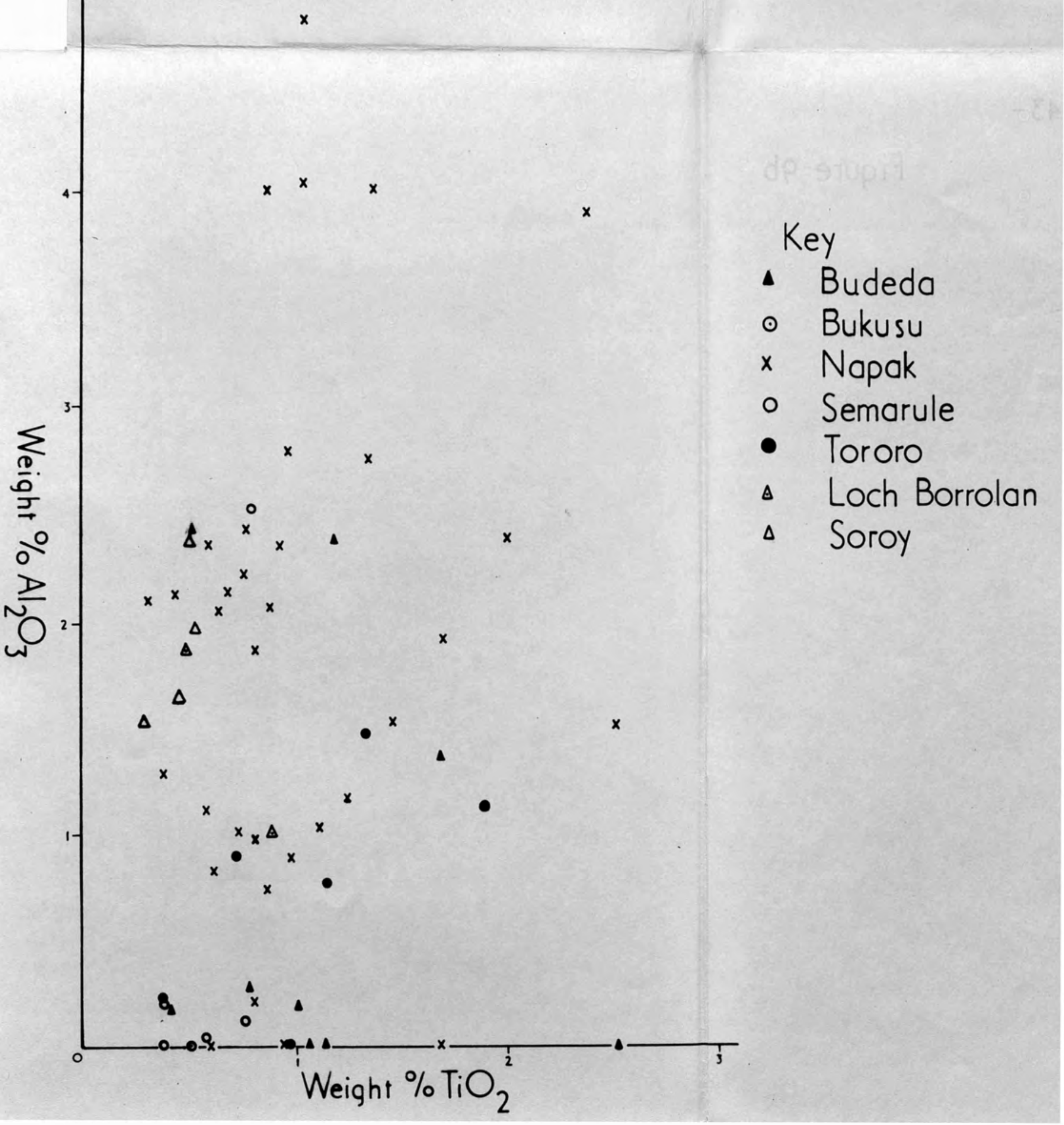
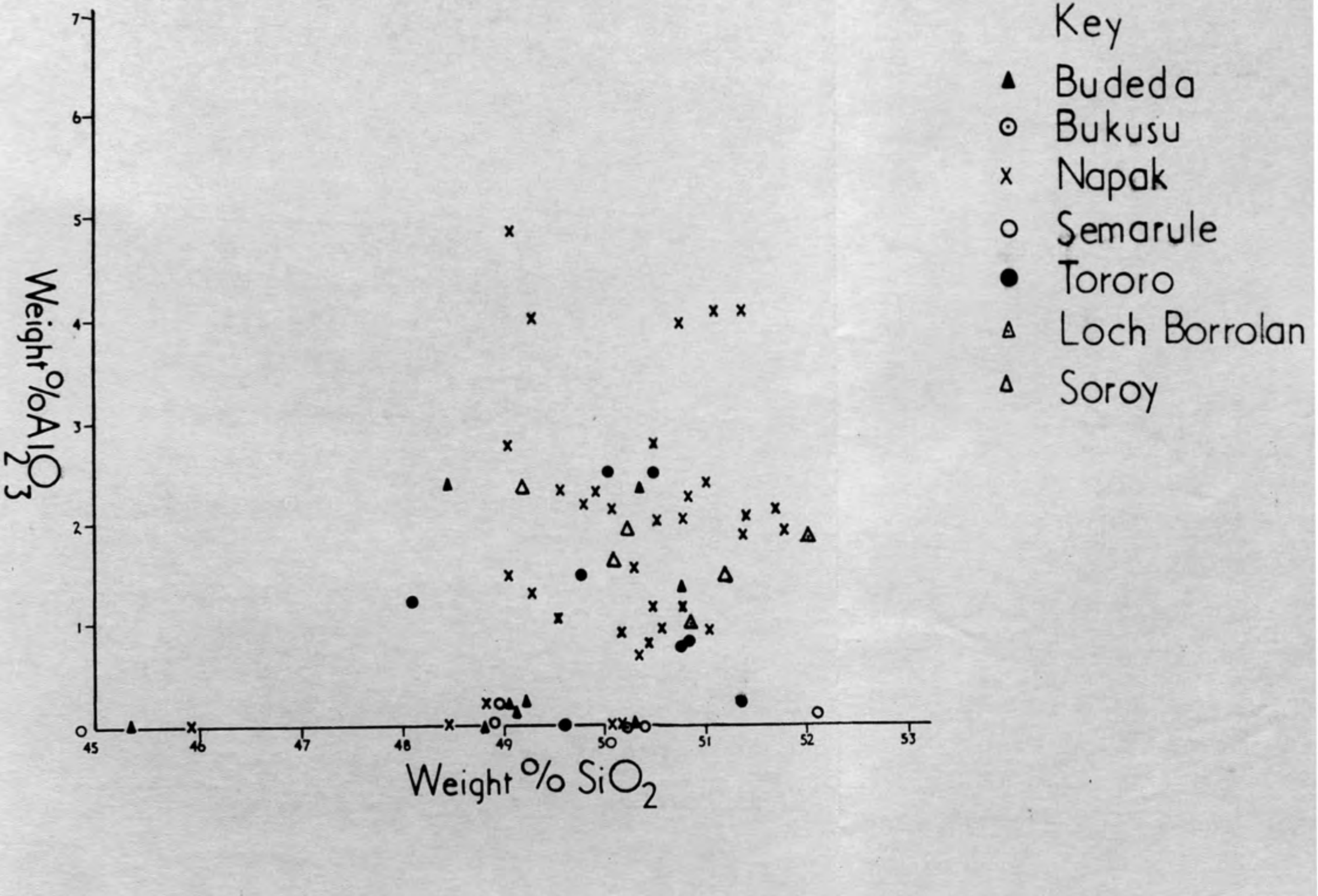


Figure 9c

Figure 9c PLOT OF $Al_2O_3$ AGAINST $SiO_2$



## (3) $TiO_2$

The $TiO_2$ content varies and is found, where sufficient analyses are available, to be highest in those pyroxenes from rocks in which melanite is absent. This suggests that $TiO_2$ preferentially enters melanite, which characteristically contains considerable amounts of this constituent (Table III). The pyroxene only contains appreciable amounts of $TiO_2$ where it is the only dark mineral in the rock.

Variations in the $TiO_2$ content of the pyroxenes in different areas are shown in Figure 10 a - f:

(i) The pyroxenes from Assynt and Soroy are low in $TiO_2$;

(ii) Pyroxenes from Budeda and Semarule are usually low in $TiO_2$, but B 101 contains 2.5% $TiO_2$;

(iii) The pyroxenes from Tororo and Napak are richer in $TiO_2$. The Tororo pyroxenes, which are all acmitic varieties, always contain high $TiO_2$. Similarly, at Napak, $TiO_2$ is highest in the acmitic pyroxenes; these are never associated with melanite. The diopsidic pyroxenes from Napak always occur with melanite.

Of the previously published analyses only those from the Homa Bay, Iivaara and Napak ijolites, and from Nyiragongo and Nyamunuka lavas are strictly comparable. The pyroxenes from the ijolites contain from 0.6 to 1.0%

Figure 10a

## TABLE III

## $TiO_2$ AND MnO IN GARNETS FROM NAPAK, SEMARULE, LOCH BORROLAN AND SØRØY

| Specimen Number | MnO (Wt.%) | $TiO_2$ (Wt.%) |
|---|---|---|
| Napak | | |
| N 23 | 0.51 | 8.23 |
| N 48 | 0.13 | 6.60 |
| N 93 | 0.18 | 8.51 |
| N 114 | 0.20 | 8.14 |
| N 517A | 0.13 | 6.41 |
| Semarule | | |
| K 44 | 0.44 | 3.11 |
| K 450 | 0.19 | None |
| Loch Borrolan | | |
| Bo 98 | 0.44 | 4.04 |
| Bo 282 | 0.34 | 4.50 |
| Sørøy | | |
| S | 1.54 | 1.23 |

