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A STUDY OF MANTLE INCLUSIONS IN THE KOFFIEFONTEIN
KIMBERLITE PIPE, SOUTH AFRICA

by

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ABSTRACT

Mantle derived rock and mineral fragments from the Koffiefontein Kimberlite Pipe have been studied in the form of xenoliths, megacrysts, concentrate minerals and inclusions in diamonds.

Mantle derived xenoliths are unusually scarce.

The predominant xenoliths are pyroxenites. Peridotites are rare and eclogites are very rare.

The pyroxenites have been assigned to five categories. In general they show a clear metamorphic textural history with widespread evidence of exsolution, polygonisation and deformation. Some of these pyroxenites are interpreted to represent the crystallisation products of basaltic magma at depth. Some have been metasomatised. The pyroxene chemistries suggest that more than one pyroxenite body has been sampled.

The peridotites are very similar to the common peridotites of N. Lesotho, and are thought to represent depleted mantle.

The Koffiefontein diamonds contain both eclogitic and peridotitic inclusions. The inclusions show evidence for lack of equilibration and one appears to link together the two parageneses mentioned above. The presence of (MgFe)O as an inclusion is reported.

The megacrysts studied consisted only of garnets, and a few pyroxenes. They are interpreted to have crystallised from a magma which cooled slowly and was relatively deficient in TiO_2 to account for the scarcity of ilmenite.

The heavy mineral concentrate contained garnet, orthopyroxene, opaque minerals and clinopyroxene in order of abundance. The opaque minerals were chromite and ilmenite. The chemical compositions of most of the concentrate grains do not match the mineral compositions found

in xenoliths, or megacrysts. A small number of concentrate grains have compositions matched by the diamond inclusions.

Attempts to apply geothermobarometry to the pyroxenites and to the diamond inclusions gave conflicting results which are ascribed to lack of equilibration between co-existing mineral phases and/or within individual mineral grains.

The Koffiefontein xenolith suite is unusual for the relative abundance of pyroxenite and the scarcity of peridotite.

The concentrate is unusual for the relative abundance of orthopyroxene particularly and of chromite.

CHAPTER 1

INTRODUCTION

Present chemical models for the composition of the Earth have generally placed heavy emphasis on extraterrestrial sources and on a study of rocks derived from the earth's mantle. Geophysical models and experimental work on natural and synthetic systems have in addition been used to place some constraints on such models and have led to an estimation of an upper mantle of ultramafic composition (e.g. Wyllie, 1971).

Of the rocks derived from the upper mantle those occurring as nodules in kimberlite and alkali basalt magmas are perhaps the most widely studied and provide direct insight into the upper mantle.

Kimberlite is a "volatile-rich, potassic ultrabasic, igneous rocks which has a distinctively inequigranular texture resulting from the presence of macrocrysts set in an essentially microporphyrific matrix" (Clement et al., 1977). Kimberlites occur throughout the world as relatively small bodies, to date found only in stable cratonic areas, and their chemical and geological similarities suggest a common process controlling their origin (e.g. MacGregor, 1970). Kimberlites are derived from great depths (~200 km, e.g. Egger and Wendlandt, 1977) and are emplaced at high velocities which allows the transportation of dense ultramafic nodules to the surface. The preservation of high pressure phases such as diamond (e.g. Dawson, 1972) and limited evidence of reaction between nodules and kimberlite magma suggest that little interaction has occurred between the mantle fragments and their host.

The most abundant xenoliths are peridotites followed by eclogites, (e.g. Harte, 1978) which have varied textures, mineralogy and chemical composition, indicating mantle inhomogeneity. Study of the chemistry of such nodules enables constraints to be placed on whether they represent

- 1) undepleted mantle,
- 2) residual mantle after partial melting,
- 3) igneous melts crystallised at depth, or
- 4) cumulates from such magmas (e.g. Wyllie, 1971).

In addition, the chemistry of coexisting minerals enables temperature and pressures of equilibration to be determined.