Figure 10a

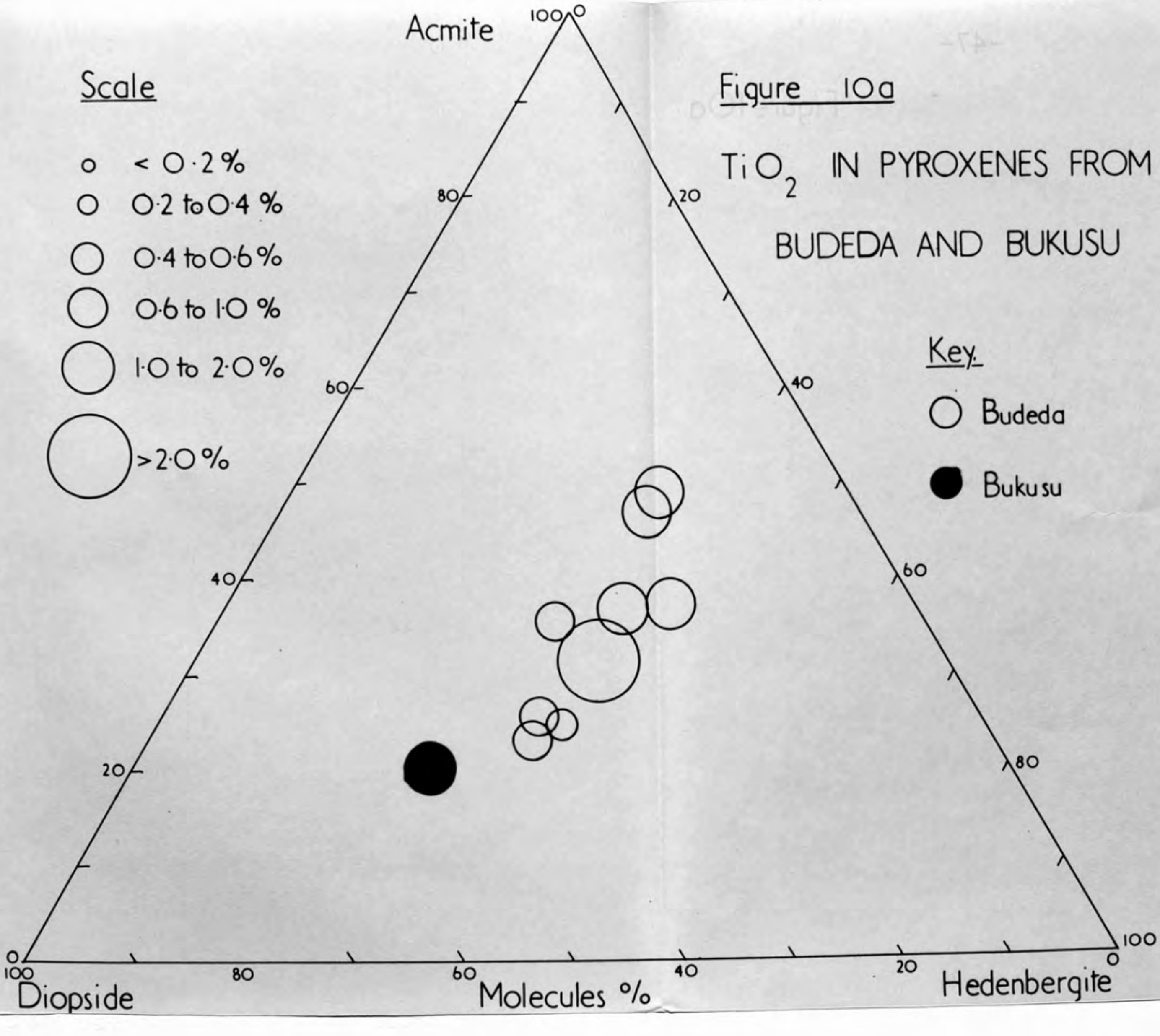


Figure 10a

$TiO_2$ IN PYROXENES FROM BUDEDA AND BUKUSU

Figure 10b

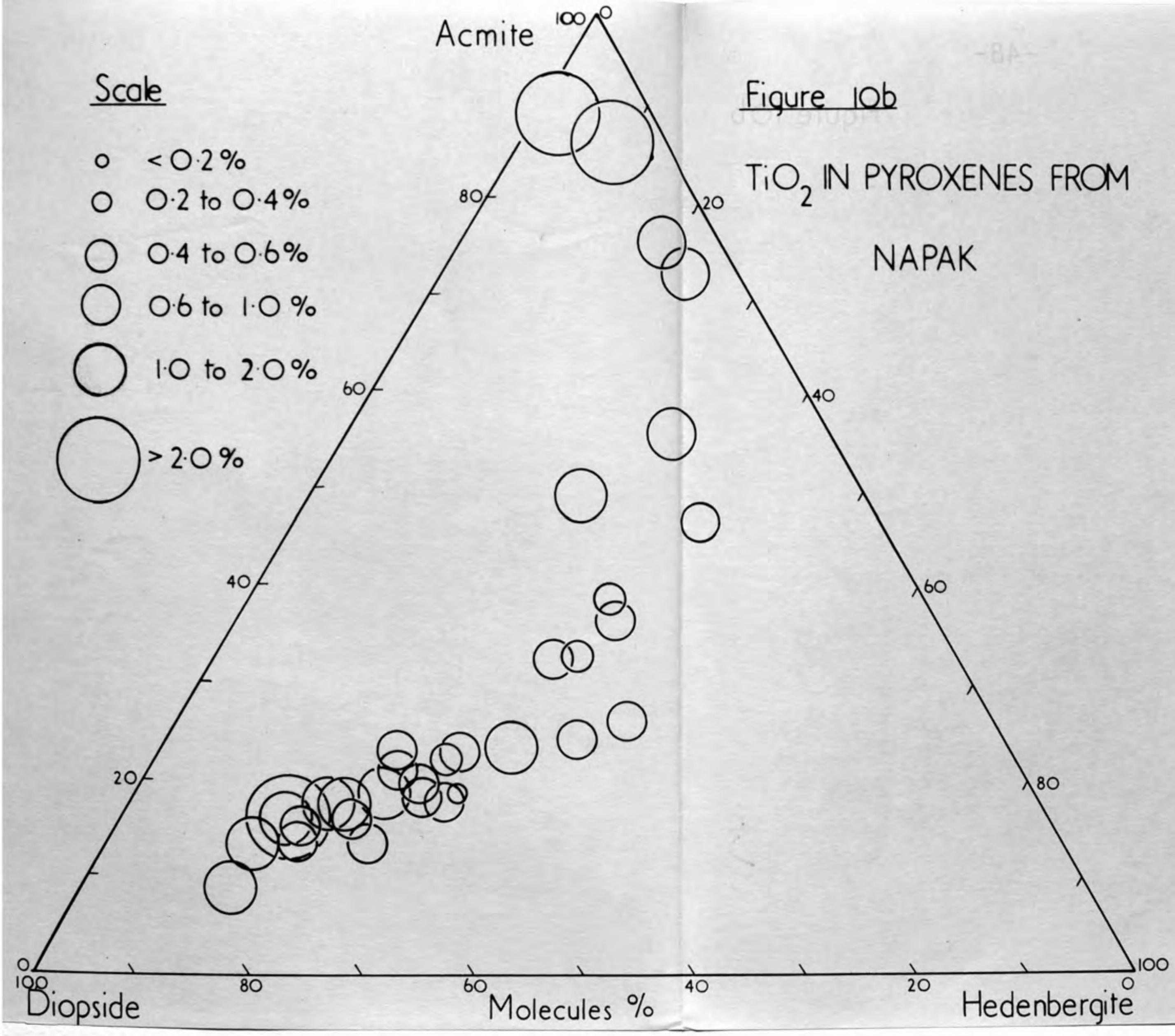


Figure 10b

$TiO_2$ IN PYROXENES FROM NAPAK

Figure 10c

Figure 10c

TiO$_2$ IN PYROXENES FROM SEMARULE

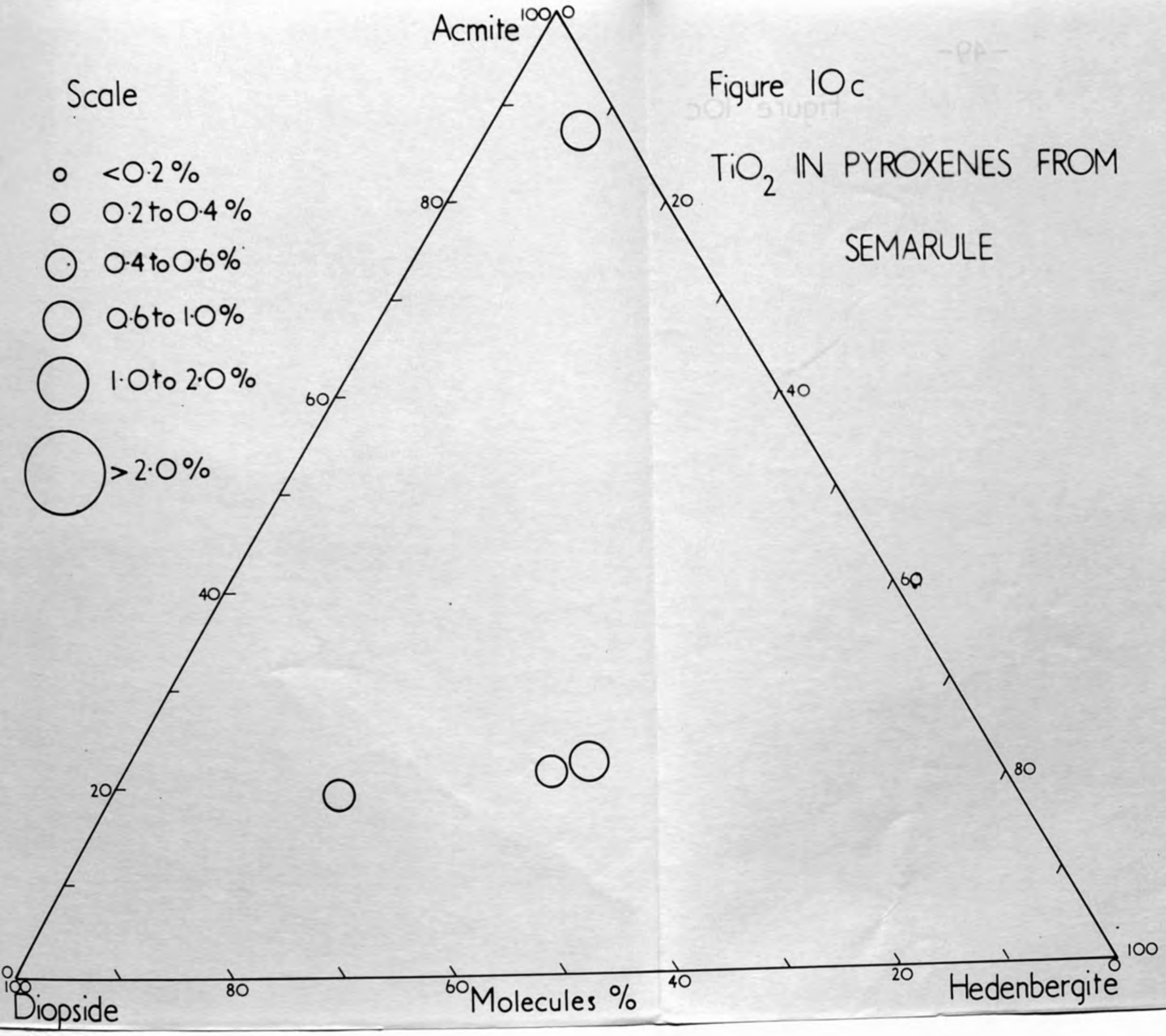


Figure 10 d

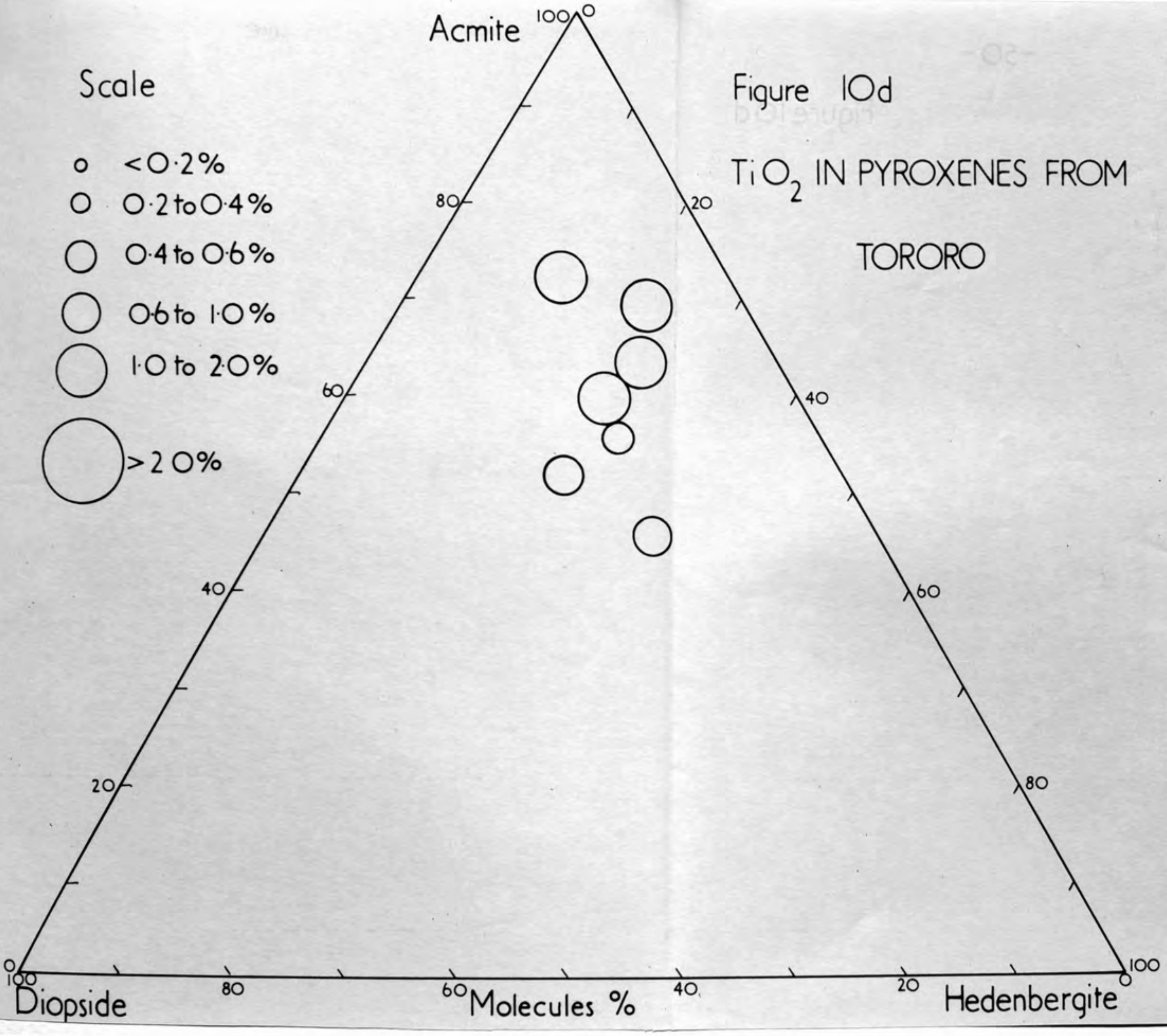


Figure 10d

$TiO_2$ IN PYROXENES FROM

TORORO

Figure 10e

Figure 10e

TiO$_2$ IN PYROXENES FROM LOCH BORROLAN

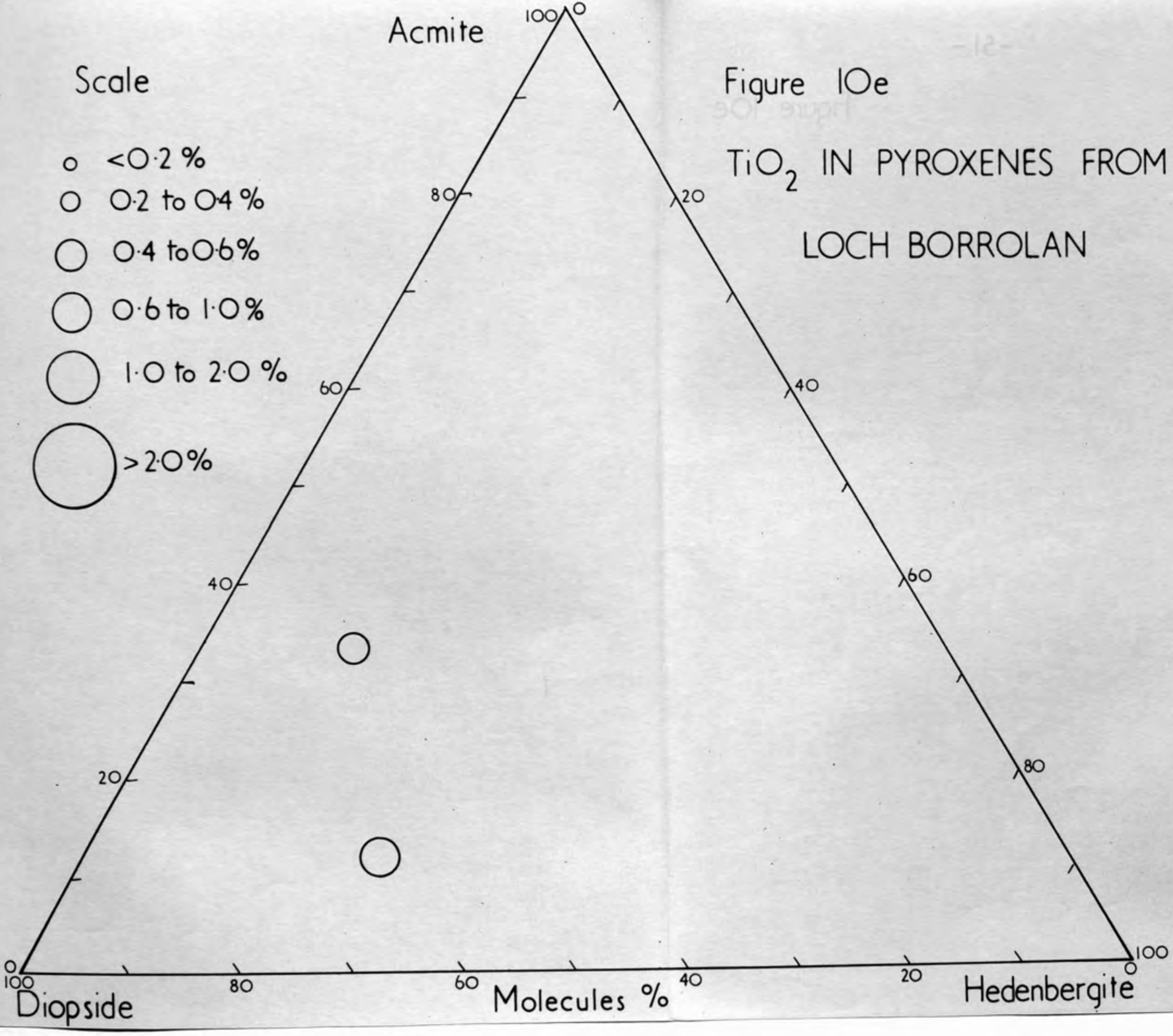


Figure 10f

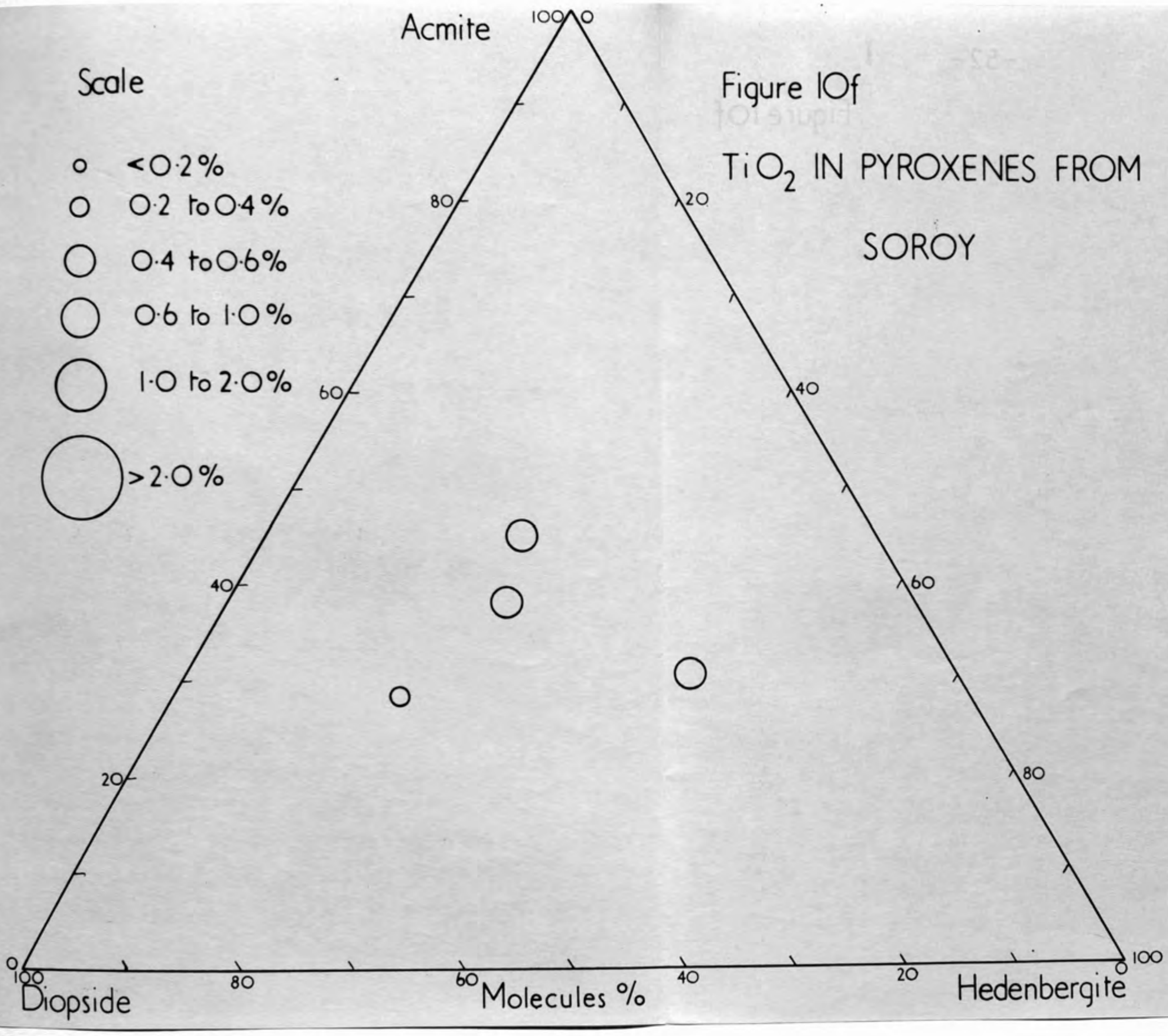


Figure 10f

TiO$_2$ IN PYROXENES FROM SOROY

$TiO_2$ and those from the lavas between 3 and 5% $TiO_2$, suggesting that this is a $TiO_2$ rich area.

Details of many of the other rocks are not available so comparisons cannot be made, but many of the pyroxenes contain high $TiO_2$.

(4) MnO

The amount of MnO in the pyroxenes shows considerable variation in the different areas. It also shows a dependence on the hedenbergite content of the pyroxene suggesting that Mn substitutes for $Fe^{+2}$. Where many analyses are available from one area, such as Napak, it can be seen that the MnO content increases with increase in hedenbergite (Figure 11b).

Figure 11 a - f shows that relatively little MnO is present in the African pyroxenes compared with those from Sørøy which contain much larger amounts. That Sørøy is a relatively manganese rich area is also shown by the manganese content of a calcium rich garnet which has been analysed; this contains 1.54% MnO compared with an average of 0.3% MnO in analysed melanite from African localities (Table III).

Among African examples, the Napak pyroxenes are low in MnO whereas those from Budeda are relatively higher. This is shown by pyroxenes from the two localities which contain comparable amounts of hedenbergite (Figure 11 a and b).

Figure 11a

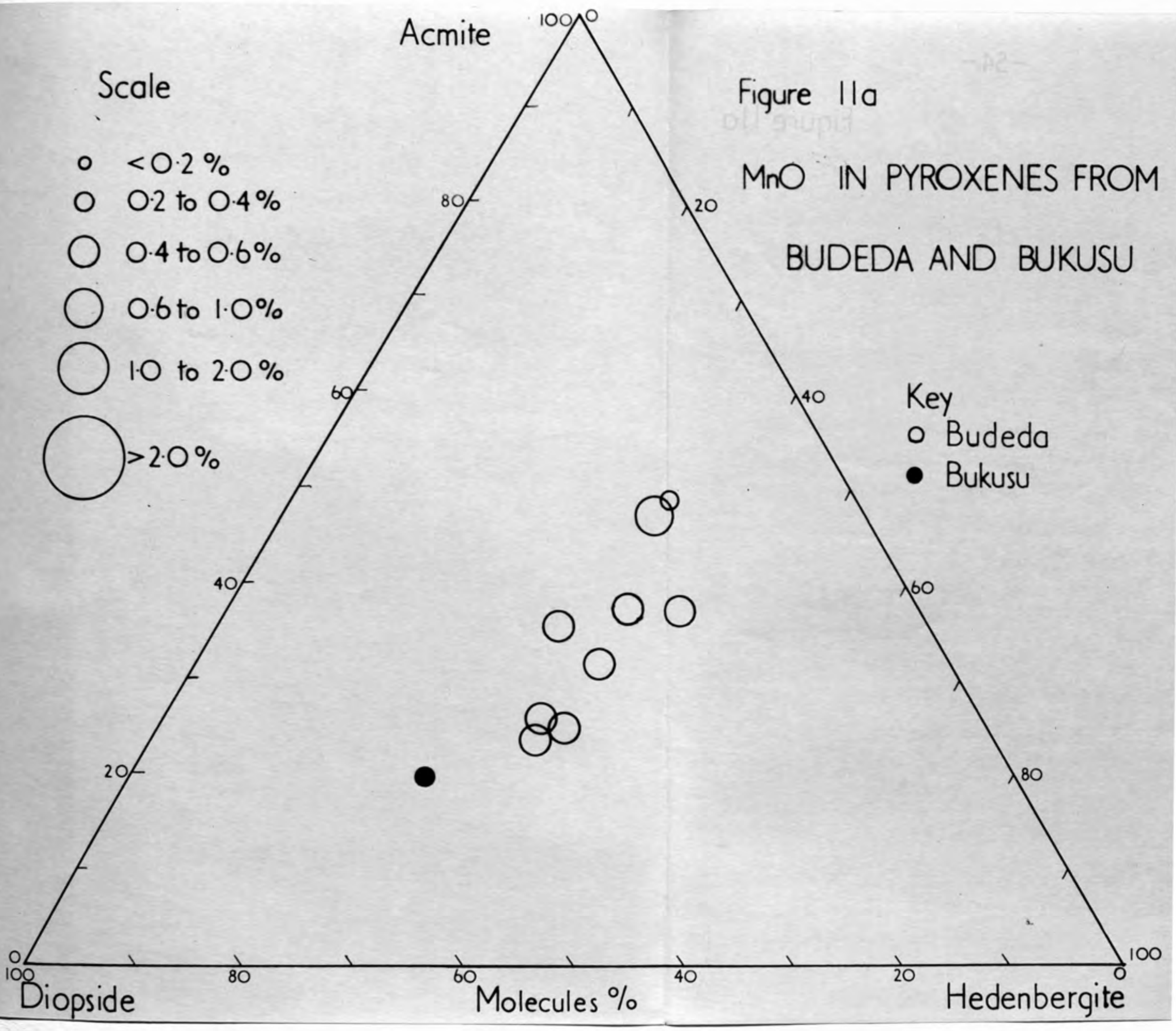


Figure 11a

MnO IN PYROXENES FROM BUDEDA AND BUKUSU

Figure 11b

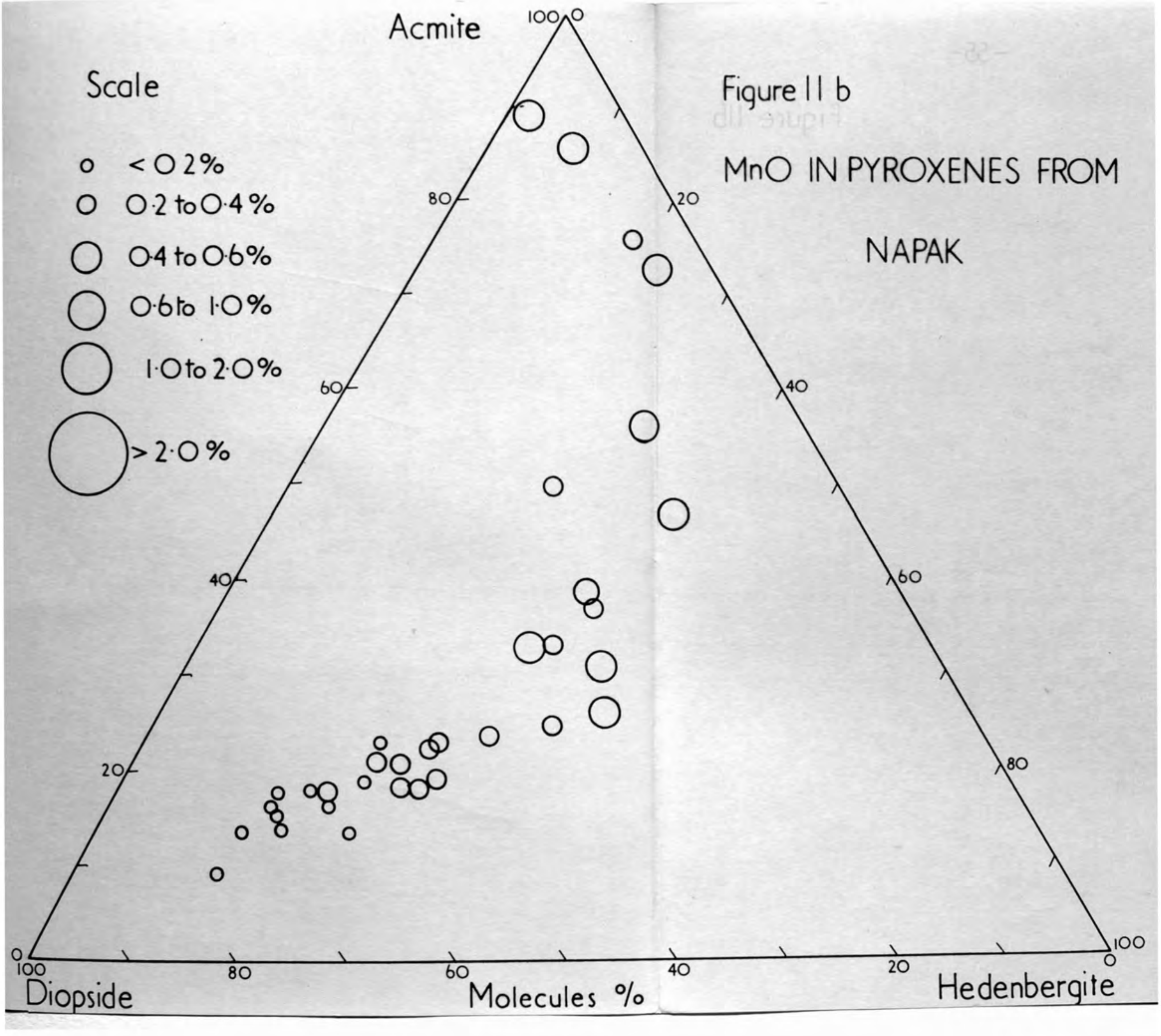


Figure 11 b

MnO IN PYROXENES FROM NAPAK

Figure 11c

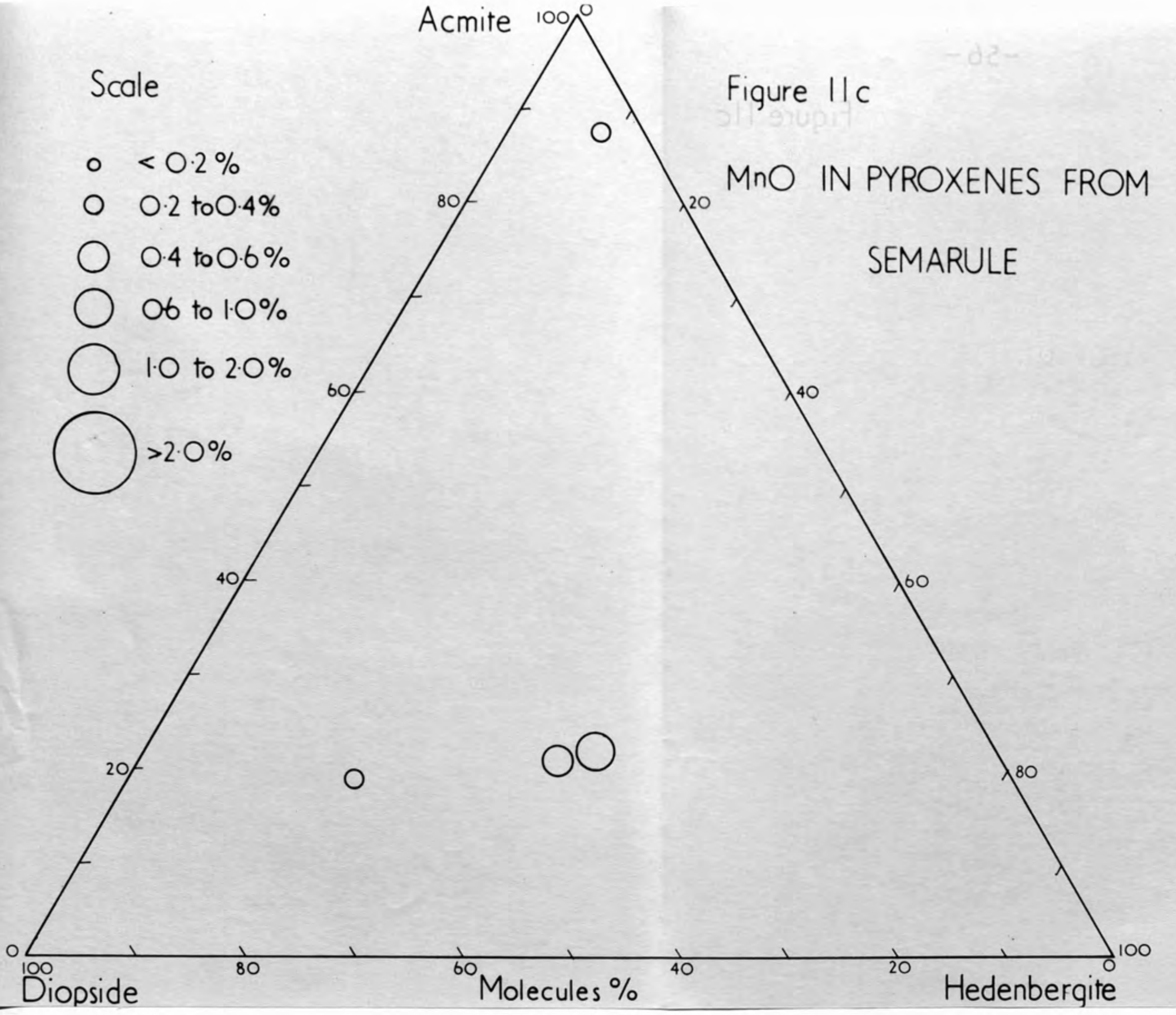


Figure 11c

MnO IN PYROXENES FROM SEMARULE

Figure 11d

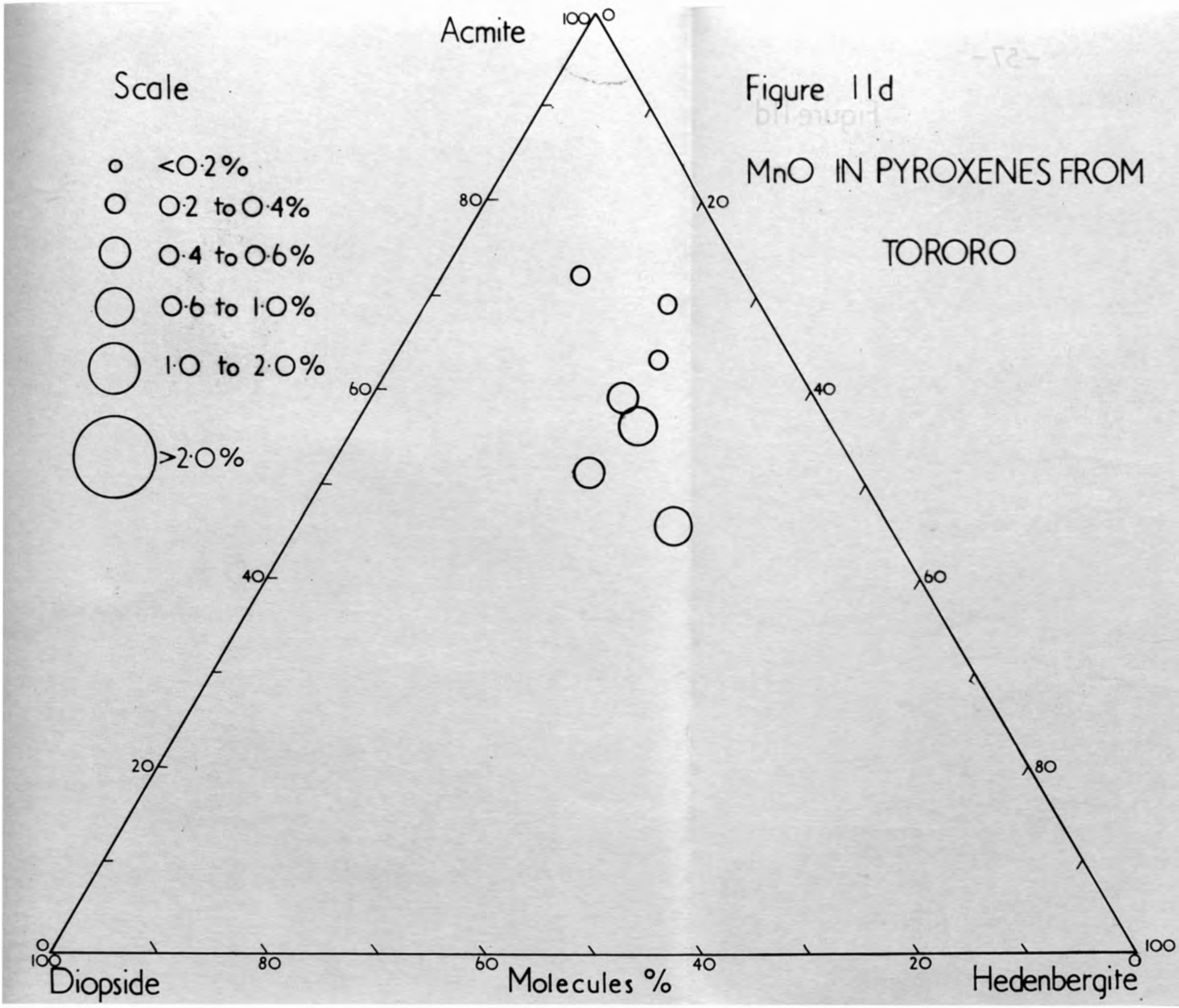


Figure 11d

MnO IN PYROXENES FROM TORORO

Figure II e

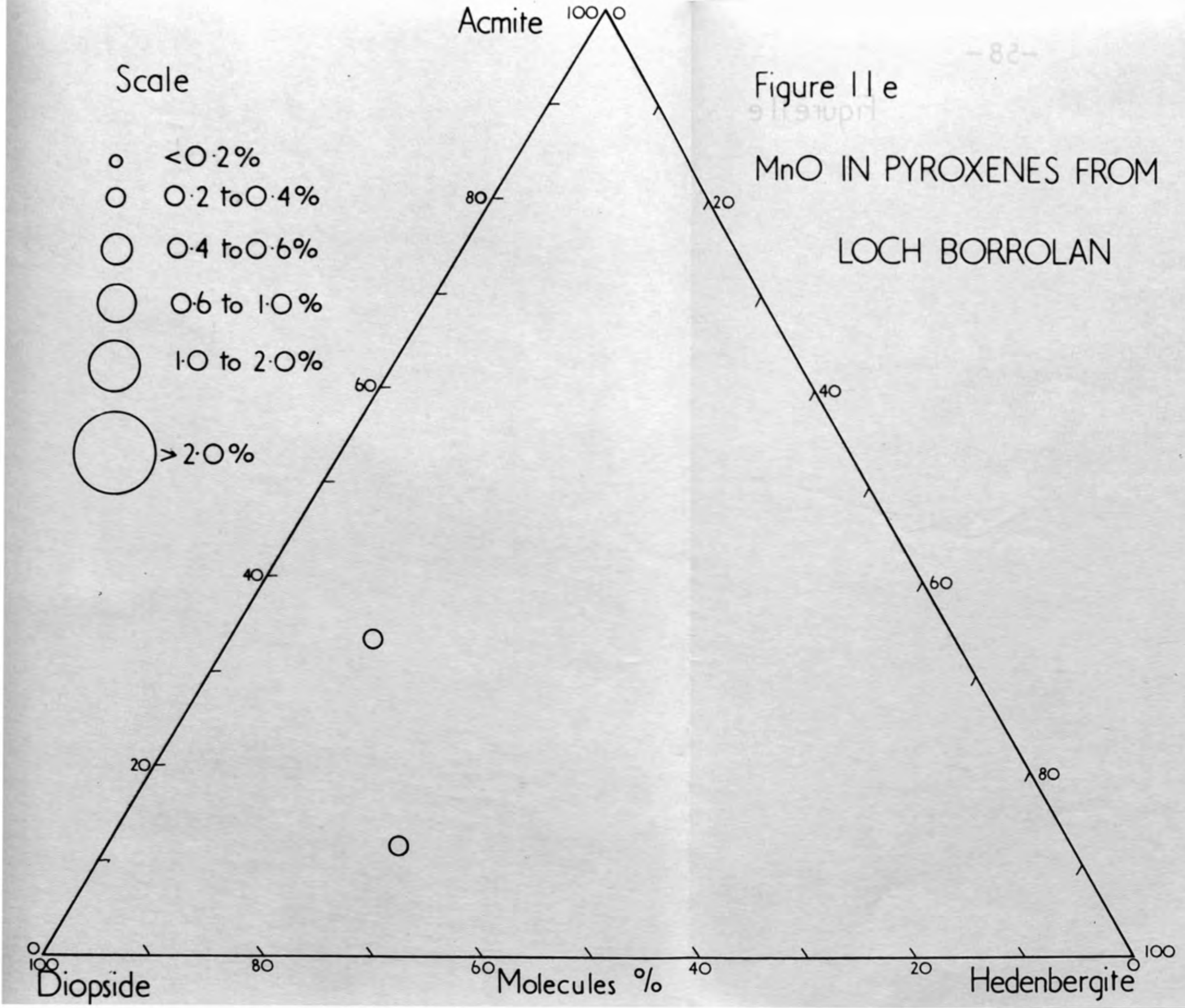


Figure 11e

MnO IN PYROXENES FROM

LOCH BORROLAN

Figure II f

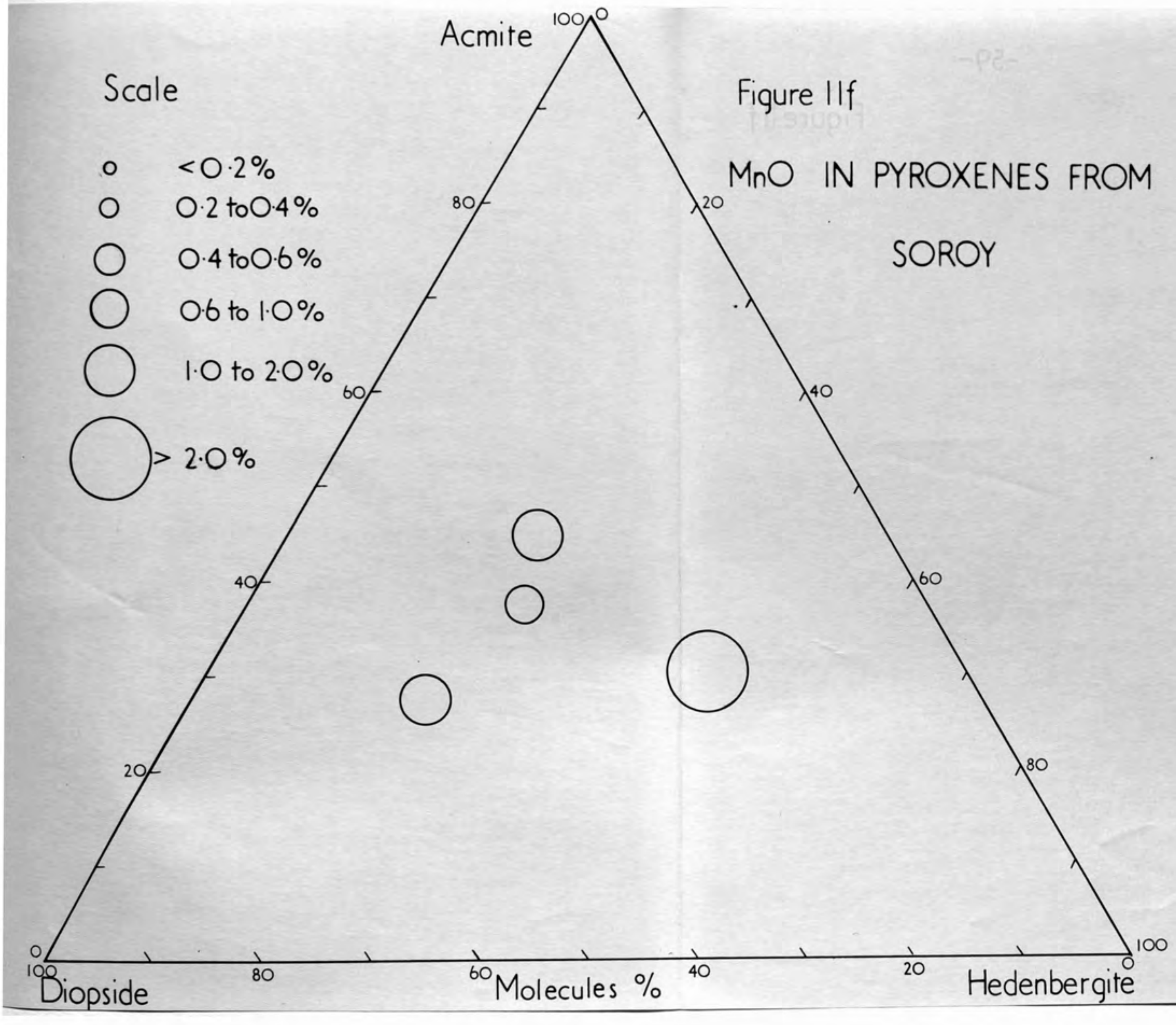


Figure 11f

MnO IN PYROXENES FROM SOROY

# V PHYSICAL PROPERTIES

The physical properties which have been studied are colour, Refractive Index, Specific Gravity and the A $\wedge$ c angle (King 1962).

## 1. COLOUR

This is influenced by the amounts of the hedenbergite and acmite molecules in the pyroxene. In the most diopsidic pyroxenes the colour is a very pale green. As the contents of hedenbergite and acmite increase, the colour of the pyroxenes changes to a darker green and the most acmitic pyroxenes are a dark olive green. Pleochroism is distinct or moderately strong in all but the paler varieties.

The pyroxenes from Sørøy show a deep moss green colour compared with the more yellow green tint of those from the African areas which have a similar content of the principal molecules. Since the only chemical difference detected is the relatively high content of MnO in the Sørøy pyroxenes, it seems possible that this is responsible for the distinctive colour.

Some of the most sodic pyroxenes of the African alkali rocks show the yellow brown colour regarded as characteristic of acmite, (Washington and Merwin 1927, Sabine 1950) but no examples of this variety have been analysed. Most of the acmitic ones analysed are green, except for a yellowish tinge in the Z direction, and are therefore referred to as aegirine, since the term acmite is applied to the theoretical molecule and to the brown form.

## 2. REFRACTIVE INDEX

The refractive indices were measured using the immersion method with an Abbé or Jelley refractometer for measuring the liquids. The values have been plotted as shown in Figures 12, 13 and 14.

$\alpha$ was relatively easy to determine even for the most acmitic pyroxenes as the liquids could be maintained at a constant concentration for a sufficient length of time in which to make the measurements. In the determination of $\gamma$ the liquids used were more difficult to maintain at the same concentration and therefore the results are not so reliable. For the highest refractive indices a liquid of suitable refractive index was prepared by dissolving sulphur in methylene iodide. $\gamma$ was not determined for the most acmitic pyroxenes.

The main factor influencing the values of the refractive indices of the acmite poor pyroxenes is the $Mg/Fe^{+2}$ ratio, so that the refractive indices show an

Figure 12

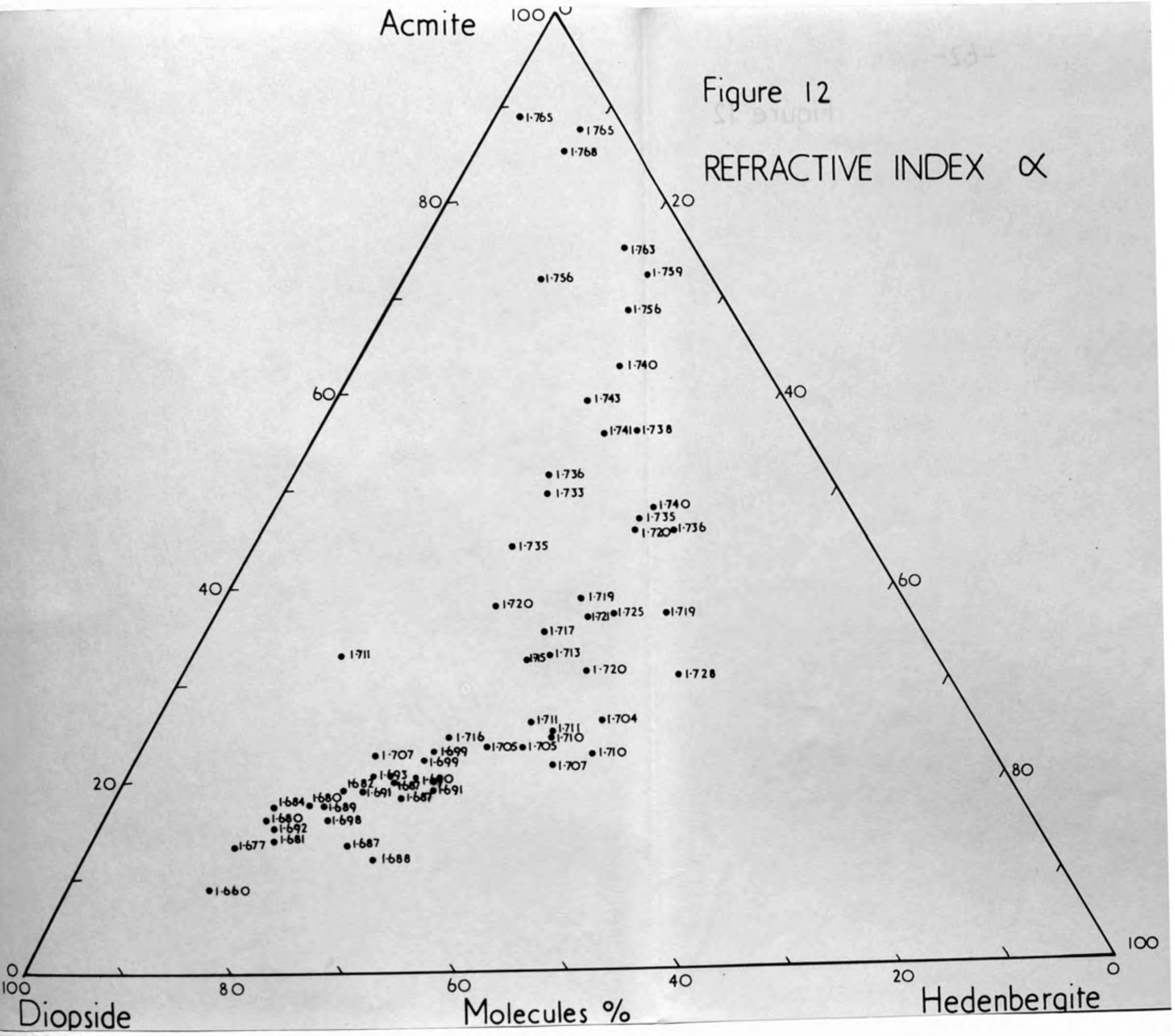


Figure 12

REFRACTIVE INDEX α

Figure 12a

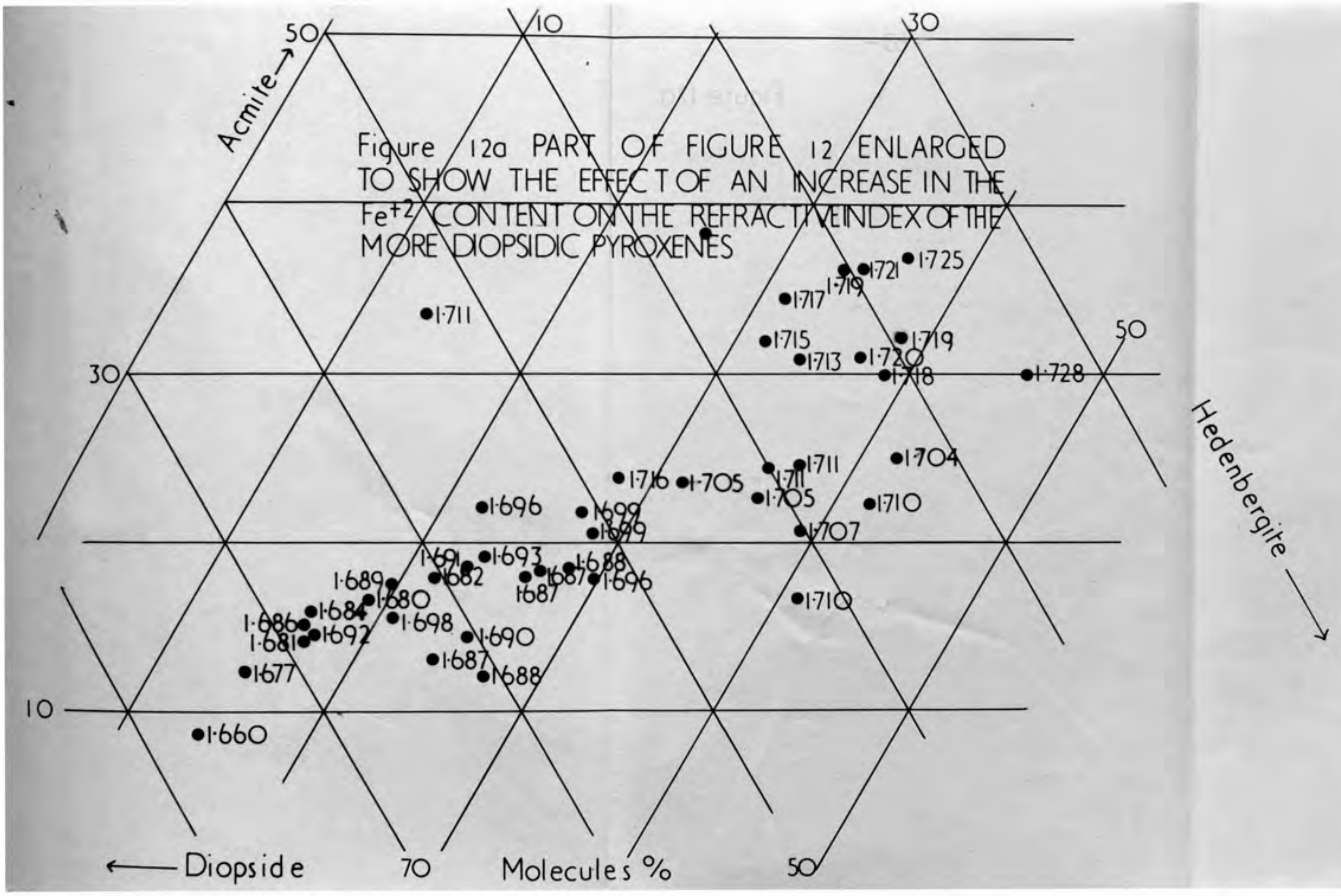


Figure 12a PART OF FIGURE 12 ENLARGED TO SHOW THE EFFECT OF AN INCREASE IN THE $Fe^{+2}$ CONTENT ON THE REFRACTIVE INDEX OF THE MORE DIOPSIDIC PYROXENES

Figure 13

Figure 13 REFRACTIVE INDEX α PLOTTED ON THE LINE FROM FIGURE 5

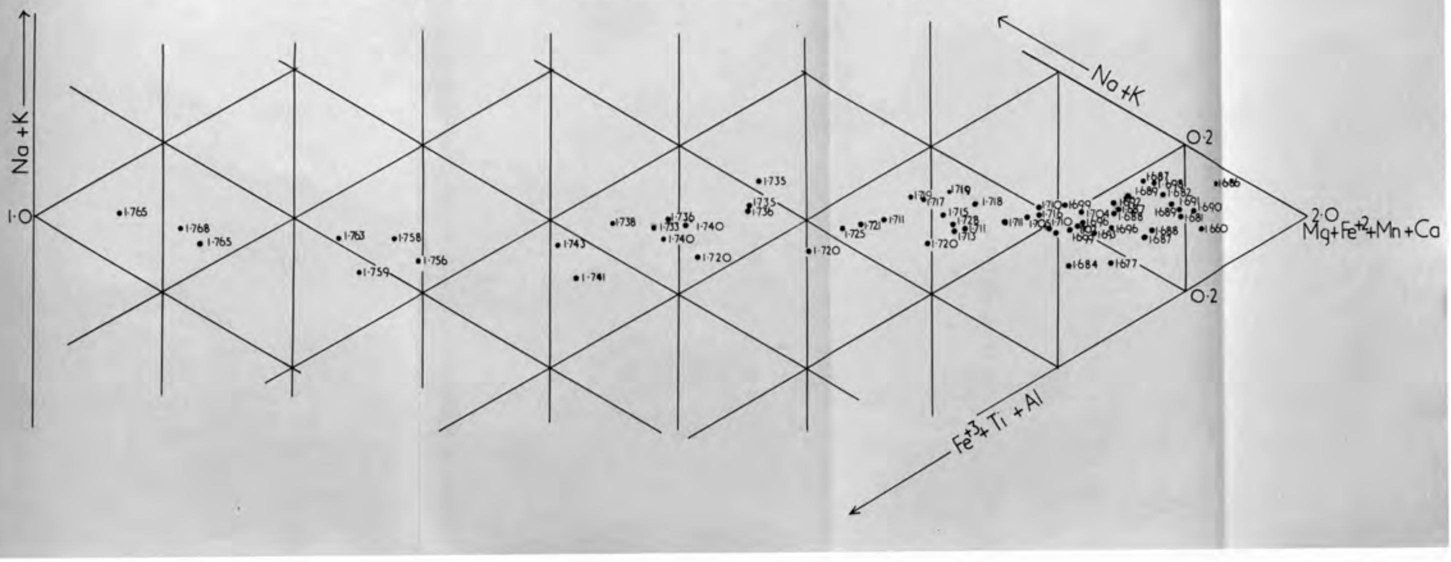
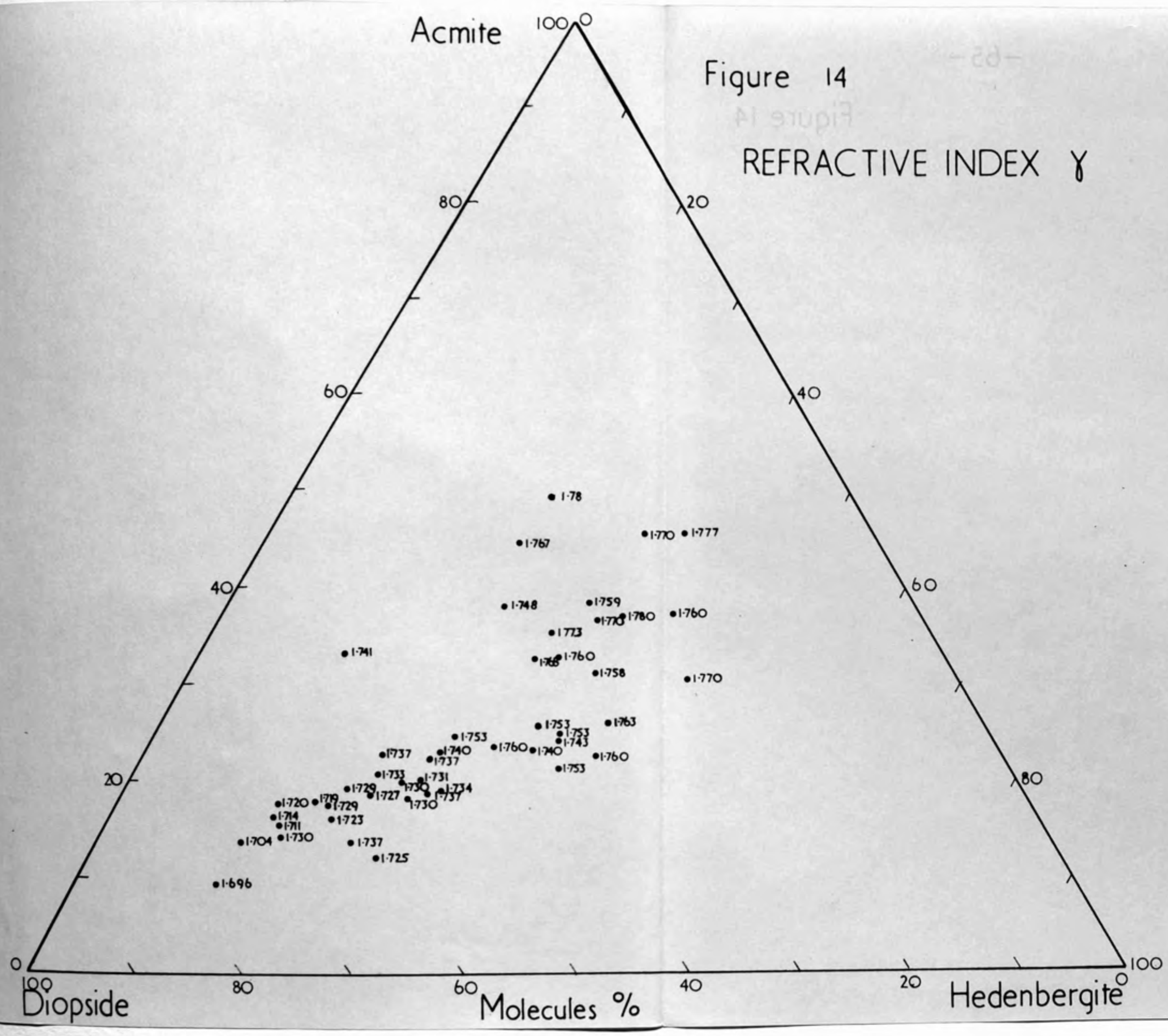


Figure 14

Figure 14

REFRACTIVE INDEX γ



unsystematic variation at the $MgFe^{+2}$ end of the line in Figure 13. In Figure 12 where the composition is expressed in terms of the three chief molecules, the refractive indices show a continuous increase, first with increase in hedenbergite and then with acmite. Figure 12a shows that pyroxenes with the same acmite content but with differing diopside/hedenbergite ratios have different refractive indices.

In the more acmitic pyroxenes, the percentage of diopside and hedenbergite present in the minerals is small and therefore the main factor affecting the refractive index is the $Fe^{+3}$ content. In both Figures 12 and 13 the values for the refractive indices fall in order at the acmitic end.

The pyroxenes containing large excesses of $CaSiO_3$ show anomalously low refractive indices (e.g. N 170, N 155, N 159).

## 3. SPECIFIC GRAVITY

This was measured in most cases using a pycnometer. Reproducible results were obtainable except for the pyroxenes which were only available in small quantities. In such cases, a fairly accurate method was devised using Clerici's solution at different dilutions of which the specific gravities were determined by standard blocks.

A few grains of the mineral were put into a range of solutions which were then centrifuged to ascertain in which of the liquids the pyroxenes floated or sank. The specific gravity could then be determined to within narrow limits depending on the intervals of specific gravity of the standard blocks.