On the basis of chemistry, texture and temperatures and pressures of equilibration of ultramafic nodules derived from several neighbouring localities, early work attempted to construct stratigraphic models for the upper mantle (e.g. Boyd, 1973; Boyd and Nixon, 1973). More recent studies have however illustrated the importance of small scale inhomogeneity and disequilibrium, and emphasized that the xenoliths may have undergone textural modifications that can be related to the diapiric movements associated with the genesis of kimberlite (e.g. Goetze, 1975). In addition, the application of geothermometers and geobarometers to reconstruct temperature-pressure relations can be misleading (e.g. MacGregor and Basu, 1976; Mitchell, 1977) and should be applied to "isothermal suites of xenoliths" (Wilshire and Jackson, 1975). In an attempt to overcome these problems the emphasis has shifted from constructing upper mantle models based on nodules from multiple pipes to a focus on nodules from individual localities (e.g. Boyd et al., 1976; Hatton, 1978; Shee, 1978).

This work is specifically concerned with mantle derived material (rocks, inclusions in diamonds, concentrate minerals and megacrysts) from the Koffiefontein kimberlite pipe. An attempt has been made at determining the chemical composition of the samples available, establishing a genetic relationship between them, their temperatures and pressures of equilibration and their possible mode of origin. Where possible, they have been compared to mantle samples found elsewhere in kimberlite pipes in southern Africa.

CHAPTER II

LOCALITY DESCRIPTION AND SAMPLING

1. LOCALITY DESCRIPTION

The Koffiefontein kimberlite pipe is situated in the Orange Free State, S.A., ~100 km south of Kimberley. It has been described in an unpublished report by R. Clement, and the following description is largely based on that report.

The Koffiefontein pipe has an almost circular shape and a surface area of ~10,3 hectares. It decreases in diameter to a depth of ~250 m, with the walls dipping inwards at an average angle of 85° . The configuration of the pipe is still largely unknown at greater depths, where a kimberlite bulge has been intersected at ~480 - 520 m on the eastern side.

The Koffiefontein kimberlite has two dyke extensions trending NW-SE, known as the West and East fissures, which are considered to predate the pipe. A second kimberlite, known as the Ebenhaezer pipe, occurs approximately 165 m NW of Koffiefontein, and the two probably converged into a single pipe, at a height above the present day erosion level.

The Koffiefontein kimberlite was intruded into Karroo sediments, which in this region lie directly on the Archaean granite-gneiss basement. At present, the country rocks consist of ~300 m of Karroo shales, which are intruded by dolerite sills; the presence of Stormberg lava inclusions

prove the existence of this formation at the time of emplacement. The best available estimate of the subsequent amount of erosion is ~2000 metres (Hawthorne, 1975). The emplacement occurred during the Cretaceous period (Zircon age: 90.4 m.y., Davis, pers. comm. to Gurney). This age is similar to the ages of many other kimberlites occurring in the Karroo Basin on the Transvaal Craton, as listed below (Davis, 1977):

Zircon ages of kimberlites in the Transvaal Craton:

<u>Kimberlite</u>	<u>age (m.y.)</u>
Finsch, S.A.	94.1
Leicester, S.A.	93.6
Orapa, Botswana	93.1
Roberts Victor, S.A.	92.2
De Beers, S.A.	92.0
Wesselton, S.A.	90.3
Monastery, S.A.	90.4
Mothae, Lesotho	87.1
Kampfersdam	86.9

The upper part of the pipe comprises tuffaceous kimberlite and contains small (<2 cm) subangular to subrounded inclusions of shales, dolerites and granite-gneiss, anhedral macrocrysts and subhedral or euhedral phenocrysts of olivine, phlogopite macrocrysts, opaque minerals, garnets, xenocrysts from country rocks, earlier generation kimberlite and numerous autoliths. The latter are very small (<0.05 mm. in size,

with rare exceptions exceeding 2 cms.), usually with central kernels of anhedral to euhedral phenocrysts of olivine, which is almost always replaced by serpentine, clay minerals or chlorite. Phlogopite, garnet, country rock minerals/fragments can also occur as occasional kernels of these autoliths. The tuffaceous kimberlite has an altered clayey matrix, containing cryptocrystalline serpentine and calcite.

At depth (~480 m.), two porphyritic kimberlite varieties have been intersected, but the geology at this depth is largely unknown.

Late-stage kimberlite dykes (<0.5 m.) occasionally cut across the tuffaceous kimberlite, and they have a porphyritic texture. They have abundant fresh to partly serpentinised olivine, which can be divided into two different populations on the basis of habit, set in a matrix of phlogopite, diopside, calcite and serpentine, with subordinate amounts of apatite, perovskite and opaque minerals.

The Koffiefontein pipe is worked as an open pit mine and diamond production was initiated around 1898 (Wagner, 1914) and lasted until 1931, when the mine was closed down at the onset of the world-wide "Great Depression", which adversely affected the diamond market. Koffiefontein, as a low grade producer of diamonds (~50% industrial diamonds) was ill placed to resist these difficult trading conditions.

The diamond production during this period is summarised by Wagner (1914) and Williams (1932). Diamonds weighing

734273 carats were recovered at an average grade of 4-5 carats/100 loads (1 load = 0.75 tons) between 1898 and 1913 (Wagner, 1914). The mine was not reopened with the other major South African pipes after the great economic depression of the 1930's because of its unexceptional low yield of diamonds.

However, when Jagersfontein was reaching the end of its life the nearby Koffiefontein kimberlite was reassessed and on the closure of the former, Koffiefontein was reopened, with some relocation of staff and equipment. Subsequent results summarised in De Beers Consolidated Mines Annual Reports, show an apparent increase in grade at the mine to 11 carats/100 metric tons. It is unusual for grades to increase in this way and they normally decline with depth. Whether the higher grades are a real feature of the kimberlite or a consequence of improved technology is not clear. However, diamond quality has also proved better than expected.

2. SAMPLING

The xenoliths and megacrysts analysed in this study were collected by the writer and Dr. J.J. Gurney during a one day visit to the Koffiefontein Mine in 1977. Sampling was very limited due to security precautions at the mine, and we were only allowed to sample a few very small dumps of processed concentrate. Most rock fragments were very small, because all the concentrate had been through the

primary crusher, which is set at 1½".

However, both earlier and subsequent visits have all shown that it is not possible to find many mantle rock fragments on any of the Koffiefontein dumps, whether from the current or older mining operations. The material which was provided for inspection at the mine on the day in question when the sampling was done was specially treated in the processing plant to provide an especially dense concentrate. It should represent the best sampling opportunity anyone has ever had at the mine.

Mantle xenoliths and megacrysts were extremely rare in comparison to other kimberlites. One of the reasons that so little work has been done on xenoliths from this major mine is undoubtedly the difficulty of finding mantle rock xenoliths. Xenoliths of basement rocks including garnet amphibolites are quite common by comparison. The lack of inclusions in the Koffiefontein kimberlite was already noticed by Williams (1932), who states "This mine, down to the present depth (330 feet in the open) is remarkably free from foreign inclusions of either country rock or cognate xenoliths. To its present depth this mine has undoubtedly produced the cleanest kimberlite of any mine in S.A., though at a depth of 500 feet an inclusion of red mudstone or sandstone has been struck" - p. 29 (Williams, 1932).

The most abundant mantle rocks found during the 1977 visit to the mine, were pyroxenite/websterites (± garnet,

± Cr-spinel) and there was a remarkable lack of olivine bearing rocks, again in contrast to pipes such as those at Kimberley or nearby Jagersfontein.

A large amount of heavy mineral concentrates was also made available by De Beers Consolidated Mines, from which the individual minerals studied here were carefully selected.

CHAPTER III

SAMPLE PREPARATION AND ANALYTICAL METHODS

1. SAMPLE PREPARATION

Polished thin sections of all the xenoliths were prepared following Moreland et al. (1971). Mineral grains from the Koffiefontein concentrate and two fragments from each megacryst (one from the edge and one from the centre) were mounted on cylindrical discs of hard resin (9 Araldite AY 103: 1 Hardener HY051). All samples were then polished and coated with a thin layer of carbon, to provide conductivity.