The specific gravities have been plotted on the triangular diagram in which the pyroxenes are expressed in terms of the diopside, hedenbergite and acmite molecules (Figure 15). The diagram shows an increase in specific gravity with increase in hedenbergite content at the lower end of the curve. Further along the curve, the specific gravities show little change, since the effect of an increase in the acmite content tends to be offset by the decrease in hedenbergite.

Plotting specific gravities on a diagram constructed according to the method adopted by Sabine is less effective since Mg and $Fe^{+2}$ are represented at the same corner, so that pyroxenes which are low in acmite but which are rich in either diopside or hedenbergite and fall on the same part of the line show widely differing specific gravities. In the acmitic pyroxenes, where the Mg and $Fe^{+2}$ contents are small, a systematic variation of specific gravity is seen.

It was noted that those pyroxenes with a large excess

Figure 15

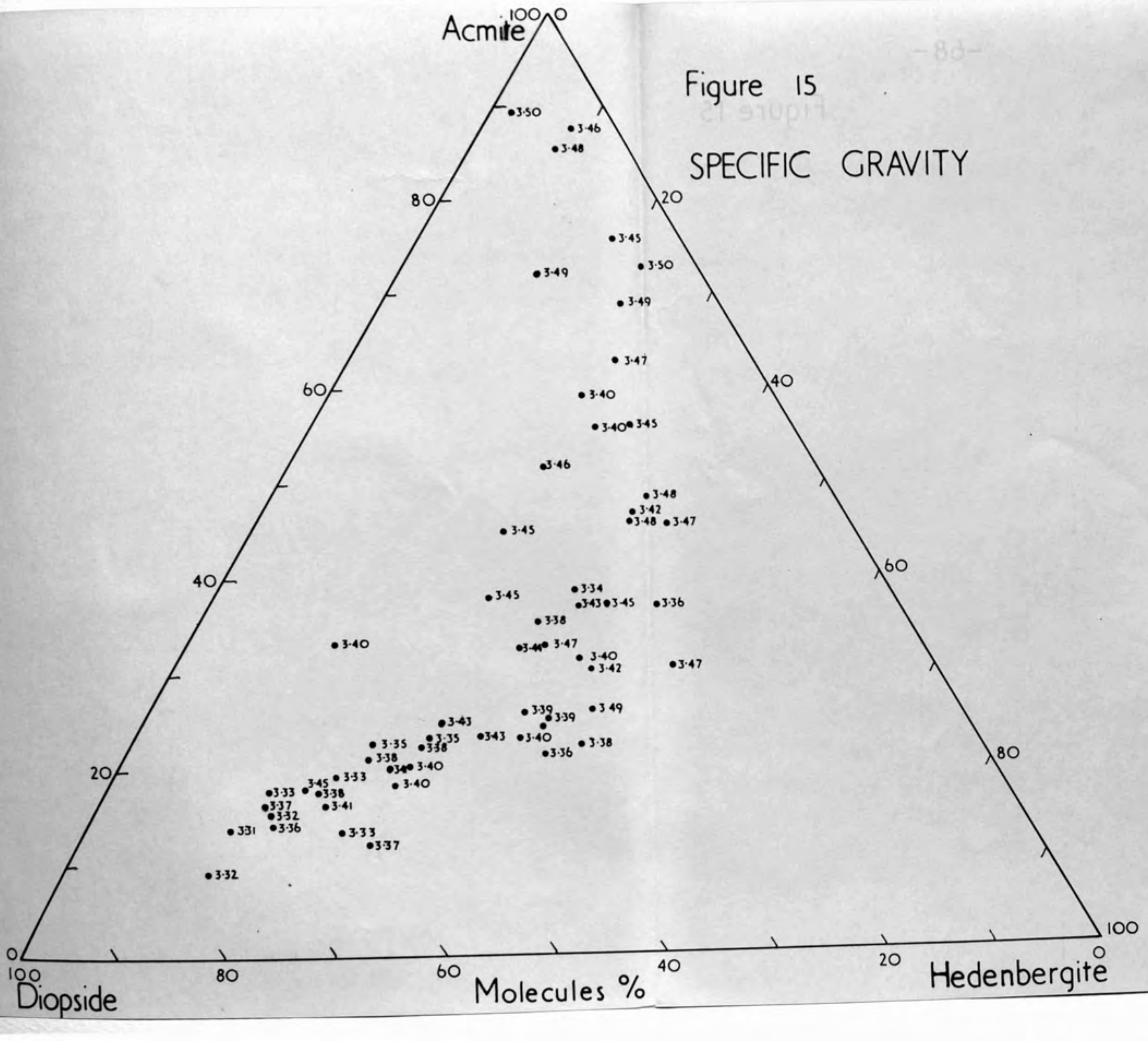


Figure 15

SPECIFIC GRAVITY

of $CaSiO_3$ at the diopside end of the curve shows anomalously low specific gravities (N 155, N 159, N 170).

## 4. THE A' $\wedge$ c ANGLE

The A' $\wedge$ c angle was determined using the method described by King (1962). The determinations were not made by the writer.

The angles have been plotted as shown in Figure 16. The values vary from 10° for the most diopsidic pyroxene (N 170) to 33° (K 320) and 35° (N 102) which were the most acmitic ones which could be determined. Owing to the prismatic form, and dark body colour of many of the more acmitic pyroxenes, it was not possible to measure the angle accurately.

The values increase from the diopsidic end of the curve, first mainly with increase in hedenbergite and then with increase in acmite.

Figure 16

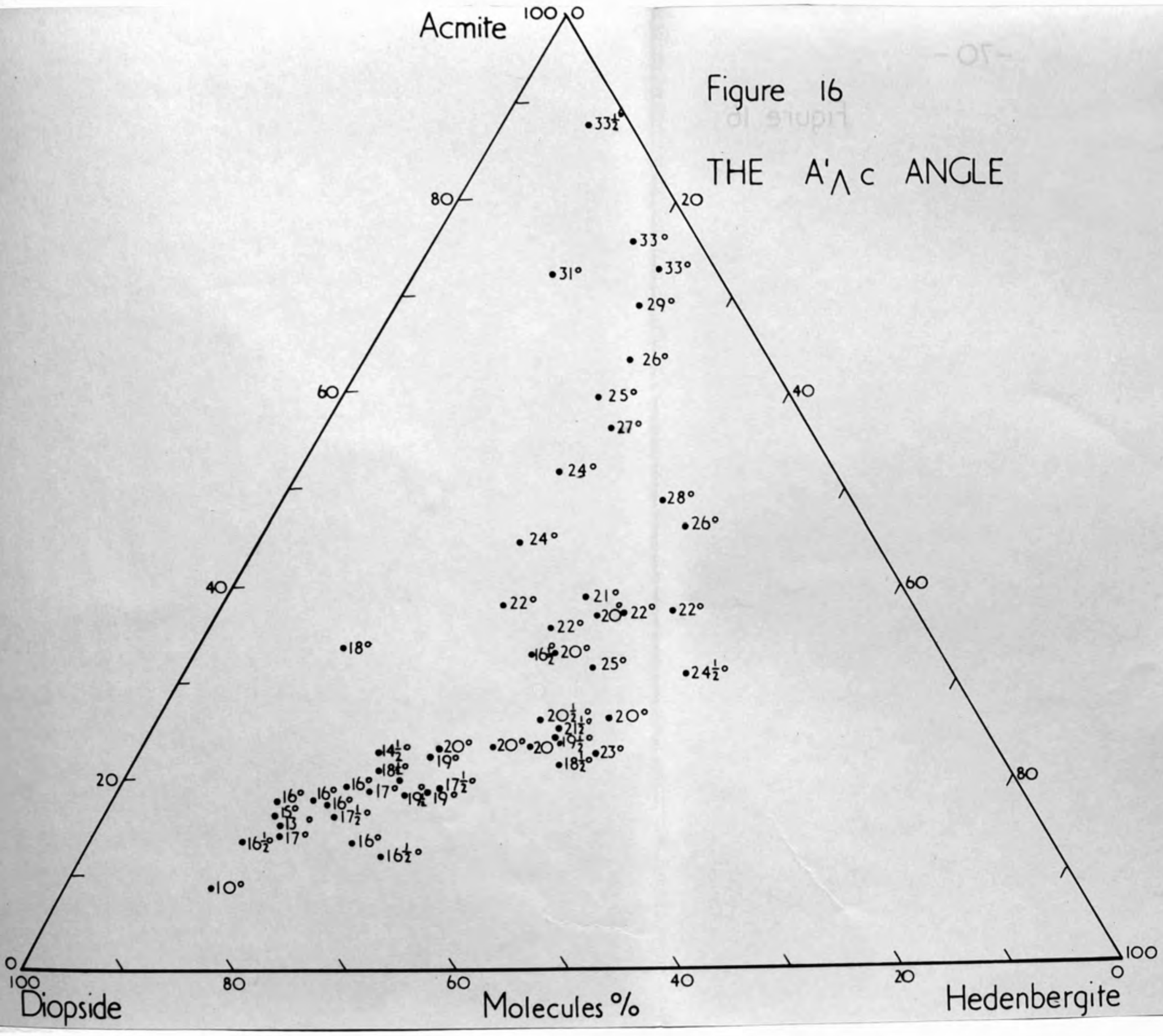


Figure 16

THE A'∧c ANGLE

# VI PETROLOGY AND RELATION OF COMPOSITIONS OF PYROXENES TO THE ROCK TYPES

## 1. EAST AFRICAN ROCKS

The rocks in which the pyroxenes occur are chiefly from the alkaline centres of Eastern Uganda. The suite is typically soda-rich and highly undersaturated. These complexes can be accurately dated from their relations with the Miocene peneplain. The older centres are cut by the surface and the younger volcanoes rest on top of it:-

- Pre-Miocene
  - Budeda
  - Bukusu
  - Sekulu
  - Tororo
- Post-Miocene
  - Elgon
  - Kadam
  - Morotu
  - Napak
  - Toror

Elgon, Kadam, Morotu and Napak are eroded volcanoes, but only in the case of Napak has erosion proceeded so far as to reveal the intrusive rocks of the centre. At Toror, the extrusive rocks have been completely removed by erosion. The pre-Miocene centres consist only of intrusive rocks.

The range of rocks found at the centres is:-

Increasing Undersaturation ↓
Fenites
Alkali syenites
Nepheline syenites
Ijolite Series: Urtite - ijolite - melteigite
(leucocratic) (melanocratic)
Carbonatites

The relative proportions of the various rock types differ from centre to centre, and all are not always present.

The intrusive masses are usually small, being only a few miles in diameter. Characteristically, they show some sort of ring structure similar to that of the Alnö alkaline complex in Sweden, described by von Eckermann, and taken as the standard pattern (King & Sutherland 1960, part II).

Mineralogically, the alkaline character is marked by the presence of alkali felspar and/or felspathoids. Of the dark minerals, pyroxene is the most abundant. This varies from nearly pure diopside to nearly pure aegirine, passing through varieties which contain about equal amounts of the diopside, hedenbergite and acmite molecules. The lavas sometimes contain a titanaugite. No pyroxenes from lavas have been analysed.

Other dark minerals include sodic amphibole, common brown hornblende, melanite and biotite. In addition to the alkali felspars and felspathoids, other light minerals found are wollastonite and calcite. Apatite is a common accessory, and there are often minerals of the rarer elements present in the carbonatites.

The pyroxenes vary according to the rock type in which they occur.

## (1) The carbonatites

The carbonatites commonly contain large prismatic crystals of pyroxene rich in aegirine. The percentage of the acmite molecule varies from 50% (To 572) to 72% (To 17).

## (2) The ultra mafic rocks

The ultra mafic rocks associated with the carbonatites contain abundant pyroxene. At Budeda there is a central mass of pyroxene melteigite which passes locally into carbonatite by gradual replacement of the rock by calcite. Napak also has pyroxenites. These rocks are not very alkaline in character. They consist of a diopside with only 14% acmite (N 35 C).

The turjaites, which provide a link between the ijolite series and the uncompahgrites, also contain diopside with only 10% acmite (N 170).

## (3) The Ijolite Series

The melteigite - ijolite - urtite series is divided according to the relative proportions of the essential minerals, pyroxene and nepheline. The series, which is well developed at Napak, is very soda rich although the pyroxenes themselves are often low in acmite; the value varies from 10% to 40% in those analysed. Owing to the small amount of pyroxene in the urtites (less than 5%), none has been analysed.

Davies (1956) reports 10% acmite in pyroxenes from Tororo ijolites. At Napak the value varies from 13% to 35%. Davies gives a value of 18% for Bukusu, and the new analysis shows 21%. The pyroxenes from the Budeda ijolites contain generally more of the acmite molecule, the value being between 24% and 37%. There is a general tendency for the acmite content to increase in the pyroxenes of successively later phases in the ijolite series.

### (4) The malignites and nepheline syenites

The malignites and nepheline syenites contain alkali felspar in addition to the felspathoids. At Tororo and Budeda nepheline syenite occurs between the ijolite and marginal syenite showing the same arrangement as at Alnö. The pyroxenes of these rocks are more sodic containing from 45% (N 107A) to 76% (N 102) acmite.

A pyroxene from nepheline syenite from Sørøy, northern Norway, one of the areas taken for comparison, is less sodic containing only 37% acmite.

### (5) The alkali syenites

The alkali syenites occur in close association with the nepheline syenites. This is well shown at Tororo and Budeda. The pyroxenes are sodic and contain up to

89% acmite (N 103C) or down to 62% (To 1).

### (6) The fenites

The term fenite was used by Brogger to describe the siliceous part of the metasomatic aureole round the Fen complex in Norway (King & Sutherland 1960, part II).

The fenites contain a fairly sodic pyroxene with between 35% (B 38) and 56% (To 43) acmite.

## 2. OTHER AREAS

The pyroxenes from Semarule, Bechuanaland are from alkali syenites. They range from a variety containing 21% acmite (K 353) to those containing 89% acmite (K 320).

Of the pyroxenes used in comparison with the African ones, two are from the Loch Borrolan alkali complex (Sabine 1950). The two rocks are cromaltite (Bo 330) and a xenolith in borolanite (Bo 270). This second pyroxene is of an unusual composition compared with the other alkali pyroxenes.

The other four rocks are from the island of Sørøy, northern Norway. They occur in an alkali complex in metamorphic rocks.

Figure 17 shows the difference in composition of pyroxenes from different rock types.

Figure 17

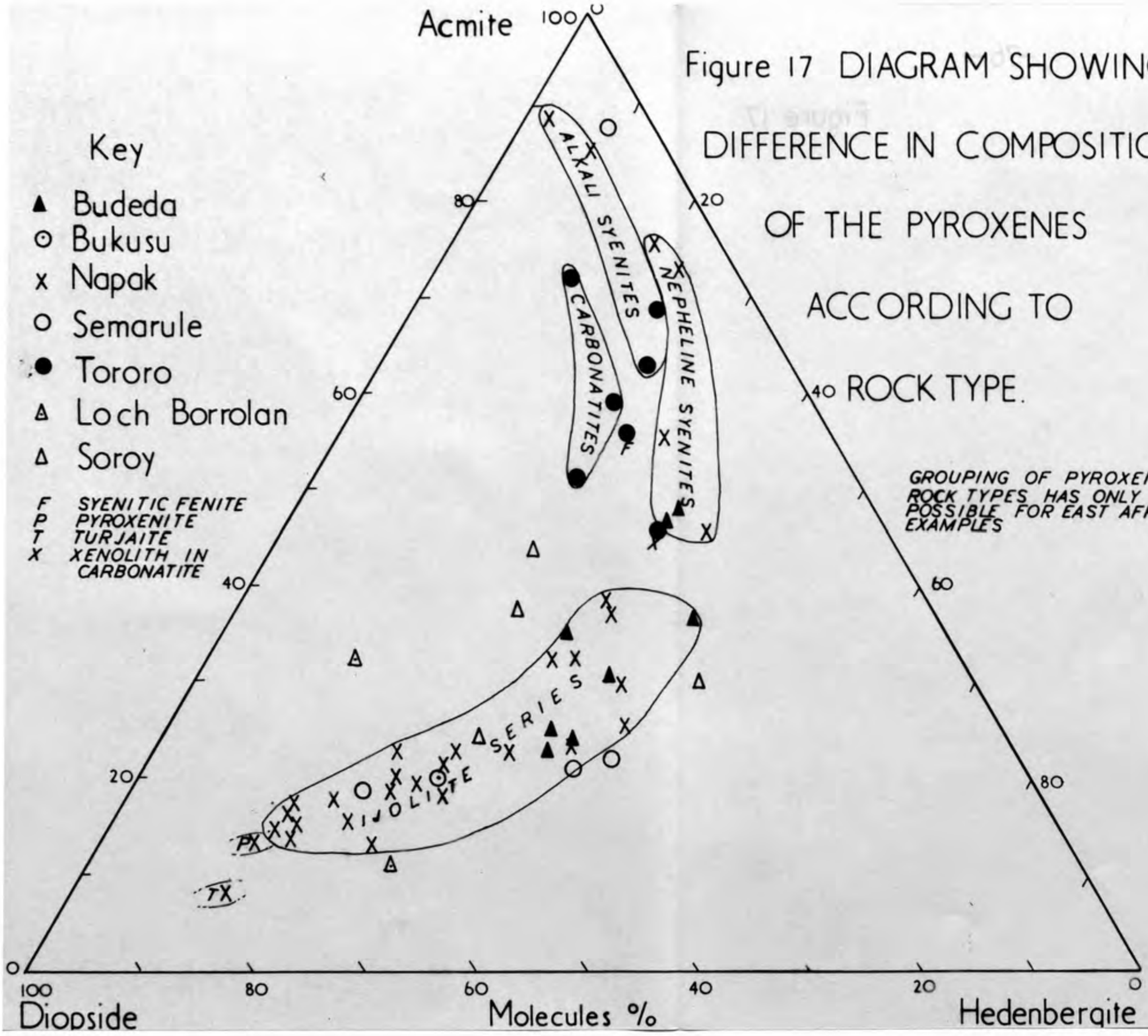


Figure 17 DIAGRAM SHOWING THE DIFFERENCE IN COMPOSITION OF THE PYROXENES ACCORDING TO ROCK TYPE.

GROUPING OF PYROXENES IN ROCK TYPES HAS ONLY BEEN POSSIBLE FOR EAST AFRICAN EXAMPLES

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# TABLE I

## ANALYSES OF PYROXENES

### Key to Localities

B = Budeda, Uganda, East Africa.
Bu = Bukusu, Uganda, East Africa.
N = Napak, Uganda, East Africa.
To = Tororo, Uganda, East Africa.
K = Semarule Bechuanaland.
Bo = Loch Borrolan, Assynt, Sutherland.
SB = Brevikbotn, Island of Soroy, near Hammerfest, Norway.

### Index to Table I

Analyses of Pyroxenes from Budeda 84-92

| | |
|---|---|
| B 7 | Ijolite |
| B 28 | Melteigite |
| B 29 | Melteigite |
| B 33 | Biotite-Melteigite |
| B 38 | Ijolite |
| B 68 | Syenitic fenite with nepheline |
| B 96 | Nepheline-cancrinite-syenite dyke |
| B 101 | Altered ijolite |
| B 282 | Cancrinite syenite |

Analysis of pyroxene from Bukusu 93

| | |
|---|---|
| Bu 414 | Ijolite |

Analyses of pyroxenes from Napak 94-127

| | |
|---|---|
| N 23 | Moderately coarse grained ijolite with melanite |
| N 30 | Fine-grained ijolite with melanite |
| N 35C | Medium-grained pyroxenite |
| N 35F | Fine-grained ijolite |
| N 48 | Medium-grained melanite ijolite |
| N 52 | Medium-grained melanite ijolite |
| N 62 | Melteigite |
| N 93 | Coarse-grained melteigite |

| | |
|---|---|
| N 95 | Cancrinite syenite |
| N 102 | Cancrinite syenite |
| N 103C | Coarse-grained alkali syenite |
| N 103F | Fine-grained alkali syenite |
| N 107A | Nepheline syenite |
| N 108 | Coarse-grained melanite ijolite |
| N 114 | Mesocratic ijolite, with melanite |
| N 117 | Medium granular ijolite with melanite |
| N 118 | Fine-grained ijolite |
| N 119 | Variable ijolite |
| N 120R | Coarse-grained ijolite |
| N 120V | Vein in coarse-grained ijolite |
| N 121 | Nepheline syenite |
| N 152 | Coarse-grained ijolite |
| N 155 | Medium-grained ijolite with melanite |
| N 159 | Medium granular ijolite with melanite |
| N 163 | 'Schistose' ijolite |
| N 170 | Turjaite |
| N 178 | Medium-grained ijolite with melanite |
| N 511 | Fine granualr ijolite with melanite and wollastonite |
| N 514 | Coarse-grained ijolite |
| N 516 | Ijolite pegmatite |
| N 517A | Ijolite |
| N 518 | Banded ijolite |
| N 520 | Mesocratic ijolite with melanite |
| N 529 | Coarse-grained ijolite with melanite |

## Analyses of Pyroxenes from Tororo 128-134

| | |
|---|---|
| To 1 | Syenite |
| To 14 | Carbonate-syenite rock |
| To 17 | Pyroxene-bearing carbonatite |
| To 21 | Pyroxene apatite carbonatite |
| To 43 | Syenitic fenite |
| To 572 | Coarse carbonatite with pyroxene |
| To 585 | Pyroxene-rich xenolith in carbonatite |

## Analyses of pyroxenes from Semarule 135-138

| | |
|---|---|
| K 62 | Syenite pegmalite |
| K 320 | Banded syenite |
| K 353 | Coarse even-grained syenite |
| K 440 | Pyroxene schlieren in coarse-grained syenite |

### Analyses of pyroxenes from Loch Borrolan 139-140

| | |
|---|---|
| Bo 270 | Xenolith in borolanite |
| Bo 330 | Cromaltite |

### Analyses of pyroxenes from Sørøy 141-144

| | |
|---|---|
| S | Pyroxene segregation in carbonatite |
| SB 78 | Fenite |
| SB 190 | Nepheline syenite |
| SB 245 | Fenite |

TABLE I

B 7 Ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.29 | Si | 1.956 | 2.00 |
| $TiO_2$ | 1.23 | Ti | 0.035 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.019 | |
| $Fe_2O_3$ | 12.84 | $Fe^{+3}$ | 0.354 | 0.99 |
| FeO | 10.94 | $Fe^{+2}$ | 0.355 | |
| MnO | 0.34 | Mn | 0.012 | |
| MgO | 4.68 | Mg | 0.273 | |
| CaO | 15.26 | Ca | 0.635 | 1.00 |
| $Na_2O$ | 4.36 | Na | 0.326 | |
| $K_2O$ | 0.84 | K | 0.042 | |
| $H_2O+$ | - | O'' | | 6.00 |
| $P_2O_5$ | trace | | | |
| | 100.78 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 26.61 | α | 1.725 |
| Hedenbergite | 36.32 | γ | 1.780 |
| Acmite | 36.56 | A ∧ c | 22½° |
| $MgSiO_3$ | 0.46 | S.G. | 3.45 |
| | 99.95 | | |

TABLE I (CONTINUED)

B 28 Melteigite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.30 | Si | 1.923 | 2.00 |
| $TiO_2$ | 0.78 | Al | 0.014 | |
| $Al_2O_3$ | 0.27 | Ti | 0.023 | |
| $Fe_2O_3$ | 9.08 | $Fe^{+3}$ | 0.040 | |
| FeO | 10.45 | $Fe^{+3}$ | 0.227 | 0.98 |
| MnO | 0.40 | $Fe^{+2}$ | 0.340 | |
| MgO | 6.88 | Mn | 0.014 | |
| CaO | 19.12 | Mg | 0.403 | |
| $Na_2O$ | 2.40 | Ca | 0.801 | 1.04 |
| $K_2O$ | 1.04 | Na | 0.183 | |
| $H_2O+$ | - | K | 0.052 | |
| $P_2O_5$ | 0.16 | O'' | | 6.00 |
| | 99.88 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 38.29 | α | 1.711 |
| Hedenbergite | 33.63 | γ | 1.753 |
| Acmite | 22.26 | $A \wedge c$ | $20\frac{1}{2}^\circ$ |
| Wollastonite | 5.79 | S.G. | 3.39 |
| | 99.97 | | |

TABLE I (CONTINUED)

B 29 Melteigite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.12 | Si | 1.926 | 2.00 |
| $TiO_2$ | 0.40 | Al | 0.009 | |
| $Al_2O_3$ | 0.18 | Ti | 0.012 | |
| $Fe_2O_3$ | 9.48 | $Fe^{+3}$ | 0.053 | |
| FeO | 10.50 | $Fe^{+3}$ | 0.225 | 0.88 |
| MnO | 0.42 | $Fe^{+2}$ | 0.343 | |
| MgO | 6.76 | Mn | 0.014 | |
| CaO | 19.12 | Mg | 0.298 | |
| $Na_2O$ | 2.62 | Ca | 0.804 | 1.05 |
| $K_2O$ | 0.99 | Na | 0.198 | |
| $H_2O+$ | - | K | 0.047 | |
| $P_2O_5$ | 0.14 | $O''$ | | 6.00 |
| | 99.73 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 37.87 | $\alpha$ | 1.711 |
| Hedenbergite | 36.30 | $\gamma$ | 1.753 |
| Acmite | 23.30 | $A \wedge c$ | $21\frac{1}{2}^{\circ}$ |
| Wollastonite | 2.47 | S.G. | 3.39 |
| | 99.94 | | |