2. ANALYTICAL METHODS

2. (a) Electron microprobe analyses

Megacrysts, heavy concentrate minerals and minerals from most of the Koffiefontein xenoliths were analysed using a Cambridge Microscan V Microanalyser at the Geochemistry Department, University of Cape Town.

Instrumental conditions, calibration and reduction of data have been discussed by Lawless (1974), Reid (1977) and le Roex (1980), and are summarised below:

Beam current	15 μ A
Accelerating voltage:	15 kV
Analysing crystals:	Quartz (Fe, Mn, Ca, Ti, Cr, K) RAP (Si, Al, Mg, Na)
Detection:	Flow counters with Ar/CO ₂ gas mixture
Beam:	Focussed (1-2 μ). (For hydrous minerals a defocussed beam of 10 - 30 μ was used).
Standards:	Mg, Al, Mn, Fe, Ca, Si, Na, K, Ti - Kakanui pyrope and hornblende Cr - Stillwater chromite Mg, Fe, Ca, Si - Marjalahti olivine and pure diopside glass (synthetic) Ti - Rutile (synthetic)

Raw counts were corrected for dead time and background and nominal concentrations were calculated from the standard K-factors (cps/% oxide). Nominal concentrations were subsequently corrected using the method of Bence and Albee (1968) with the α -factors of Albee and Ray (1970).

Precision of the data, estimated from 12 analyses of the same spot of a garnet megacryst from Koffiefontein (KF78), is given in Table III-1. The standard deviations about the mean of the 12 analyses are compared with the uncertainty due to counting statistics; the theoretical

detection limits are also reported in Table III-1.

Nickel was determined in olivines using the following operating conditions:

Beam current	1,0 μ A
Accelerating voltage:	25 kV
Crystal:	LiF (200)
Detector:	Sealed counter
PHA :	E = 1.8 v (threshold)
Standard:	natural olivine from a kimberlite nodule with 0.35% NiO

Total counting times at the peak and background positions were 150 sec. and 100 sec., respectively. The detection limit of NiO in olivines is 0,011%, with a relative precision error based on counting statistics of 3.36% on 0,23% NiO (at 99% and 95% confidence level, respectively).

A few samples were analysed using the Anglo American Research Laboratories microprobe (ALR-SEM) in Johannesburg (analyst: G. Hutchinson). Details of the analytical procedure, instrumental conditions and standards used are given by Lawless (1978) and the precision of the data is comparable to that obtained at the University of Cape Town.

2. (b) X-ray Fluorescence

Whole rock compositions were determined by X-ray fluorescence (XRF). Major elements (with the exception of Na)

were analysed using the method of Norrish and Hutton (1969). The determination of Na was done on pressed powder briquettes. All analyses were performed according to the routine procedures adopted at the Geochemistry Department, University of Cape Town (Willis et al., 1971; 1972).

Estimates of the precision and detection limits for the major oxides and of the accuracy of the date are given in Table III-2.

CHAPTER IV

MANTLE DERIVED ROCKS FROM THE KOFFIEFONTEIN
KIMBERLITE PIPE

1. INTRODUCTION

Mantle derived nodules occurring in kimberlites can be subdivided into five categories: 1 - peridotites and dunites; 2 - garnet-pyroxenites; 3 - eclogites and grospydites; 4 - megacrysts (discrete nodules) and 5 - amphibole and mica-rich types (Harte, 1978). Out of the above rock types, peridotites are the overall most abundant xenoliths in kimberlite pipes, although there are individual localities where eclogites are predominant (e.g. Roberts Victor - Hatton, 1978; Orapa - Shee, 1978). Garnet pyroxenites are usually rare (e.g. Harte, 1978) and due perhaps to their scarcity as nodules in kimberlites, they have received little attention in the study of the upper mantle.

Pyroxenite (including garnet poor and garnet bearing varieties) is the most abundant xenolith type found at Koffiefontein (32 of a total of 36) whereas peridotite is extremely rare (a total of only 4 were found). The xenoliths at this locality have been therefore subdivided into two groups: Group A - pyroxenites and Group B - peridotites.

On a textural basis, Group A can be further subdivided into five types:

- Type I - These xenoliths are believed to represent original highly aluminous clinopyroxenes, which have exsolved garnet, \pm orthopyroxene and \pm chromite. They consist mainly of large clinopyroxenes, which exhibit both lamellar and coarse exsolution of the above phases. Some primary garnet and/or orthopyroxene may be present.
- Type II - These xenoliths are believed to represent original aluminous orthopyroxenes, which have exsolved garnet, \pm clinopyroxene, \pm chromite.
- Type III - Large orthopyroxene crystals are the main constituents of these xenoliths, with smaller amounts of clinopyroxene, garnet and chromite. These three minerals seem to be primary phases, with the exception of a small modal percentage of clinopyroxene in a few specimens, which may be the product of exsolution from their orthopyroxene hosts.
- Type IV - In this category there is a gradation from orthopyroxenites, through websterites to clinopyroxenites sensu stricto. They are characterised by polygonisation of individual

grains, and exsolution lamellae are widely displayed by pyroxene grains. With one exception, they are all phlogopite or amphibole bearing. Garnet and spinel are absent.

Type V - Olivine bearing websterite (pyroxenite).

Group B : Of the four peridotites, one is a garnet lherzolite, two are harzburgites and one is a chromite harzburgite.

Each of the above groups will be separately discussed, but particular attention will be focussed on Types I and II pyroxenites.

2. GROUP A : KOFFIEFONTEIN PYROXENITE XENOLITHS

2.1. Type I pyroxenites

2.1.1 Introduction

Type I pyroxenites comprise a group of xenoliths in which the main constituent is a "dull" to bright green clinopyroxene, with smaller but usually significant amounts of garnet and/or orthopyroxene, often recognisable as exsolution products. They are roundish in shape, $\sim 3 - 3,5$ cm. in average size, occasionally covered with a thin greyish reaction rim. In thin section the minerals are fresh to slightly altered and their textures often display unmixing features. The occurrence of clinopyroxenites showing

exsolution of garnet and/or orthopyroxene have also been reported from the Jagersfontein (Borley and Suddaby, 1973), Frank Smith (Boyd, 1973) and Matsoku (Harte and Gurney, 1975) kimberlite pipes, in southern Africa.

In the individual specimens studied, it is not always possible to decide on textural evidence whether or not the orthopyroxene and garnet have been totally exsolved from the clinopyroxene, or whether they are present as primary phases that crystallised simultaneously with it. As will be discussed during individual descriptions of these samples, there is a complete gradation in rock textures from:

- 1) evidence of total exsolution of garnet and orthopyroxene (e.g. PC21)
- 2) total exsolution of garnet and orthopyroxene, now partly obliterated by recrystallisation or coarsening of the exsolved phases (e.g. PC55 and PC25)
- 3) very little or no evidence for exsolution, as in PC34 and PC35, respectively, where most garnet and orthopyroxene could have been primary phases. (PC34 is the only "eclogite" found at Koffiefontein).

Regardless of the above features, these xenoliths will be discussed as a group, because of chemical similarities between their constituent minerals.

Due to the small size of the specimens only one thin section of each rock could be obtained. This was a

shortcoming, since the observation of three thin sections at right angles is essential, especially in the case of unmixing textures. Modal proportions were not estimated by point-counting because of the limited area available and coarse grain size (Soloman and Green, 1965). They were estimated by overlaying a grid over photographs of the thin sections used for microprobe work. They were also calculated by computer: the percentage of each phase in each rock required to reconstruct the total rock composition was calculated according to mineral probe analyses and total-rock XRF analyses, respectively. Both estimates are given in Table IV-1; the wide discrepancies between the two can be accounted for by the uneven distribution of the minerals in each xenolith (Note: whenever modal proportions are referred to, theoretical ones are preferred).

A brief description of the individual xenoliths is given below:

(Note: Throughout this study the end member molecules of the pyroxenes was calculated according to Papike et al. (1974). For bulk rock compositions, where $Fe/Fe+Mg < 0.5$ and $Ca/Ca+Mg < 0.5$, the Tschermak molecule was calculated as a Mg end member preferably to Ca-Tschermakite (Papike et al., 1974).