## TABLE I (CONTINUED)

### B 33 Biotite Melteigite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.10 | Si | 1.902 | 2.00 |
| $TiO_2$ | 1.00 | Al | 0.009 | |
| $Al_2O_3$ | 0.20 | Ti | 0.030 | |
| $Fe_2O_3$ | 8.60 | $Fe^{+3}$ | 0.059 | |
| FeO | 10.90 | $Fe^{+3}$ | 0.192 | 0.99 |
| MnO | 0.42 | $Fe^{+2}$ | 0.351 | |
| MgO | 7.37 | Mn | 0.014 | |
| CaO | 20.06 | Mg | 0.428 | |
| $Na_2O$ | 2.60 | Ca | 0.843 | 1.06 |
| $K_2O$ | 0.48 | Na | 0.195 | |
| $H_2O+$ | - | K | 0.023 | |
| $P_2O_5$ | 0.02 | O'' | | 6.00 |
| | 100.75 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 40.23 | $\alpha$ | 1.705 |
| Hedenbergite | 34.33 | $\gamma$ | 1.746 |
| Acmite | 20.56 | $A \wedge c$ | $20\frac{1}{2}^{\circ}$ |
| Wollastonite | 4.81 | S.G. | 3.40 |
| | 99.93 | | |

TABLE I (CONTINUED)

B 38 Ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 48.49 | Si | 1.904 | 2.00 |
| $TiO_2$ | 0.51 | Al | 0.096 | |
| $Al_2O_3$ | 2.43 | Al | 0.017 | 0.98 |
| $Fe_2O_3$ | 7.88 | Ti | 0.014 | |
| FeO | 12.05 | $Fe^{+3}$ | 0.231 | |
| MnO | 0.48 | $Fe^{+2}$ | 0.394 | |
| MgO | 5.23 | Mn | 0.016 | |
| CaO | 17.61 | Mg | 0.309 | |
| $Na_2O$ | 3.87 | Ca | 0.739 | 1.07 |
| $K_2O$ | 0.87 | Na | 0.292 | |
| $H_2O+$ | - | K | 0.043 | |
| $P_2O_5$ | 0.24 | O'' | | 6.00 |
| | 99.66 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 28.72 | α | 1.719 |
| Hedenbergite | 38.14 | γ | 1.760 |
| Acmite | 31.12 | A ∧ c | 22° |
| Wollastonite | 1.97 | S.G. | 3.36 |
| | 99.95 | | |

## TABLE I (CONTINUED)

### B 68 Syenite fenite with nepheline

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.83 | Si | 1.942 | 2.00 |
| $TiO_2$ | 0.67 | Al | 0.058 | |
| $Al_2O_3$ | 1.36 | Al | 0.002 | 0.91 |
| $Fe_2O_3$ | 8.86 | Ti | 0.018 | |
| FeO | 9.09 | $Fe^{+3}$ | 0.252 | |
| MnO | 0.48 | $Fe^{+2}$ | 0.289 | |
| MgO | 5.85 | Mn | 0.016 | |
| CaO | 18.50 | Mg | 0.335 | |
| $Na_2O$ | 3.52 | Ca | 0.757 | 1.09 |
| $K_2O$ | 1.42 | Na | 0.262 | |
| $H_2O+$ | - | K | 0.068 | |
| $P_2O_5$ | trace | O'' | | 6.00 |
| | 100.58 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 30.77 | α | 1.717 |
| Hedenbergite | 28.05 | γ | 1.773 |
| Acmite | 30.35 | A ∧ c | 22° |
| Wollastonite | 10.75 | S.G. | 3.38 |
| | 99.92 | | |

TABLE I (CONTINUED)

B 96 Nepheline cancrinite syenite dyke

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.39 | Si | 1.948 | 2.00 |
| $TiO_2$ | 1.16 | Al | 0.052 | |
| $Al_2O_3$ | 2.39 | Al | 0.055 | 1.02 |
| $Fe_2O_3$ | 13.85 | Ti | 0.035 | |
| FeO | 10.25 | $Fe^{+3}$ | 0.404 | |
| MnO | 0.32 | $Fe^{+2}$ | 0.330 | |
| MgO | 3.16 | Mn | 0.012 | |
| CaO | 12.30 | Mg | 0.183 | |
| $Na_2O$ | 6.25 | Ca | 0.510 | 0.99 |
| $K_2O$ | 0.19 | Na | 0.469 | |
| $H_2O+$ | 0.06 | K | 0.009 | |
| $P_2O_5$ | 0.04 | OH' | 0.013 | 6.00 |
| | 100.36 | O'' | 5.987 | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 17.04 | α | 1.740 |
| Hedenbergite | 34.33 | γ | - |
| Acmite | 47.19 | A ∧ c | 28° |
| $MgSiO_3$ | 1.40 | S.G. | 3.48 |
| | 99.96 | | |

TABLE I (CONTINUED)

B 101 Altered ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 45.32 | Si | 1.812 | 2.00 |
| $TiO_2$ | 2.51 | Ti | 0.074 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.114 | |
| $Fe_2O_3$ | 13.36 | $Fe^{+3}$ | 0.285 | 1.00 |
| FeO | 10.96 | $Fe^{+2}$ | 0.365 | |
| MnO | 0.53 | Mn | 0.017 | |
| MgO | 5.48 | Mg | 0.329 | |
| CaO | 17.27 | Ca | 0.739 | 1.06 |
| $Na_2O$ | 3.63 | Na | 0.264 | |
| $K_2O$ | 1.05 | K | 0.053 | |
| $H_2O+$ | - | O'' | | 6.00 |
| $P_2O_5$ | 0.24 | | | |
| | 100.35 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 31.11 | $\alpha$ | 1.720 |
| Hedenbergite | 36.11 | $\gamma$ | 1.758 |
| Acmite | 29.99 | $A \wedge c$ | 25° |
| Wollastonite | 2.70 | $X \wedge c$ | 20° |
| | 99.91 | S.G. | 3.40 |

TABLE I (CONTINUED)

B 282 Cancrinite syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 48.82 | Si | 1.932 | 2.00 |
| $TiO_2$ | 1.05 | Ti | 0.031 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.037 | |
| $Fe_2O_3$ | 15.33 | $Fe^{+3}$ | 0.418 | 0.95 |
| FeO | 9.76 | $Fe^{+2}$ | 0.323 | |
| MnO | 0.64 | Mn | 0.021 | |
| MgO | 3.14 | Mg | 0.185 | |
| CaO | 14.54 | Ca | 0.615 | 1.11 |
| $Na_2O$ | 6.15 | Na | 0.470 | |
| $K_2O$ | 0.43 | K | 0.023 | |
| $H_2O+$ | - | O'' | | 6.00 |
| $P_2O_5$ | trace | | | |
| | 99.86 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 17.28 | $\alpha$ | 1.735 |
| Hedenbergite | 32.14 | $\gamma$ | 1.770 |
| Acmite | 42.55 | $A \wedge c$ | - |
| Wollastonite | 7.98 | S.G. | 3.42 |
| | 99.95 | | |

TABLE I (CONTINUED)

Bu 414 Melteigite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.21 | Si | 1.930 | 2.00 |
| $TiO_2$ | 0.51 | Ti | 0.014 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.056 | |
| $Fe_2O_3$ | 4.30 | $Fe^{+3}$ | 0.069 | 0.98 |
| FeO | 7.85 | $Fe^{+2}$ | 0.252 | |
| MnO | 0.28 | Mn | 0.009 | |
| MgO | 11.21 | Mg | 0.646 | |
| CaO | 23.08 | Ca | 0.948 | 0.99 |
| $Na_2O$ | 1.54 | Na | 0.115 | |
| $K_2O$ | 0.51 | K | 0.023 | |
| $H_2O+$ | - | $O''$ | | 6.00 |
| $P_2O_5$ | none | | | |
| | 99.49 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 59.43 | $\alpha$ | 1.690 |
| Hedenbergite | 23.98 | $\gamma$ | 1.731 |
| Acmite | 12.74 | $A \wedge c$ | - |
| Wollastonite | 3.82 | S.G. | 3.40 |
| | 99.97 | | |

TABLE I (CONTINUED)

N 23 Moderately coarse-grained ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.30 | Si | 1.946 | 2.00 |
| $TiO_2$ | 0.39 | Al | 0.054 | |
| $Al_2O_3$ | 1.28 | Al | 0.008 | 0.92 |
| $Fe_2O_3$ | 9.31 | Ti | 0.012 | |
| FeO | 9.54 | $Fe^{+3}$ | 0.275 | |
| MnO | 0.52 | $Fe^{+2}$ | 0.317 | |
| MgO | 5.84 | Mn | 0.017 | |
| CaO | 18.49 | Mg | 0.287 | |
| $Na_2O$ | 4.49 | Ca | 0.782 | 1.14 |
| $K_2O$ | 0.27 | Na | 0.341 | |
| $H_2O+$ | - | K | 0.014 | |
| $P_2O_5$ | 0.06 | O'' | | 6.00 |
| | 99.49 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 25.20 | $\alpha$ | 1.719 |
| Hedenbergite | 29.17 | $\gamma$ | 1.759 |
| Acmite | 31.25 | $A \wedge c$ | 21° |
| Wollastonite | 14.38 | S.G. | 3.34 |
| | 100.00 | | |

TABLE I (CONTINUED)

N 30 Fine-grained ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.80 | Si | 1.976 | 2.00 |
| $TiO_2$ | 0.87 | Al | 0.024 | |
| $Al_2O_3$ | 2.06 | Al | 0.069 | 0.97 |
| $Fe_2O_3$ | 8.80 | Ti | 0.026 | |
| FeO | 10.07 | $Fe^{+3}$ | 0.257 | |
| MnO | 0.32 | $Fe^{+2}$ | 0.327 | |
| MgO | 4.80 | Mn | 0.009 | |
| CaO | 16.15 | Mg | 0.280 | |
| $Na_2O$ | 3.66 | Ca | 0.674 | 1.02 |
| $K_2O$ | 1.40 | Na | 0.275 | |
| $H_2O+$ | - | K | 0.070 | |
| $P_2O_5$ | 0.10 | O'' | | 6.00 |
| | 99.03 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 27.44 | $\alpha$ | 1.721 |
| Hedenbergite | 32.93 | $\gamma$ | 1.770 |
| Acmite | 33.85 | $A \wedge c$ | 20° |
| Wollastonite | 5.72 | S.G. | 3.43 |
| | 99.94 | | |

TABLE I (CONTINUED)

N 35C Medium-grained pyroxenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.10 | Si | 1.902 | 2.00 |
| $TiO_2$ | 1.36 | Al | 0.098 | |
| $Al_2O_3$ | 4.09 | Al | 0.081 | 1.01 |
| $Fe_2O_3$ | 3.10 | Ti | 0.038 | |
| FeO | 3.71 | $Fe^{+3}$ | 0.085 | |
| MnO | 0.11 | $Fe^{+2}$ | 0.116 | |
| MgO | 12.24 | Mn | 0.004 | |
| CaO | 21.90 | Mg | 0.683 | |
| $Na_2O$ | 1.10 | Ca | 0.873 | 0.97 |
| $K_2O$ | 0.28 | Na | 0.080 | |
| $H_2O+$ | - | K | 0.013 | |
| $P_2O_5$ | 0.01 | O'' | | 6.00 |
| | 99.00 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 70.64 | $\alpha$ | 1.677 |
| Hedenbergite | 12.46 | $\gamma$ | 1.704 |
| Acmite | 9.70 | $A \wedge c$ | $16\frac{1}{2}^{\circ}$ |
| Wollastonite | 7.16 | S.G. | 3.31 |
| | 99.96 | | |

TABLE I (CONTINUED)

N 35F Ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.73 | Si | 1.879 | 2.00 |
| $TiO_2$ | 2.35 | Al | 0.121 | |
| $Al_2O_3$ | 3.93 | Al | 0.052 | 1.00 |
| $Fe_2O_3$ | 4.49 | Ti | 0.064 | |
| FeO | 3.97 | $Fe^{+3}$ | 0.124 | |
| MnO | 0.19 | $Fe^{+2}$ | 0.122 | |
| MgO | 11.32 | Mn | 0.007 | |
| CaO | 21.40 | Mg | 0.628 | |
| $Na_2O$ | 1.55 | Ca | 0.849 | 0.97 |
| $K_2O$ | 0.18 | Na | 0.111 | |
| $H_2O+$ | - | K | 0.009 | |
| $P_2O_5$ | 0.03 | $O''$ | | 6.00 |
| | 100.14 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 64.91 | $\alpha$ | 1.684 |
| Hedenbergite | 13.30 | $\gamma$ | 1.720 |
| Acmite | 12.38 | $A \wedge c$ | 16° |
| Wollastonite | 9.40 | S.G. | 3.33 |
| | 99.99 | | |

## TABLE I (CONTINUED)

### N 48 Medium-grained melanite ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.81 | Si | 1.896 | 2.00 |
| $TiO_2$ | 0.75 | Al | 0.101 | |
| $Al_2O_3$ | 2.21 | Ti | 0.003 | |
| $Fe_2O_3$ | 6.57 | Ti | 0.018 | 0.97 |
| FeO | 7.97 | $Fe^{+3}$ | 0.187 | |
| MnO | 0.22 | $Fe^{+2}$ | 0.254 | |
| MgO | 8.75 | Mn | 0.007 | |
| CaO | 21.39 | Mg | 0.500 | |
| $Na_2O$ | 2.22 | Ca | 0.873 | 1.06 |
| $K_2O$ | 0.34 | Na | 0.164 | |
| $H_2O+$ | 0.02 | K | 0.018 | |
| $P_2O_5$ | 0.15 | OH' | 0.005 | 6.00 |
| | 100.40 | O'' | 5.995 | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 47.86 | $\alpha$ | 1.699 |
| Hedenbergite | 24.66 | $\gamma$ | 1.740 |
| Acmite | 17.30 | $A \wedge c$ | 20° |
| Wollastonite | 10.60 | S.G. | 3.35 |
| | 100.42 | | |

TABLE I (CONTINUED)

N 52 Medium-grained melanite ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.40 | Si | 1.910 | 2.00 |
| $TiO_2$ | 0.60 | Al | 0.036 | |
| $Al_2O_3$ | 0.82 | Ti | 0.018 | |
| $Fe_2O_3$ | 5.87 | $Fe^{+3}$ | 0.036 | |
| FeO | 9.17 | $Fe^{+3}$ | 0.132 | 0.99 |
| MnO | 0.27 | $Fe^{+2}$ | 0.289 | |
| MgO | 9.47 | Mn | 0.009 | |
| CaO | 21.14 | Mg | 0.562 | |
| $Na_2O$ | 2.34 | Ca | 0.857 | 1.05 |
| $K_2O$ | 0.44 | Na | 0.168 | |
| $H_2O+$ | - | K | 0.023 | |
| $P_2O_5$ | 0.32 | O'' | | 6.00 |
| | 100.84 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 53.22 | α | 1.688 |
| Hedenbergite | 28.34 | γ | 1.737 |
| Acmite | 18.18 | A ∧ c | 19° |
| Wollastonite | 0.22 | S.G. | 3.35 |
| | 99.96 | | |

## TABLE I (CONTINUED)

### N 62 Melteigite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.32 | Si | 1.892 | 2.00 |
| $TiO_2$ | 0.86 | Al | 0.108 | |
| $Al_2O_3$ | 4.03 | Al | 0.076 | 1.11 |
| $Fe_2O_3$ | 2.90 | Ti | 0.025 | |
| FeO | 6.07 | $Fe^{+3}$ | 0.249 | |
| MnO | 0.13 | $Fe^{+2}$ | 0.193 | |
| MgO | 11.91 | Mn | 0.005 | |
| CaO | 21.67 | Mg | 0.571 | |
| $Na_2O$ | 1.84 | Ca | 0.891 | 1.09 |
| $K_2O$ | 1.43 | Na | 0.133 | |
| $H_2O+$ | – | K | 0.069 | |
| $P_2O_5$ | none | O'' | | 6.00 |
| | 100.16 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 52.20 | α | 1.696 |
| Hedenbergite | 18.10 | γ | 1.731 |
| Acmite | 18.52 | A ∧ c | $14\frac{1}{2}^\circ$ |
| Wollastonite | 11.15 | S.G. | 3.35 |
| | 99.97 | | |

TABLE I (CONTINUED)

N 93 Coarse-grained melteigite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.55 | Si | 1.886 | 2.00 |
| $TiO_2$ | 1.01 | Al | 0.050 | |
| $Al_2O_3$ | 1.09 | Ti | 0.030 | |
| $Fe_2O_3$ | 4.37 | $Fe^{+3}$ | 0.034 | |
| FeO | 4.32 | $Fe^{+3}$ | 0.089 | 1.01 |
| MnO | 0.18 | $Fe^{+2}$ | 0.137 | |
| MgO | 12.56 | Mn | 0.069 | |
| CaO | 23.88 | Mg | 0.717 | |
| $Na_2O$ | 1.23 | Ca | 0.973 | 1.12 |
| $K_2O$ | 1.17 | Na | 0.091 | |
| $H_2O+$ | - | K | 0.055 | |
| $P_2O_5$ | none | O'' | | 6.00 |
| | 99.36 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 65.44 | $\alpha$ | 1.686 |
| Hedenbergite | 13.13 | $\gamma$ | 1.714 |
| Acmite | 11.26 | $A \wedge c$ | $15^\circ$ |
| Wollastonite | 10.21 | S.G. | 3.37 |
| | 100.04 | | |

## TABLE I (CONTINUED)

### N 95 Cancrinite syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.30 | Si | 1.954 | 2.00 |
| $TiO_2$ | 1.44 | Al | 0.046 | |
| $Al_2O_3$ | 1.53 | Al | 0.054 | 1.05 |
| $Fe_2O_3$ | 24.17 | Ti | 0.042 | |
| FeO | 5.75 | $Fe^{+3}$ | 0.704 | |
| MnO | 0.44 | $Fe^{+2}$ | 0.187 | |
| MgO | 0.78 | Mn | 0.014 | |
| CaO | 5.93 | Mg | 0.047 | |
| $Na_2O$ | 7.59 | Ca | 0.247 | 0.91 |
| $K_2O$ | 1.86 | Na | 0.569 | |
| $H_2O+$ | none | K | 0.093 | |
| $P_2O_5$ | 0.30 | O'' | | 6.00 |
| | 100.09 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 5.13 | $\alpha$ | 1.759 |
| Hedenbergite | 22.04 | $\gamma$ | - |
| Acmite | 72.00 | $A \wedge c$ | 33° |
| Wollastonite | - | $X \wedge c$ | 0 |
| | 99.17 | S.G. | 3.50 |

TABLE I (CONTINUED)

N 102 Cancrinite syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.36 | Si | 1.956 | 2.00 |
| $TiO_2$ | 1.08 | Al | 0.044 | |
| $Al_2O_3$ | 4.14 | Al | 0.143 | 0.98 |
| $Fe_2O_3$ | 21.14 | Ti | 0.030 | |
| FeO | 5.00 | $Fe^{+3}$ | 0.603 | |
| MnO | 0.16 | $Fe^{+2}$ | 0.158 | |
| MgO | 0.66 | Mn | 0.005 | |
| CaO | 6.75 | Mg | 0.039 | |
| $Na_2O$ | 9.69 | Ca | 0.276 | 1.01 |
| $K_2O$ | 0.49 | Na | 0.713 | |
| $H_2O+$ | 0.02 | K | 0.023 | |
| $P_2O_5$ | 0.03 | OH' | 0.005 | 6.00 |
| | 100.52 | O'' | 5.995 | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 3.93 | α | 1.763 |
| Hedenbergite | 16.40 | γ | – |
| Acmite | 72.06 | A ∧ c | 33° |
| Wollastonite | 7.62 | X ∧ c | -2° |
| | 100.01 | S.G. | 3.45 |

## TABLE I (CONTINUED)

### N 103C Coarse alkali syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.07 | Si | 1.886 | 2.00 |
| $TiO_2$ | 2.49 | Al | 0.069 | |
| $Al_2O_3$ | 1.51 | Ti | 0.045 | |
| $Fe_2O_3$ | 29.69 | Ti | 0.027 | 1.01 |
| FeO | 0.34 | $Fe^{+3}$ | 0.859 | |
| MnO | 0.29 | $Fe^{+2}$ | 0.012 | |
| MgO | 1.73 | Mn | 0.009 | |
| CaO | 2.61 | Mg | 0.099 | |
| $Na_2O$ | 11.81 | Ca | 0.109 | 1.03 |
| $K_2O$ | 0.94 | Na | 0.877 | |
| $H_2O+$ | - | K | 0.046 | |
| $P_2O_5$ | none | $O''$ | | 6.00 |
| | 100.48 | | | |

### Molecules %

| | | | |
|---|---|---|---|
| Diopside | 8.41 | $\alpha$ | 1.765 |
| Hedenbergite | 1.99 | $\gamma$ | - |
| Acmite | 88.49 | $A \wedge c$ | - |
| $MgSiO_3$ | 1.11 | S.G. | 3.50 |
| | 100.00 | | |

TABLE I (CONTINUED)

N 103F Fine grained alkali syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.83 | Si | 1.944 | 2.00 |
| $TiO_2$ | 1.99 | Al | 0.056 | |
| $Al_2O_3$ | 2.39 | Al | 0.051 | 1.01 |
| $Fe_2O_3$ | 26.70 | Ti | 0.058 | |
| FeO | 1.44 | $Fe^{+3}$ | 0.777 | |
| MnO | 0.45 | $Fe^{+2}$ | 0.047 | |
| MgO | 1.06 | Mn | 0.014 | |
| CaO | 2.47 | Mg | 0.060 | |
| $Na_2O$ | 10.62 | Ca | 0.102 | 0.97 |
| $K_2O$ | 1.49 | Na | 0.795 | |
| $H_2O+$ | - | K | 0.074 | |
| $P_2O_5$ | 0.13 | O'' | | 6.00 |
| | 98.57 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 5.57 | $\alpha$ | 1.768 |
| Hedenbergite | 7.97 | $\gamma$ | - |
| Acmite | 84.05 | $A \wedge c$ | - |
| $MgSiO_3$ | 2.45 | S.G. | 3.48 |
| | 100.04 | | |

### TABLE I (CONTINUED)

### N 107A Nepheline Syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.10 | Si | 1.904 | 2.00 |
| $TiO_2$ | 0.59 | Al | - | |
| $Al_2O_3$ | none | Ti | 0.016 | |
| $Fe_2O_3$ | 15.02 | $Fe^{+3}$ | 0.080 | |
| FeO | 11.35 | $Fe^{+3}$ | 0.363 | 0.94 |
| MnO | 0.46 | $Fe^{+2}$ | 0.372 | |
| MgO | 3.32 | Mn | 0.014 | |
| CaO | 13.12 | Mg | 0.195 | |
| $Na_2O$ | 5.62 | Ca | 0.553 | 1.02 |
| $K_2O$ | 0.85 | Na | 0.429 | |
| $H_2O+$ | - | K | 0.042 | |
| $P_2O_5$ | 0.04 | O'' | | 6.00 |
| | 100.47 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 15.96 | $\alpha$ | 1.736 |
| Hedenbergite | 36.82 | $\gamma$ | 1.760 |
| Acmite | 44.49 | $A \wedge c$ | 26° |
| $MgSiO_3$ | 2.69 | S.G. | 3.47 |
| | 99.96 | | |

## TABLE I (CONTINUED)

### N 108 Coarse-grained melanite ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.40 | Si | 2.030 | - 2.03 |
| $TiO_2$ | 0.30 | Al | 0.100 | 1.06 |
| $Al_2O_3$ | 2.10 | Ti | 0.010 | |
| $Fe_2O_3$ | 3.63 | $Fe^{+3}$ | 0.110 | |
| FeO | 8.92 | $Fe^{+2}$ | 0.296 | |
| MnO | 0.24 | Mn | 0.007 | |
| MgO | 9.03 | Mg | 0.539 | |
| CaO | 20.49 | Ca | 0.873 | 1.05 |
| $Na_2O$ | 1.49 | Na | 0.115 | |
| $K_2O$ | 1.13 | K | 0.057 | |
| | 98.73 | O'' | | 6.00 |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 51.58 | α | 1.696 |
| Hedenbergite | 28.98 | γ | 1.734 |
| Acmite | 16.43 | $A \wedge c$ | $17\frac{1}{2}^\circ$ |
| Wollastonite | 2.97 | S.G. | 3.36 |
| | 99.96 | | |

## TABLE I (CONTINUED)

### N 114 Mesocratic ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 45.99 | Si | 1.784 | 2.00 |
| $TiO_2$ | 1.68 | Al | nil | |
| $Al_2O_3$ | none | Ti | 0.049 | |
| $Fe_2O_3$ | 9.39 | $Fe^{+3}$ | 0.167 | |
| FeO | 5.37 | $Fe^{+3}$ | 0.108 | 0.97 |
| MnO | 0.19 | $Fe^{+2}$ | 0.172 | |
| MgO | 11.77 | Mn | 0.007 | |
| CaO | 23.18 | Mg | 0.685 | |
| $Na_2O$ | 1.63 | Ca | 0.965 | 1.11 |
| $K_2O$ | 0.49 | Na | 0.121 | |
| $H_2O+$ | none | K | 0.023 | |
| $P_2O_5$ | 0.21 | $O''$ | | 6.00 |
| | 99.90 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 61.70 | $\alpha$ | 1.680 |
| Hedenbergite | 16.17 | $\gamma$ | 1.709 |
| Acmite | 13.02 | $A \wedge c$ | 16° |
| Wollastonite | 9.03 | S.G. | 3.45 |
| | 99.92 | | |

TABLE I (CONTINUED)

N 117 Medium granular ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.59 | Si | 1.950 | 2.00 |
| $TiO_2$ | 0.63 | Al | 0.050 | |
| $Al_2O_3$ | 2.04 | Al | 0.042 | 0.98 |
| $Fe_2O_3$ | 8.02 | Ti | 0.018 | |
| FeO | 9.42 | $Fe^{+3}$ | 0.231 | |
| MnO | 0.36 | $Fe^{+2}$ | 0.302 | |
| MgO | 6.45 | Mn | 0.012 | |
| CaO | 17.85 | Mg | 0.372 | |
| $Na_2O$ | 3.40 | Ca | 0.736 | 1.05 |
| $K_2O$ | 1.22 | Na | 0.254 | |
| $H_2O+$ | - | K | 0.060 | |
| $P_2O_5$ | none | O'' | | 6.00 |
| | 99.98 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 35.36 | $\alpha$ | 1.715 |
| Hedenbergite | 29.87 | $\gamma$ | 1.766 |
| Acmite | 29.87 | $A \wedge c$ | $16\frac{1}{2}^{\circ}$ |
| Wollastonite | 4.83 | S.G. | 3.44 |
| | 99.93 | | |

TABLE I (CONTINUED)

N 118 Fine-grained ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.70 | Si | 2.060 | - 2.06 |
| $TiO_2$ | 0.43 | Al | 0.100 | 1.01 |
| $Al_2O_3$ | 2.12 | Ti | 0.012 | |
| $Fe_2O_3$ | 7.05 | $Fe^{+3}$ | 0.210 | |
| FeO | 9.43 | $Fe^{+2}$ | 0.327 | |
| MnO | 0.28 | Mn | 0.010 | |
| MgO | 5.87 | Mg | 0.351 | |
| CaO | 18.59 | Ca | 0.791 | 1.10 |
| $Na_2O$ | 3.31 | Na | 0.253 | |
| $K_2O$ | 1.03 | K | 0.053 | |
| $H_2O+$ | - | $O''$ | | 6.00 |
| $P_2O_5$ | none | | | |
| | 99.81 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 31.99 | $\alpha$ | 1.713 |
| Hedenbergite | 30.69 | $\gamma$ | 1.760 |
| Acmite | 27.86 | $A \wedge c$ | $20^{\circ}$ |
| Wollastonite | 9.36 | S.G. | 3.47 |
| | 99.90 | | |

### TABLE I (CONTINUED)

### N 119 Variable ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.39 | Si | 1.928 | 2.00 |
| $TiO_2$ | 0.80 | Al | 0.072 | |
| $Al_2O_3$ | 1.86 | Al | 0.009 | 0.99 |
| $Fe_2O_3$ | 4.34 | Ti | 0.023 | |
| FeO | 6.98 | $Fe^{+3}$ | 0.121 | |
| MnO | 0.18 | $Fe^{+2}$ | 0.218 | |
| MgO | 10.95 | Mn | 0.007 | |
| CaO | 22.45 | Mg | 0.616 | |
| $Na_2O$ | 1.44 | Ca | 0.899 | 1.01 |
| $K_2O$ | 0.08 | Na | 0.103 | |
| $H_2O+$ | - | K | 0.005 | |
| $P_2O_5$ | 0.03 | $O''$ | | 6.00 |
| | 100.49 | | | |

### Molecules %

| | | | |
|---|---|---|---|
| Diopside | 61.15 | $\alpha$ | 1.687 |
| Hedenbergite | 22.31 | $\gamma$ | 1.737 |
| Acmite | 10.70 | $A \wedge c$ | 16° |
| Wollastonite | 5.80 | S.G. | 3.33 |
| | 99.96 | | |

TABLE I (CONTINUED)

N 120R Coarse-grained ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.38 | Si | 1.912 | |
| $TiO_2$ | 0.85 | Al | 0.032 | 2.00 |
| $Al_2O_3$ | 0.73 | Ti | 0.025 | |
| $Fe_2O_3$ | 4.50 | $Fe^{+3}$ | 0.031 | |
| FeO | 6.71 | $Fe^{+3}$ | 0.097 | 0.98 |
| MnO | 0.20 | $Fe^{+2}$ | 0.212 | |
| MgO | 11.72 | Mn | 0.007 | |
| CaO | 22.26 | Mg | 0.668 | |
| $Na_2O$ | 1.66 | Ca | 0.905 | 1.09 |
| $K_2O$ | 1.23 | Na | 0.123 | |
| $H_2O+$ | - | K | 0.064 | |
| $P_2O_5$ | none | $O''$ | | 6.00 |
| | 100.24 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 62.70 | $\alpha$ | 1.698 |
| Hedenbergite | 20.54 | $\gamma$ | 1.723 |
| Acmite | 14.98 | $A \wedge c$ | 17½° |
| Wollastonite | 1.71 | S.G. | 3.41 |
| | 99.93 | | |

## TABLE I (CONTINUED)

### N 120 V  Vein in coarse-grained ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.50 | Si | 1.930 | 2.00 |
| $TiO_2$ | 0.95 | Al | 0.070 | |
| $Al_2O_3$ | 2.80 | Al | 0.054 | 1.00 |
| $Fe_2O_3$ | 15.48 | Ti | 0.028 | |
| FeO | 7.02 | $Fe^{+3}$ | 0.445 | |
| MnO | 0.15 | $Fe^{+2}$ | 0.225 | |
| MgO | 4.22 | Mn | 0.005 | |
| CaO | 12.36 | Mg | 0.241 | |
| $Na_2O$ | 6.71 | Ca | 0.507 | 1.02 |
| $K_2O$ | 0.33 | Na | 0.495 | |
| $H_2O+$ | 0.03 | K | 0.018 | |
| $P_2O_5$ | 0.05 | $O''$ | | 6.00 |
| | 100.60 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 24.81 | α | 1.733 |
| Hedenbergite | 23.63 | γ | 1.780 |
| Acmite | 47.75 | A ∧ c | - |
| Wollastonite | 3.78 | S.G. | - |
| | 99.97 | | |

TABLE I (CONTINUED)

N 121 Nepheline syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.20 | Si | 1.946 | 2.00 |
| $TiO_2$ | 0.97 | Al | 0.042 | |
| $Al_2O_3$ | 0.89 | Ti | 0.012 | |
| $Fe_2O_3$ | 18.60 | Ti | 0.016 | 1.02 |
| FeO | 8.58 | $Fe^{+3}$ | 0.541 | |
| MnO | 0.42 | $Fe^{+2}$ | 0.277 | |
| MgO | 2.88 | Mn | 0.014 | |
| CaO | 10.42 | Mg | 0.168 | |
| $Na_2O$ | 6.61 | Ca | 0.433 | 0.98 |
| $K_2O$ | 1.00 | Na | 0.499 | |
| $H_2O+$ | - | K | 0.051 | |
| $P_2O_5$ | 0.08 | $O''$ | | 6.00 |
| | 100.65 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 14.08 | $\alpha$ | 1.738 |
| Hedenbergite | 28.87 | $\gamma$ | - |
| Acmite | 54.50 | $A \wedge c$ | - |
| $MgSiO_3$ | 2.54 | S.G. | 3.45 |
| | 99.99 | | |

TABLE I (CONTINUED)

N 152 Coarse-grained ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.60 | Si | 1.898 | 2.00 |
| $TiO_2$ | 0.91 | Al | 0.102 | |
| $Al_2O_3$ | 2.36 | Al | 0.004 | 0.99 |
| $Fe_2O_3$ | 2.80 | Ti | 0.025 | |
| FeO | 8.71 | $Fe^{+3}$ | 0.083 | |
| MnO | 0.20 | $Fe^{+2}$ | 0.278 | |
| MgO | 10.29 | Mn | 0.007 | |
| CaO | 21.88 | Mg | 0.589 | |
| $Na_2O$ | 2.11 | Ca | 0.895 | 1.11 |
| $K_2O$ | 1.11 | Na | 0.156 | |
| $H_2O+$ | - | K | 0.055 | |
| $P_2O_5$ | none | $O''$ | | 6.00 |
| | 99.97 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 54.41 | $\alpha$ | 1.687 |
| Hedenbergite | 26.20 | $\gamma$ | 1.730 |
| Acmite | 17.36 | $A \wedge c$ | $19\frac{1}{2}°$ |
| Wollastonite | 1.91 | $X \wedge c$ | 42° |
| | 99.88 | S.G. | 3.40 |

## TABLE I (CONTINUED)

### N 155 Medium-grained ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.00 | Si | 1.926 | 2.00 |
| $TiO_2$ | 0.75 | Al | 0.074 | |
| $Al_2O_3$ | 2.39 | Al | 0.030 | 0.96 |
| $Fe_2O_3$ | 4.95 | Ti | 0.020 | |
| FeO | 6.49 | $Fe^{+3}$ | 0.141 | |
| MnO | 0.19 | $Fe^{+2}$ | 0.204 | |
| MgO | 9.94 | Mn | 0.007 | |
| CaO | 21.87 | Mg | 0.562 | |
| $Na_2O$ | 2.12 | Ca | 0.884 | 1.05 |
| $K_2O$ | 0.21 | Na | 0.154 | |
| $H_2O+$ | - | K | 0.009 | |
| $P_2O_5$ | 0.05 | O'' | | 6.00 |
| | 99.96 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 53.65 | $\alpha$ | 1.693 |
| Hedenbergite | 20.12 | $\gamma$ | 1.733 |
| Acmite | 15.57 | $A \wedge c$ | 18½° |
| Wollastonite | 10.60 | S.G. | 3.38 |
| | 99.94 | | |

TABLE I (CONTINUED)

N 159 Medium granular ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.20 | Si | 1.931 | 2.00 |
| $TiO_2$ | 0.97 | Ti | 0.028 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.041 | |
| $Fe_2O_3$ | 5.66 | $Fe^{+3}$ | 0.125 | 0.95 |
| FeO | 7.66 | $Fe^{+2}$ | 0.247 | |
| MnO | 0.26 | Mn | 0.009 | |
| MgO | 9.85 | Mg | 0.567 | |
| CaO | 22.09 | Ca | 0.906 | 1.11 |
| $Na_2O$ | 1.84 | Na | 0.138 | |
| $K_2O$ | 1.44 | K | 0.069 | |
| $H_2O+$ | - | O'' | | 6.00 |
| $P_2O_5$ | 0.02 | | | |
| | 99.99 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 52.86 | $\alpha$ | 1.687 |
| Hedenbergite | 23.85 | $\gamma$ | 1.730 |
| Acmite | 15.47 | $A \wedge c$ | $16\frac{1}{2}^\circ$ |
| Wollastonite | 7.78 | S.G. | 3.41 |
| | 99.96 | | |

## TABLE I (CONTINUED)

### N 163 Schistose ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.09 | Si | 1.875 | 2.00 |
| $TiO_2$ | 0.68 | Al | 0.094 | |
| $Al_2O_3$ | 2.14 | Ti | 0.020 | |
| $Fe_2O_3$ | 4.12 | $Fe^{+3}$ | 0.011 | |
| FeO | 5.46 | $Fe^{+3}$ | 0.106 | 1.00 |
| MnO | 0.07 | $Fe^{+2}$ | 0.171 | |
| MgO | 12.94 | Mn | 0.002 | |
| CaO | 23.15 | Mg | 0.725 | |
| $Na_2O$ | 1.58 | Ca | 0.928 | 1.07 |
| $K_2O$ | 0.58 | Na | 0.112 | |
| $H_2O+$ | - | K | 0.027 | |
| $P_2O_5$ | 0.01 | O'' | | 6.00 |
| | 100.82 | | | |

### Molecules %

| | | | |
|---|---|---|---|
| Diopside | 67.96 | $\alpha$ | 1.681 |
| Hedenbergite | 16.21 | $\gamma$ | 1.720 |
| Acmite | 13.05 | $A \wedge c$ | 17° |
| Wollastonite | 2.74 | S.G. | 3.36 |
| | 99.96 | | |

TABLE I (CONTINUED)

N 170 Turjaite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.80 | Si | 1.916 | 2.00 |
| $TiO_2$ | 1.68 | Al | 0.084 | |
| $Al_2O_3$ | 1.91 | Ti | 0.047 | 1.01 |
| $Fe_2O_3$ | 1.92 | $Fe^{+3}$ | 0.053 | |
| FeO | 4.28 | $Fe^{+2}$ | 0.131 | |
| MnO | 0.18 | Mn | 0.007 | |
| MgO | 13.84 | Mg | 0.768 | |
| CaO | 23.46 | Ca | 0.930 | 1.01 |
| $Na_2O$ | 0.96 | Na | 0.071 | |
| $K_2O$ | 0.07 | K | 0.004 | |
| $H_2O+$ | none | OH' | 0.000 | 6.000 |
| $P_2O_5$ | 0.06 | O'' | 6.000 | |
| | 100.16 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 76.32 | $\alpha$ | 1.660 |
| Hedenbergite | 13.68 | $\gamma$ | 1.710 |
| Acmite | 7.51 | $A \wedge c$ | $10^{\circ}$ |
| Wollastonite | 2.43 | $X \wedge c$ | $48\frac{1}{2}^{\circ}$ |
| | 99.94 | S.G. | 3.32 |

TABLE I (CONTINUED)

N 178 Medium-grained ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.56 | Si | 1.964 | 2.00 |
| $TiO_2$ | 0.80 | Al | 0.036 | |
| $Al_2O_3$ | 0.96 | Al | 0.006 | 0.95 |
| $Fe_2O_3$ | 5.52 | Ti | 0.023 | |
| FeO | 11.25 | $Fe^{+3}$ | 0.163 | |
| MnO | 0.27 | $Fe^{+2}$ | 0.364 | |
| MgO | 6.63 | Mn | 0.009 | |
| CaO | 19.60 | Mg | 0.387 | |
| $Na_2O$ | 2.79 | Ca | 0.816 | 1.05 |
| $K_2O$ | 0.43 | Na | 0.210 | |
| $H_2O+$ | - | K | 0.023 | |
| $P_2O_5$ | 0.44 | $O''$ | | 6.00 |
| | 99.25 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 36.86 | $\alpha$ | 1.710 |
| Hedenbergite | 35.54 | $\gamma$ | 1.743 |
| Acmite | 22.21 | $A \wedge c$ | 19½° |
| Wollastonite | 5.33 | S.G. | 3.45 |
| | 99.94 | | |

## TABLE I (CONTINUED)

### N 511 Fine granular ijolite with melanite and wollastonite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.08 | Si | 1.882 | 2.00 |
| $TiO_2$ | 1.33 | Al | 0.118 | |
| $Al_2O_3$ | 2.77 | Al | 0.006 | 1.00 |
| $Fe_2O_3$ | 6.39 | Ti | 0.037 | |
| FeO | 9.60 | $Fe^{+3}$ | 0.184 | |
| MnO | 0.36 | $Fe^{+2}$ | 0.306 | |
| MgO | 7.93 | Mn | 0.012 | |
| CaO | 19.48 | Mg | 0.455 | |
| $Na_2O$ | 2.53 | Ca | 0.800 | 1.03 |
| $K_2O$ | 0.91 | Na | 0.184 | |
| $H_2O+$ | - | K | 0.046 | |
| $P_2O_5$ | 0.17 | O'' | | 6.00 |
| | 100.75 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 44.16 | $\alpha$ | 1.705 |
| Hedenbergite | 30.79 | $\gamma$ | 1.760 |
| Acmite | 22.31 | $A \wedge c$ | 20° |
| Wollastonite | 2.68 | S.G. | 3.43 |
| | 99.94 | | |

TABLE I (CONTINUED)

N 514 Coarse-grained ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.81 | Si | 1.924 | 2.00 |
| $TiO_2$ | 0.58 | Al | 0.076 | |
| $Al_2O_3$ | 2.37 | Al | 0.033 | 0.99 |
| $Fe_2O_3$ | 4.73 | Ti | 0.018 | |
| FeO | 8.49 | $Fe^{+3}$ | 0.132 | |
| MnO | 0.29 | $Fe^{+2}$ | 0.268 | |
| MgO | 9.29 | Mn | 0.009 | |
| CaO | 20.52 | Mg | 0.527 | |
| $Na_2O$ | 2.25 | Ca | 0.831 | 1.05 |
| $K_2O$ | 1.02 | Na | 0.168 | |
| $H_2O+$ | - | K | 0.050 | |
| $P_2O_5$ | 0.11 | O'' | | 6.00 |
| | 100.46 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 50.20 | $\alpha$ | 1.699 |
| Hedenbergite | 26.40 | $\gamma$ | 1.733 |
| Acmite | 20.76 | $A \wedge c$ | 19° |
| Wollastonite | 2.60 | S.G. | 3.38 |
| | 99.96 | | |

TABLE I (CONTINUED)

N 516 Ijolite pegmatite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.49 | Si | 1.948 | |
| $TiO_2$ | 0.57 | Al | 0.051 | 2.00 |
| $Al_2O_3$ | 1.13 | Ti | 0.001 | |
| $Fe_2O_3$ | 8.06 | Ti | 0.018 | |
| FeO | 11.34 | $Fe^{+3}$ | 0.236 | |
| MnO | 0.45 | $Fe^{+2}$ | 0.363 | 0.93 |
| MgO | 5.17 | Mn | 0.016 | |
| CaO | 19.26 | Mg | 0.299 | |
| $Na_2O$ | 3.21 | Ca | 0.796 | |
| $K_2O$ | 0.79 | Na | 0.255 | 1.09 |
| $H_2O+$ | - | K | 0.042 | |
| $P_2O_5$ | 0.14 | O'' | | 6.00 |
| | 100.61 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 27.66 | $\alpha$ | 1.718 |
| Hedenbergite | 35.17 | $\gamma$ | 1.769 |
| Acmite | 26.16 | S.G. | 3.42 |
| Wollastonite | 10.94 | $A \wedge c$ | - |
| | 99.93 | | |

TABLE I (CONTINUED)

N 517A Ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 48.89 | Si | 1.912 | 2.00 |
| $TiO_2$ | 0.79 | Al | 0.009 | |
| $Al_2O_3$ | 0.20 | Ti | 0.024 | |
| $Fe_2O_3$ | 6.75 | $Fe^{+3}$ | 0.055 | |
| FeO | 11.84 | $Fe^{+3}$ | 0.142 | 0.99 |
| MnO | 0.39 | $Fe^{+2}$ | 0.385 | |
| MgO | 7.72 | Mn | 0.014 | |
| CaO | 19.24 | Mg | 0.453 | |
| $Na_2O$ | 2.21 | Ca | 0.807 | 1.06 |
| $K_2O$ | 1.70 | Na | 0.164 | |
| $H_2O+$ | - | K | 0.085 | |
| $P_2O_5$ | 0.44 | O'' | | 6.00 |
| | 100.17 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 30.68 | $\alpha$ | 1.704 |
| Hedenbergite | 39.21 | $\gamma$ | 1.763 |
| Acmite | 21.53 | $A \wedge c$ | 20° |
| $MgSiO_3$ | 8.53 | S.G. | 3.49 |
| | 99.95 | | |

TABLE I (CONTINUED)

N 518 Banded ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.81 | Si | 1.918 | 2.00 |
| $Al_2O_3$ | 1.16 | Al | 0.055 | |
| $Fe_2O_3$ | 4.17 | Ti | 0.027 | |
| FeO | 6.07 | Ti | 0.007 | 0.98 |
| MnO | 0.19 | $Fe^{+3}$ | 0.118 | |
| MgO | 11.57 | $Fe^{+2}$ | 0.193 | |
| CaO | 21.83 | Mn | 0.007 | |
| $Na_2O$ | 2.04 | Mg | 0.655 | |
| $K_2O$ | 0.69 | Ca | 0.883 | 1.06 |
| $TiO_2$ | 1.23 | Na | 0.149 | |
| $P_2O_5$ | 0.12 | K | 0.032 | |
| | | O'' | | 6.00 |
| | 99.78 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 61.99 | $\alpha$ | 1.689 |
| Hedenbergite | 18.87 | $\gamma$ | 1.729 |
| Acmite | 16.30 | $A \wedge c$ | 16° |
| Wollastonite | 2.78 | S.G. | 3.38 |
| | 99.94 | | |

TABLE I (CONTINUED)

N 520 Mesocratic ijolite with melanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.03 | Si | 1.916 | 2.00 |
| $TiO_2$ | 0.72 | Ti | 0.020 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.064 | |
| $Fe_2O_3$ | 3.75 | $Fe^{+3}$ | 0.044 | 0.95 |
| FeO | 5.30 | $Fe^{+2}$ | 0.167 | |
| MnO | 0.20 | Mn | 0.007 | |
| MgO | 13.00 | Mg | 0.732 | |
| CaO | 23.72 | Ca | 0.953 | 1.12 |
| $Na_2O$ | 1.91 | Na | 0.139 | |
| $K_2O$ | 0.68 | K | 0.031 | |
| $H_2O+$ | - | O'' | | 6.00 |
| $P_2O_5$ | 0.04 | | | |
| | 100.35 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 67.00 | $\alpha$ | 1.692 |
| Hedenbergite | 15.88 | $\gamma$ | 1.711 |
| Acmite | 12.78 | $A \wedge c$ | 13½° |
| Wollastonite | 4.33 | S.G. | 3.32 |
| | 99.99 | | |

TABLE I (CONTINUED)

N 529 Banded ijolite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.12 | Si | 1.846 | 2.00 |
| $TiO_2$ | 1.07 | Al | 0.154 | |
| $Al_2O_3$ | 4.94 | Al | 0.062 | 1.01 |
| $Fe_2O_3$ | 2.16 | Ti | 0.034 | |
| FeO | 7.35 | $Fe^{+3}$ | 0.063 | |
| MnO | 0.19 | $Fe^{+2}$ | 0.232 | |
| MgO | 10.90 | Mn | 0.007 | |
| CaO | 21.74 | Mg | 0.613 | |
| $Na_2O$ | 1.80 | Ca | 0.875 | 1.06 |
| $K_2O$ | 1.05 | Na | 0.131 | |
| $H_2O+$ | - | K | 0.054 | |
| $P_2O_5$ | 0.04 | O'' | | 6.00 |
| | 100.36 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 61.99 | $\alpha$ | 1.689 |
| Hedenbergite | 18.87 | $\gamma$ | 1.729 |
| Acmite | 16.30 | $A \wedge c$ | 16° |
| Wollastonite | 2.78 | S.G. | 3.38 |
| | 99.94 | | |

TABLE I (CONTINUED)

To 1 Syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 48.18 | Si | 1.874 | 2.00 |
| $TiO_2$ | 1.88 | Al | 0.056 | |
| $Al_2O_3$ | 1.23 | Ti | 0.054 | |
| $Fe_2O_3$ | 17.03 | $Fe^{+3}$ | 0.016 | |
| FeO | 6.79 | $Fe^{+3}$ | 0.479 | 0.92 |
| MnO | 0.31 | $Fe^{+2}$ | 0.220 | |
| MgO | 3.56 | Mn | 0.009 | |
| CaO | 13.91 | Mg | 0.208 | |
| $Na_2O$ | 5.94 | Ca | 0.579 | 1.09 |
| $K_2O$ | 1.25 | Na | 0.449 | |
| $H_2O+$ | - | K | 0.061 | |
| $P_2O_5$ | 0.53 | O'' | | 6.00 |
| | 100.61 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 19.08 | $\alpha$ | 1.740 |
| Hedenbergite | 21.01 | $\gamma$ | - |
| Acmite | 46.74 | $A \wedge c$ | $26^{\circ}$ |
| Wollastonite | 13.08 | S.G. | 3.47 |
| | 99.91 | | |

TABLE I (CONTINUED)