End member molecules were not calculated for garnet compositions because as Boyd (1970) points out "substitutions in the six-coordinated site are not generally coupled to substitutions in the eight coordinated site" - pp. 68.

The following abbreviations will be used:

cpx - clinopyroxene; opx - orthopyroxene; gt - garnet.)

2.1.2 Petrographic Descriptions:

PC21 : cpx, opx, gt

A single clinopyroxene megacryst in which orthopyroxene, recognised by its straight extinction, occurs as bands of variable width, with no visible grain boundaries between the two minerals (Plate 1). Garnet is present as exsolved very long thin lamellae (up to 4 mm. in length) and as shorter and wider (up to 0.6 mm. in width) rod shaped grains (Plate 1). There is an almost total gradation between the two forms of occurrence and they are occasionally joined; a possible explanation for this is that it may illustrate a process of growth and coarsening of originally very thin garnet lamellae. The phenomenon of coalescing of exsolved grains has been reported by several authors such as Boyd (1973) and Dawson and Smith (1973). It can either be a deformation activated process (Dawson and Smith, op. cit.) or occur during a temperature decrease (Spry, 1969), depending on ionic mobility, which is a function of the structures of the host and inclusion. Alternatively, they may represent two different generations of exsolution, parallel to each other. The crystal is crossed by a series of parallel metasomatic veins, where phlogopite is the main constituent, and which probably is associated with the kimberlite

magmatism.

PC22 : cpx, opx, gt

Two large clinopyroxene crystals with round to elliptical "inclusions" of orthopyroxene, varying in size from 0.3 to 4 mm. (Plate 2). The clinopyroxenes are optically positive, show no cleavage and multiple twinning is observed in small areas, which indicates deformation.

The orthopyroxenes are also optically positive, and with two exceptions (see Plate 2), extinguish simultaneously within each clinopyroxene crystal; two others show slight undulose extinction, also suggesting deformation. (The orientation of the orthopyroxene inclusions relative to their two hosts is the same in the two clinopyroxenes). Although it is uncertain whether some of the larger orthopyroxene grains were primary phases (in particular the two which have a different extinction angle - see above), most have been exsolved from their hosts. This is suggested by a complete gradation in size, parallel orientation of the few grains that have an elongated lamellar shape, and their simultaneous extinction.

A small round garnet occurs near the edge of a large orthopyroxene. A brownish alteration with phlogopite flakes is present along cracks, sometimes surrounding the orthopyroxene, and is probably related to the kimberlite.

PC25 : cpx, opx, gt

This rock consists of two clinopyroxene crystals,

almost separated by a "finger" of orthopyroxene. The latter mineral also occurs throughout the rock as large irregularly shaped crystals (up to 7 mm.), parallel elongated blebs and lamellae; occasionally these are joined (Plate 3).

Garnets are present in the clinopyroxene as long thin lamellae parallel to those of orthopyroxene, and as roundish grains within both the clino- and orthopyroxenes, and along the boundaries between the two.

It is suggested that both the garnet and orthopyroxene are exsolved phases, which may have undergone subsolidus migration to minimize grain boundary energy (Spry, 1969) immediately prior to the time of emplacement. Some of the garnets enclosed within the orthopyroxene were trapped during coarsening of these grains.

PC33 : cpx, opx, gt

Bright green clinopyroxene, again showing some signs of unmixing (Plate 4). It shows exsolved orthopyroxene both as very thin lamellae and as bands of variable width (Plates 4 and 5). In one instance, the orthopyroxene forms a rim around a core of clinopyroxene, although no boundary between the two is visible, and this is recognised under polarised light (Plate 4). Since this occurs at the edge of the slide, the true relationship cannot be observed, but it could represent migration of the exsolved orthopyroxene towards the edge of its host. Garnet (Plates 4 and 5) occurs as rod-shaped crystals, small lamellae parallel to

the cleavage and as larger grains (one reaches ~5 mm. in size). Whereas the former are exsolved, it is not possible to decide texturally whether the large garnet grains are primary or exsolved, although the latter possibility is suggested by a finger-like intergrowth of clinopyroxene and garnet at the edges of one of these (large garnet on bottom right hand side of Plate 4).