To 14 Carbonate - syenite rock

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.79 | Si | 1.924 | 2.00 |
| $TiO_2$ | 1.31 | Al | 0.065 | |
| $Al_2O_3$ | 1.46 | Ti | 0.011 | |
| $Fe_2O_3$ | 24.76 | Ti | 0.026 | 1.04 |
| FeO | 6.20 | $Fe^{+3}$ | 0.715 | |
| MnO | 0.22 | $Fe^{+2}$ | 0.200 | |
| MgO | 1.62 | Mn | 0.007 | |
| CaO | 6.81 | Mg | 0.095 | |
| $Na_2O$ | 8.01 | Ca | 0.283 | 0.93 |
| $K_2O$ | 0.86 | Na | 0.599 | |
| $H_2O+$ | - | K | 0.042 | |
| $P_2O_5$ | trace | O'' | | 6.00 |
| | 101.04 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 8.13 | α | 1.756 |
| Hedenbergite | 21.90 | γ | - |
| Acmite | 67.92 | A ∧ c | 29° |
| $MgSiO_3$ | 1.97 | S.G. | 3.49 |
| | 99.92 | | |

TABLE I (CONTINUED)

To 17 Pyroxene-bearing carbonatite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.80 | Si | 1.968 | 2.00 |
| $TiO_2$ | 1.13 | Al | 0.032 | |
| $Al_2O_3$ | 0.77 | Al | 0.005 | 1.00 |
| $Fe_2O_3$ | 24.32 | Ti | 0.033 | |
| FeO | 3.33 | $Fe^{+3}$ | 0.707 | |
| MnO | 0.22 | $Fe^{+2}$ | 0.107 | |
| MgO | 2.37 | Mn | 0.007 | |
| CaO | 7.23 | Mg | 0.137 | |
| $Na_2O$ | 8.89 | Ca | 0.300 | 0.98 |
| $K_2O$ | 0.40 | Na | 0.665 | |
| $H_2O+$ | - | K | 0.018 | |
| $P_2O_5$ | 0.01 | $O''$ | | 6.00 |
| | 99.47 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 13.94 | $\alpha$ | 1.758 |
| Hedenbergite | 11.58 | $\gamma$ | - |
| Acmite | 69.50 | $A \wedge c$ | 31° |
| Wollastonite | 4.96 | S.G. | 3.49 |
| | 99.98 | | |

## TABLE I (CONTINUED)

### To 21 Pyroxene apatite carbonatite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.61 | Si | 1.950 | 2.00 |
| $TiO_2$ | 0.95 | Ti | 0.028 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.022 | |
| $Fe_2O_3$ | 21.20 | $Fe^{+3}$ | 0.601 | 0.99 |
| FeO | 6.41 | $Fe^{+2}$ | 0.210 | |
| MnO | 0.37 | Mn | 0.012 | |
| MgO | 2.79 | Mg | 0.165 | |
| CaO | 10.26 | Ca | 0.432 | 1.00 |
| $Na_2O$ | 7.00 | Na | 0.534 | |
| $K_2O$ | 0.64 | K | 0.033 | |
| $P_2O_5$ | trace | $O''$ | | 6.00 |
| | 99.23 | | | |

### Molecules %

| | | | |
|---|---|---|---|
| Diopside | 16.55 | $\alpha$ | 1.743 |
| Hedenbergite | 22.22 | $\gamma$ | - |
| Acmite | 56.75 | $A \wedge c$ | 25° |
| Wollastonite | 4.49 | S.G. | 3.40 |
| | 100.01 | | |

TABLE I (CONTINUED)

To 43 Syenitic fenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.43 | Si | 2.06 | - 2.06 |
| $TiO_2$ | 0.37 | Al | 0.010 | 1.10 |
| $Al_2O_3$ | 0.21 | Ti | 0.048 | |
| $Fe_2O_3$ | 20.78 | $Fe^{+3}$ | 0.625 | |
| FeO | 6.55 | $Fe^{+2}$ | 0.219 | |
| MnO | 0.94 | Mn | 0.031 | |
| MgO | 2.63 | Mg | 0.166 | |
| CaO | 10.74 | Ca | 0.462 | 0.99 |
| $Na_2O$ | 6.40 | Na | 0.495 | |
| $K_2O$ | 0.65 | K | 0.034 | |
| $H_2O+$ | - | O'' | | 6.00 |
| $P_2O_5$ | trace | | | |
| | 100.70 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 16.74 | α | 1.741 |
| Hedenbergite | 25.23 | γ | - |
| Acmite | 53.37 | A ∧ c | 27° |
| Wollastonite | 4.61 | S.G. | 3.40 |
| | 99.95 | | |

TABLE I (CONTINUED)

To 572 Coarse carbonatite with pyroxene

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.86 | Si | 1.960 | 2.00 |
| $TiO_2$ | 0.71 | Al | 0.040 | |
| $Al_2O_3$ | 0.89 | Al | 0.002 | 1.00 |
| $Fe_2O_3$ | 16.72 | Ti | 0.021 | |
| FeO | 7.14 | $Fe^{+3}$ | 0.481 | |
| MnO | 0.43 | $Fe^{+2}$ | 0.229 | |
| MgO | 4.32 | Mn | 0.014 | |
| CaO | 11.96 | Mg | 0.250 | |
| $Na_2O$ | 6.32 | Ca | 0.495 | 1.01 |
| $K_2O$ | 0.98 | Na | 0.471 | |
| $H_2O+$ | - | K | 0.046 | |
| $P_2O_5$ | 0.17 | O'' | | 6.00 |
| | 100.50 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 24.65 | $\alpha$ | 1.736 |
| Hedenbergite | 23.96 | $\gamma$ | - |
| Acmite | 51.12 | $A \wedge c$ | 24° |
| Wollastonite | 0.23 | S.G. | 3.46 |
| | 99.96 | | |

TABLE I (CONTINUED)

To 585 Pyroxene rich xenolith in carbonatite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.05 | Si | 1.945 | 2.00 |
| $TiO_2$ | 0.79 | Al | 0.055 | |
| $Al_2O_3$ | 2.51 | Al | 0.062 | 0.99 |
| $Fe_2O_3$ | 14.32 | Ti | 0.023 | |
| FeO | 9.03 | $Fe^{+3}$ | 0.415 | |
| MnO | 0.66 | $Fe^{+2}$ | 0.294 | |
| MgO | 2.94 | Mn | 0.021 | |
| CaO | 13.80 | Mg | 0.173 | |
| $Na_2O$ | 5.25 | Ca | 0.574 | 0.98 |
| $K_2O$ | 0.18 | Na | 0.397 | |
| $P_2O_5$ | 0.06 | K | 0.009 | |
| | 99.59 | O'' | | 6.00 |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 17.62 | α | 1.720 |
| Hedenbergite | 32.15 | γ | 1.770 |
| Acmite | 41.41 | A ∧ c | - |
| Wollastonite | 8.81 | S.G. | 3.48 |
| | 99.99 | | |

TABLE I (CONTINUED)

K 62 Syenite pegmatite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.10 | Si | 1.914 | 2.00 |
| $TiO_2$ | 0.37 | Al | 0.012 | |
| $Al_2O_3$ | 0.20 | Ti | 0.009 | |
| $Fe_2O_3$ | 7.89 | $Fe^{+3}$ | 0.065 | |
| FeO | 11.91 | $Fe^{+3}$ | 0.164 | 0.98 |
| MnO | 0.51 | $Fe^{+2}$ | 0.386 | |
| MgO | 7.12 | Mn | 0.016 | |
| CaO | 20.25 | Mg | 0.416 | |
| $Na_2O$ | 2.41 | Ca | 0.847 | 1.05 |
| $K_2O$ | 0.48 | Na | 0.183 | |
| $H_2O+$ | none | K | 0.023 | |
| $P_2O_5$ | 0.22 | O'' | | 6.00 |
| | 100.46 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 39.54 | $\alpha$ | 1.707 |
| Hedenbergite | 38.20 | $\gamma$ | 1.753 |
| Acmite | 19.54 | $A \wedge c$ | 18½° |
| Wollastonite | 2.67 | S.G. | 3.36 |
| | 99.95 | | |

TABLE I (CONTINUED)

K 320 Banded Syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 52.15 | Si | 2.013 | – 2.01 |
| $TiO_2$ | 0.76 | Al | 0.004 | 0.99 |
| $Al_2O_3$ | 0.11 | Ti | 0.023 | |
| $Fe_2O_3$ | 28.97 | $Fe^{+3}$ | 0.839 | |
| FeO | 2.15 | $Fe^{+2}$ | 0.069 | |
| MnO | 0.24 | Mn | 0.007 | |
| MgO | 0.84 | Mg | 0.046 | |
| CaO | 2.69 | Ca | 0.111 | 0.92 |
| $Na_2O$ | 10.75 | Na | 0.802 | |
| $K_2O$ | 0.22 | K | 0.009 | |
| $H_2O+$ | – | O'' | | 6.00 |
| $P_2O_5$ | 0.27 | | | |
| | 99.15 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 3.72 | $\alpha$ | 1.765 |
| Hedenbergite | 8.19 | $\gamma$ | – |
| Acmite | 86.80 | A $\wedge$ c | 33½° |
| Wollastonite | 1.24 | X $\wedge$ c | -1½% |
| | 99.95 | S.G. | 3.46 |

TABLE I (CONTINUED)

K 353 Coarse even-grained syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.31 | Si | 1.908 | 2.00 |
| $TiO_2$ | 0.37 | Ti | 0.011 | |
| $Al_2O_3$ | none | $Fe^{+3}$ | 0.081 | |
| $Fe_2O_3$ | 6.73 | $Fe^{+3}$ | 0.111 | 0.96 |
| FeO | 6.47 | $Fe^{+2}$ | 0.203 | |
| MnO | 0.21 | Mn | 0.007 | |
| MgO | 11.22 | Mg | 0.639 | |
| CaO | 23.17 | Ca | 0.945 | 1.10 |
| $Na_2O$ | 1.86 | Na | 0.137 | |
| $K_2O$ | 0.42 | K | 0.023 | |
| $H_2O+$ | - | $O''$ | | 6.00 |
| $P_2O_5$ | trace | | | |
| | 100.76 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 57.83 | $\alpha$ | 1.682 |
| Hedenbergite | 18.99 | $\gamma$ | 1.729 |
| Acmite | 14.46 | $A \wedge c$ | 16° |
| Wollastonite | 8.67 | S.G. | 3.33 |
| | 99.95 | | |

## TABLE I (CONTINUED)

### K 440 Pyroxene schlieren in coarse-grained syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 48.93 | Si | 1.91 | 2.00 |
| $TiO_2$ | 0.57 | Ti | 0.065 | |
| $Al_2O_3$ | 0.03 | $Fe^{+3}$ | 0.025 | |
| $Fe_2O_3$ | 8.79 | $Fe^{+3}$ | 0.230 | 1.06 |
| FeO | 12.96 | $Fe^{+2}$ | 0.417 | |
| MnO | 0.61 | Mn | 0.021 | |
| MgO | 6.71 | Mg | 0.389 | |
| CaO | 19.71 | Ca | 0.814 | 1.04 |
| $Na_2O$ | 2.90 | Na | 0.217 | |
| $K_2O$ | 0.23 | K | 0.009 | |
| $H_2O+$ | none | OH' | 0.000 | 6.000 |
| $P_2O_5$ | 0.15 | O'' | 6.000 | |
| | 101.59 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 35.82 | $\alpha$ | 1.710 |
| Hedenbergite | 41.53 | $\gamma$ | 1.760 |
| Acmite | 21.53 | $A \wedge c$ | $23^\circ$ |
| $MgSiO_3$ | 1.10 | S.G. | 3.38 |
| | 99.98 | | |

TABLE I (CONTINUED)

Bo 270 Xenolith in borolanite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 52.00 | Si | 1.959 | 2.00 |
| $TiO_2$ | 0.47 | Al | 0.041 | |
| $Al_2O_3$ | 1.85 | Al | 0.040 | 1.02 |
| $Fe_2O_3$ | 9.76 | Ti | 0.014 | |
| FeO | 4.22 | $Fe^{+3}$ | 0.276 | |
| MnO | 0.23 | $Fe^{+2}$ | 0.133 | |
| MgO | 9.74 | Mn | 0.007 | |
| CaO | 16.02 | Mg | 0.551 | |
| $Na_2O$ | 3.82 | Ca | 0.646 | 0.99 |
| $K_2O$ | 1.37 | Na | 0.276 | |
| $H_2O+$ | – | K | 0.068 | |
| $P_2O_5$ | 0.22 | O'' | 6.00 | |
| | 99.70 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 53.05 | α | 1.711 |
| Hedenbergite | 13.59 | γ | 1.741 |
| Acmite | 33.32 | A ∧ c | 18° |
| $Mgsio_3$ | 0.44 | S.G. | 3.40 |
| | 100.40 | | |

## TABLE I (CONTINUED)

### Bo330 Cromaltite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.90 | Si | 1.935 | 2.00 |
| $TiO_2$ | 0.88 | Al | 0.046 | |
| $Al_2O_3$ | 1.00 | Ti | 0.019 | |
| $Fe_2O_3$ | 4.66 | Ti | 0.006 | 1.00 |
| FeO | 8.02 | $Fe^{+3}$ | 0.132 | |
| MnO | 0.27 | $Fe^{+2}$ | 0.256 | |
| MgO | 10.51 | Mn | 0.009 | |
| CaO | 21.66 | Mg | 0.600 | |
| $Na_2O$ | 1.23 | Ca | 0.883 | 0.99 |
| $K_2O$ | 0.45 | Na | 0.087 | |
| $H_2O+$ | - | K | 0.023 | |
| $P_2O_5$ | 0.14 | O'' | | 6.00 |
| | 99.72 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 60.43 | $\alpha$ | 1.688 |
| Hedenbergite | 26.65 | $\gamma$ | 1.730 |
| Acmite | 11.03 | $A \wedge c$ | $16\frac{1}{2}^\circ$ |
| Wollastonite | 1.83 | S.G. | 3.37 |
| | 99.94 | | |

## TABLE I (CONTINUED)

### S Pyroxene segregation in carbonatite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 51.20 | Si | 1.954 | 2.00 |
| $TiO_2$ | 0.27 | Al | 0.046 | |
| $Al_2O_3$ | 1.51 | Al | 0.023 | 0.99 |
| $Fe_2O_3$ | 6.10 | Ti | 0.009 | |
| FeO | 8.01 | $Fe^{+3}$ | 0.174 | |
| MnO | 1.03 | $Fe^{+2}$ | 0.254 | |
| MgO | 8.66 | Mn | 0.032 | |
| CaO | 19.54 | Mg | 0.495 | |
| $Na_2O$ | 2.69 | Ca | 0.799 | 1.03 |
| $K_2O$ | 0.78 | Na | 0.201 | |
| $H_2O+$ | – | K | 0.027 | |
| $P_2O_5$ | 0.17 | $O''$ | | 6.00 |
| | 99.96 | | | |

### Molecules %

| | | | |
|---|---|---|---|
| Diopside | 47.67 | $\alpha$ | 1.716 |
| Hedenbergite | 27.58 | $\gamma$ | 1.750 |
| Acmite | 22.96 | $A \wedge c$ | – |
| Wollastonite | 1.76 | S.G. | 3.43 |
| | 99.97 | | |

TABLE I (CONTINUED)

SB 78 Fenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 49.20 | Si | 1.912 | 2.00 |
| $TiO_2$ | 0.49 | Al | 0.088 | |
| $Al_2O_3$ | 2.38 | Al | 0.024 | 1.08 |
| $Fe_2O_3$ | 8.24 | Ti | 0.056 | |
| FeO | 11.99 | $Fe^{+3}$ | 0.238 | |
| MnO | 2.07 | $Fe^{+2}$ | 0.390 | |
| MgO | 5.16 | Mn | 0.070 | |
| CaO | 16.78 | Mg | 0.301 | |
| $Na_2O$ | 3.36 | Ca | 0.700 | 1.01 |
| $K_2O$ | 0.87 | Na | 0.256 | |
| $H_2O+$ | - | K | 0.050 | |
| $P_2O_5$ | 0.16 | $O''$ | | 6.00 |
| | 100.70 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 23.94 | $\alpha$ | 1.728 |
| Hedenbergite | 45.81 | $\gamma$ | 1.770 |
| Acmite | 30.21 | $A \wedge c$ | $24\frac{1}{2}^{\circ}$ |
| Wollastonite | - | S.G. | 3.47 |
| | 99.96 | | |

TABLE I (CONTINUED)

SB 190 Nepheline syenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.25 | Si | 1.924 | 2.00 |
| $TiO_2$ | 0.52 | Al | 0.076 | |
| $Al_2O_3$ | 1.97 | Al | 0.200 | 1.17 |
| $Fe_2O_3$ | 10.69 | Ti | 0.014 | |
| FeO | 6.69 | $Fe^{+3}$ | 0.308 | |
| MnO | 0.59 | $Fe^{+2}$ | 0.246 | |
| MgO | 6.69 | Mn | 0.018 | |
| CaO | 15.94 | Mg | 0.384 | |
| $Na_2O$ | 5.19 | Ca | 0.044 | 1.09 |
| $K_2O$ | 1.14 | Na | 0.386 | |
| $H_2O+$ | - | K | 0.055 | |
| $P_2O_5$ | 0.08 | O'' | | 6.00 |
| | 99.75 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 36.34 | $\alpha$ | 1.720 |
| Hedenbergite | 25.32 | $\gamma$ | 1.748 |
| Acmite | 38.30 | $A \wedge c$ | 22° |
| Wollastonite | - | S.G. | 3.45 |
| | 99.96 | | |

## TABLE I (CONTINUED)

### SB 245 Fenite

| | | | | |
|---|---|---|---|---|
| $SiO_2$ | 50.13 | Si | 1.913 | 2.00 |
| $TiO_2$ | 0.45 | Al | 0.073 | |
| $Al_2O_3$ | 1.64 | Ti | 0.014 | |
| $Fe_2O_3$ | 13.54 | $Fe^{+3}$ | 0.389 | 0.95 |
| FeO | 6.49 | $Fe^{+2}$ | 0.206 | |
| MnO | 0.94 | Mn | 0.030 | |
| MgO | 5.65 | Mg | 0.323 | |
| CaO | 14.37 | Ca | 0.588 | 1.09 |
| $Na_2O$ | 6.08 | Na | 0.449 | |
| $K_2O$ | 1.03 | K | 0.050 | |
| $H_2O+$ | - | $O''$ | | 6.00 |
| $P_2O_5$ | 0.16 | | | |
| | 100.48 | | | |

Molecules %

| | | | |
|---|---|---|---|
| Diopside | 30.69 | $\alpha$ | 1.735 |
| Hedenbergite | 22.42 | $\gamma$ | 1.767 |
| Acmite | 43.99 | $A \wedge c$ | 24° |
| Wollastonite | 2.83 | S.G. | 3.45 |
| | 99.93 | | |

Figure 1

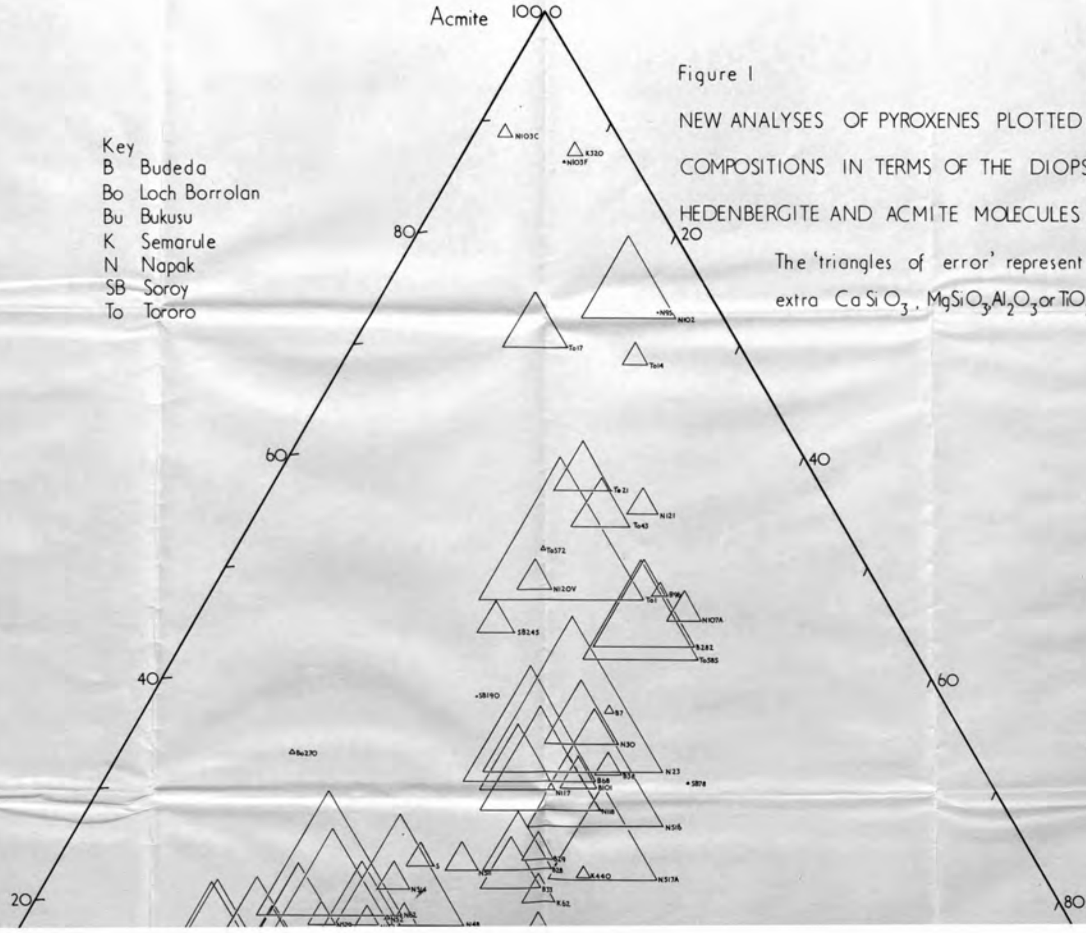
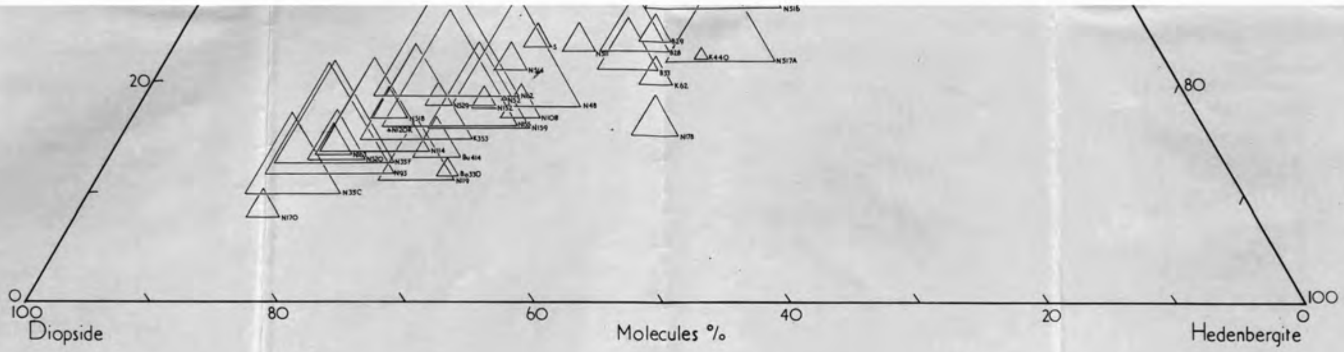


Figure 1

NEW ANALYSES OF PYROXENES PLOTTED SHOWING COMPOSITIONS IN TERMS OF THE DIOPSIDE HEDENBERGITE AND ACMITE MOLECULES

The 'triangles of error' represent extra $CaSiO_3$, $MgSiO_3$, $Al_2O_3$ or $TiO_2$



N516
S
N511
B29
B28
K440
N517A
N514
B31
K62
N62
N52
N48
N529
N152
N108
N518
N159
N120R
K353
N178
N114
N520
N35F
Bu414
N93
Bu330
N19
N35C
N170
20
80
100
0
80
60
40
20
0
100
Diopside
Molecules %
Hedenbergite

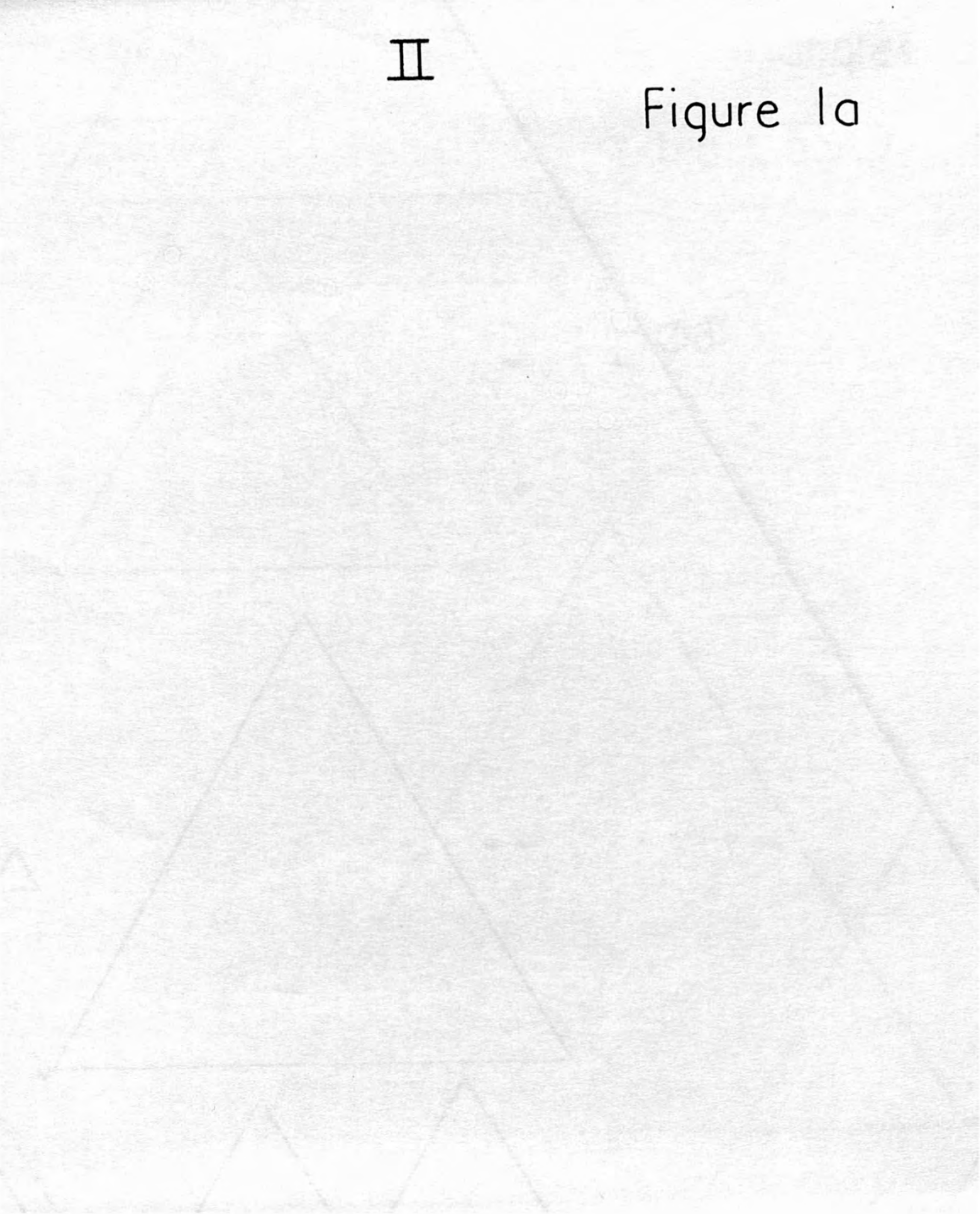
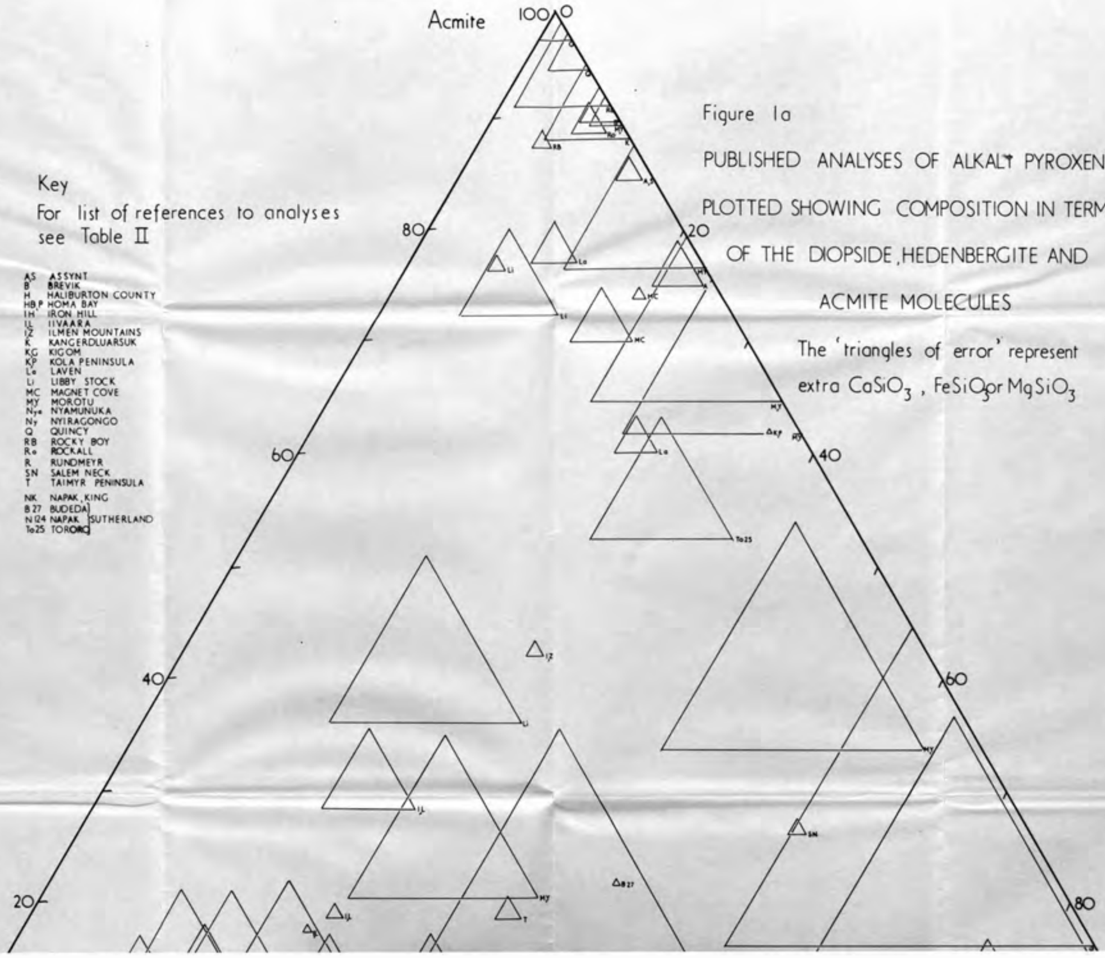


Figure 1a



Key

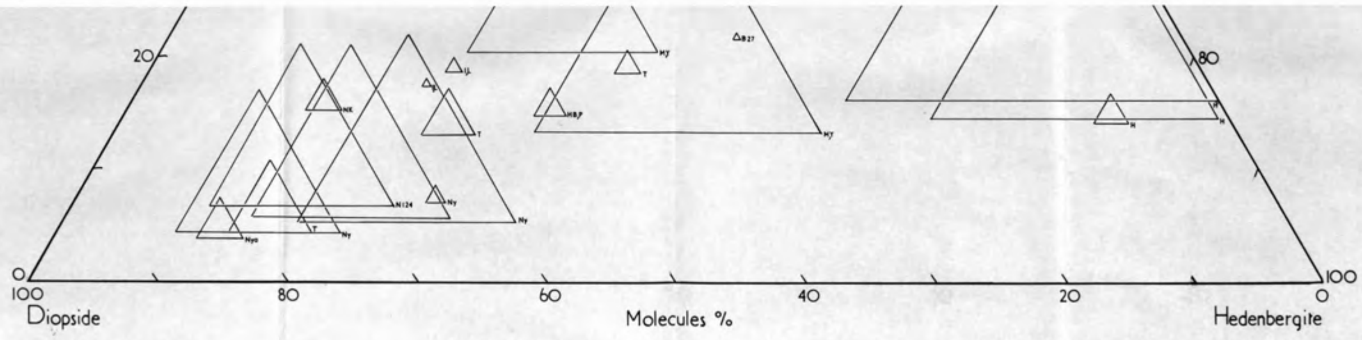
For list of references to analyses see Table II

| | |
|---|---|
| AS | ASSYNT |
| B | BREVIK |
| H | HALIBURTON COUNTY |
| HB,P | HOMA BAY |
| IH | IRON HILL |
| IL | IIVAARA |
| IZ | ILMEN MOUNTAINS |
| K | KANGERDLUARSUK |
| KG | KIGOM |
| KP | KOLA PENINSULA |
| Lo | LAVEN |
| Li | LIBBY STOCK |
| MC | MAGNET COVE |
| MY | MOROTU |
| Nyo | NYAMUNUKA |
| Ny | NYIRAGONGO |
| Q | QUINCY |
| RB | ROCKY BOY |
| Ro | ROCKALL |
| R | RUNDMEYR |
| SN | SALEM NECK |
| T | TAIMYR PENINSULA |
| NK | NAPAK, KING |
| B 27 | BUDEDA<br>SUTHERLAND |
| N 124 | NAPAK |
| To25 | TORORO |

Figure 1a

PUBLISHED ANALYSES OF ALKALI PYROXENES PLOTTED SHOWING COMPOSITION IN TERMS OF THE DIOPSIDE, HEDENBERGITE AND ACMITE MOLECULES

The 'triangles of error' represent extra $CaSiO_3$, $FeSiO_3$ or $MgSiO_3$


20
80
0
100
80
60
40
20
100
0
Diopside
Molecules %
Hedenbergite
NK
N124
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Ny
T
HBP
My
T
My
B27

III

Figure 5

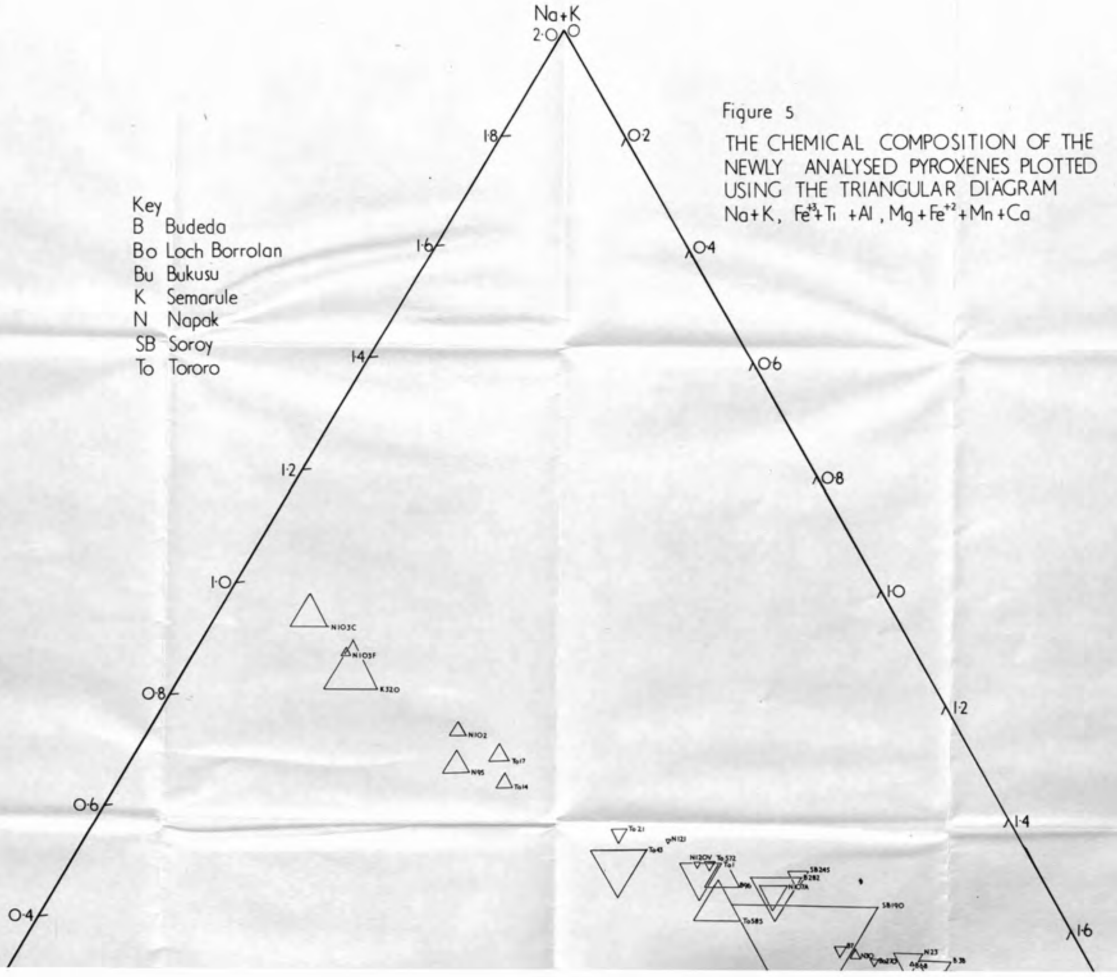
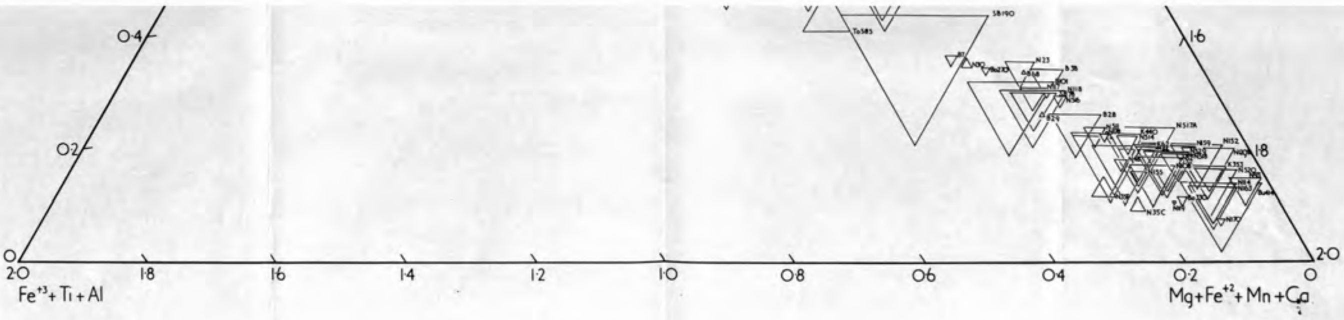


Figure 5

THE CHEMICAL COMPOSITION OF THE NEWLY ANALYSED PYROXENES PLOTTED USING THE TRIANGULAR DIAGRAM Na+K, $Fe^{+3}$+Ti +Al, Mg + $Fe^{+2}$ + Mn + Ca

O·4
O·2
O
2·O
1·8
1·6
1·4
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O·4
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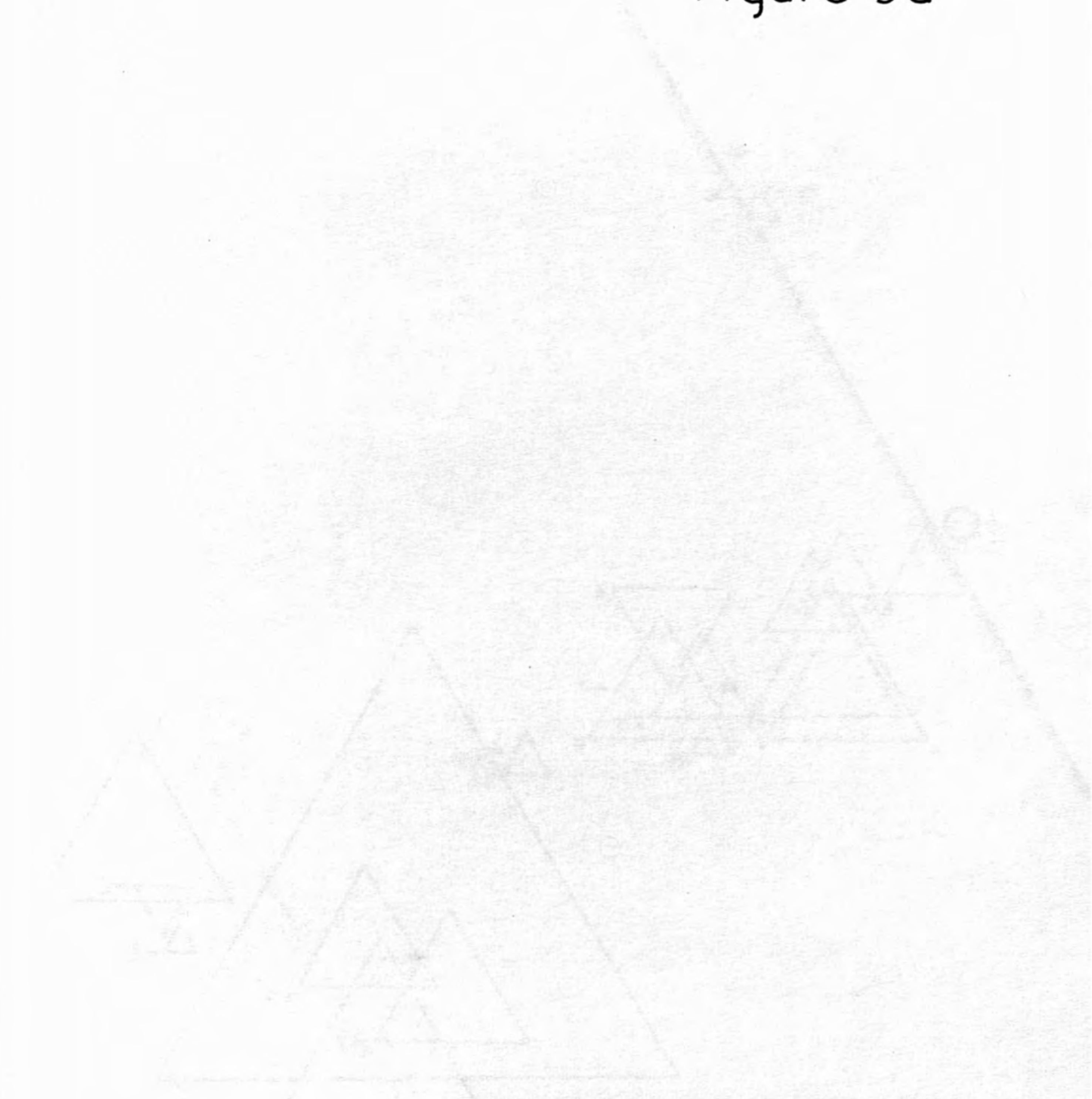
O
$Fe^{+3}$ + Ti + Al
Mg + $Fe^{+2}$ + Mn + Ca
1·6
1·8
2·O
SB190
To585
N23
N118
B28
N513A
K440
N514
N150
N152
K353
N14
N163
N155
N35C
N170

# IV

Figure 5a



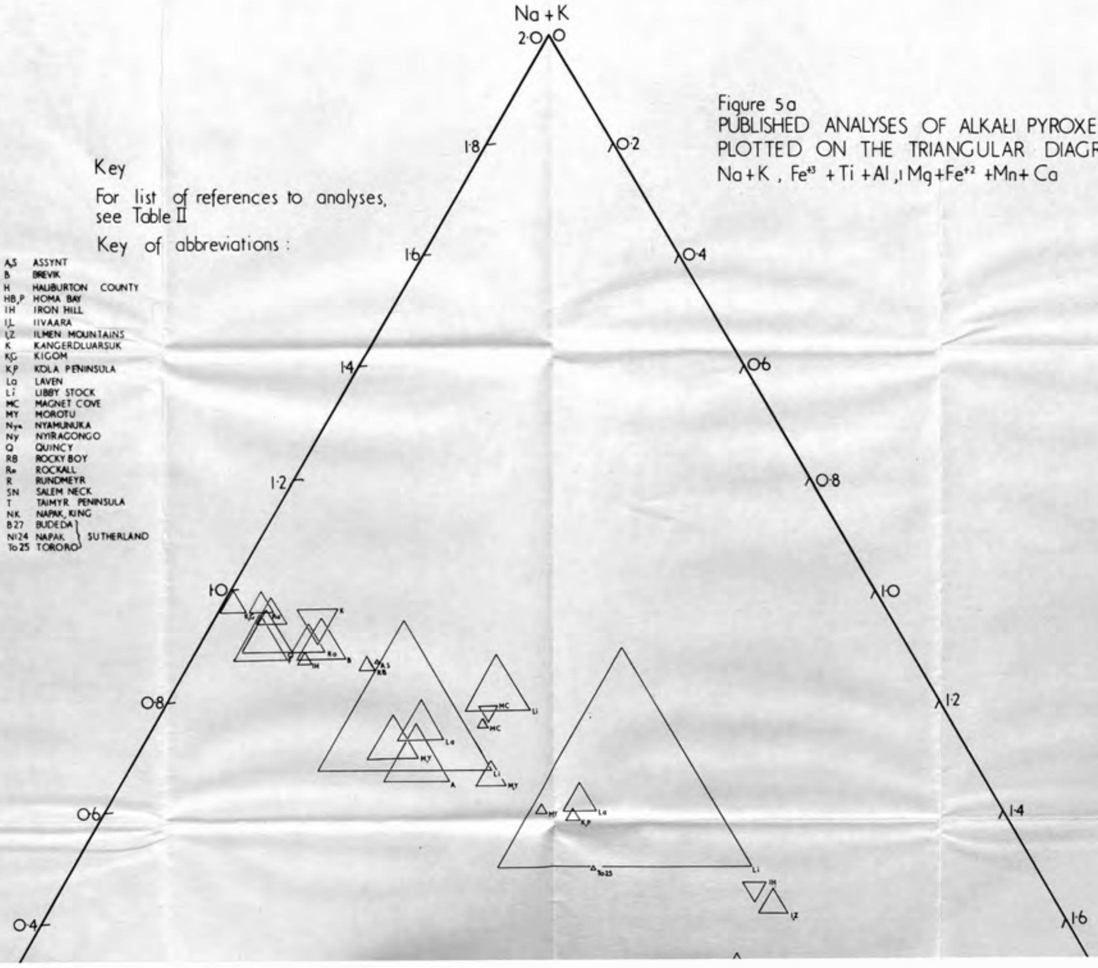


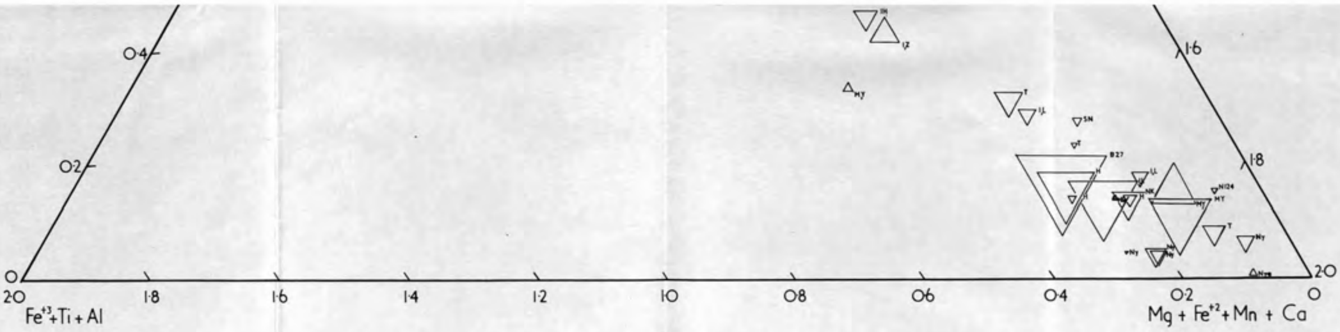
Figure 5a
PUBLISHED ANALYSES OF ALKALI PYROXENES PLOTTED ON THE TRIANGULAR DIAGRAM Na+K , $Fe^{+3}$ + Ti + Al , Mg + $Fe^{+2}$ + Mn + Ca

Key

For list of references to analyses, see Table II

Key of abbreviations :

| | |
|---|---|
| A,S | ASSYNT |
| B | BREVIK |
| H | HALIBURTON COUNTY |
| HB,P | HOMA BAY |
| IH | IRON HILL |
| I,L | IIVAARA |
| I,Z | ILMEN MOUNTAINS |
| K | KANGERDLUARSUK |
| K,G | KIGOM |
| K,P | KOLA PENINSULA |
| La | LAVEN |
| Li | LIBBY STOCK |
| MC | MAGNET COVE |
| MY | MOROTU |
| Nya | NYAMUNUKA |
| Ny | NYIRAGONGO |
| Q | QUINCY |
| RB | ROCKY BOY |
| Ro | ROCKALL |
| R | RUNDMEYR |
| SN | SALEM NECK |
| T | TAIMYR PENINSULA |
| NK | NAPAK, KING |
| B27 | BUDEDA } SUTHERLAND |
| N124 | NAPAK } SUTHERLAND |
| To25 | TORORO } SUTHERLAND |



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O
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1·6
1·8
$Fe^{+3} + Ti + Al$
$Mg + Fe^{+2} + Mn + Ca$
IH
IZ
MY
T
IL
SN
T
B27
H
IL
NK
H
N124
MY
MY
T
NY
NY
NY
NY