PC34 : cpx and gt

This specimen is the only eclogite found at Koffiefontein. There is a wide variation in grain size in both the clinopyroxene (~1 - 5 mm.) and the garnet (0.2 - 6 mm.). The clinopyroxene is very pale green in this section, and has a slightly turbid appearance. The garnets are fresh and roundish in shape. Kelyphitic alteration occurs both along cracks and edges. Two small roundish garnets are joined by a thin "bridge", indicating a possible mechanism of coarsening of grain size of garnets, if any were exsolved.

PC35 : cpx, gt, opx.

In hand specimen this xenolith consisted mainly of clinopyroxene, with lesser amounts of garnet and orthopyroxene. In contrast, the thin section available shows a predominance of coarse grained garnets (up to ~0.8 mm.), followed by orthopyroxene (one crystal ~5 mm. long) and minor clinopyroxene along the edges. Although the minerals are fresh, the garnets are surrounded by kelyphite. The coarse grain size of both garnet and orthopyroxene in this

section does not suggest exsolution.

PC54 : cpx, opx, gt

Clinopyroxene crystal with orthopyroxene and garnet present as long, narrow and almost parallel inclusions (Plate 6), which again suggests structural control by the clinopyroxene host. Both the clinopyroxene and its exsolution products have a cloudy appearance and are slightly altered.

Two large (~3 and 5 mm.) garnets are present and again not possible to decide whether they are primary or exsolved phases; one of them is enclosing a round grain of clinopyroxene. Small elongated dark brown crystals, possibly of chromite are present within one of the garnets and throughout the clinopyroxene.

PC55 : cpx, opx, gt, chr.

This xenolith shows the interesting feature that its centre and edge have a different texture. (Plate 7).

The centre consists of a single clinopyroxene crystal with very small roundish exsolved garnet and chromite grains and with narrow, dark parallel bands of an alteration product, along which orthopyroxene can occasionally be identified, across the whole grain.

The margin is formed by polygonal grains of clinopyroxene and orthopyroxene, and roundish chromites and garnets (with dark coronas around them), of larger dimensions than the ones observed in the core of the xenolith.

Within the marginal zone, there are areas resembling the

core, and within the centre a small portion of the clinopyroxene has started to develop a similar appearance to the edge. It is suggested that originally the rock was a single clinopyroxene crystal, which exsolved orthopyroxene, garnet and chromite, with a texture resembling the core of the xenolith. Subsequently, it has been recrystallised, with growth and nucleation of the exsolved phases, a process which has occurred preferentially along the margins of the crystal, but relicts of the original texture are still observed. Recrystallisation in the centre was incomplete when the xenolith was sampled and transported by the kimberlite. This is an important rock as it demonstrates the significant role that deformation can play in the obliteration of the relicts of former higher temperature equilibration.

PC58 : cpx, opx, gt

Large clinopyroxene crystal containing a garnet inclusion (~4 mm.) of garnet surrounded by kelyphite. Orthopyroxene occurs as lenses and elongated crystals which are in optical continuity throughout the clinopyroxene, suggesting exsolution.

An additional fragment of the same rock contains a small clinopyroxene crystal included within the large clinopyroxene, as well as a larger orthopyroxene, the origin of which is ambiguous (primary phase or orthopyroxene which was exsolved and has now migrated to the edge?). Phlogopite

is also present.

2.1.3. Mineral chemistry:

In general, individual phases in each rock are characterised by uniform composition and lack of zoning, and only chemical averages will be given in Table IV-2 (number in brackets indicates number of analyses). Several analyses are presented for PC21, because this sample has not attained chemical equilibrium. The unmixing of garnet and orthopyroxene from the clinopyroxene are illustrated in a qualitative microprobe scan across a zone of this crystal. Nevertheless, all the garnets analysed revealed an almost constant composition, and several ortho- and clinopyroxene analyses are almost uniform. These will be taken as average "minimum" compositions attained by these two phases, in the following discussion.

Clinopyroxenes:

The clinopyroxenes have relatively restricted ranges in Mg/Mg+Fe (88.9 - 94.7) and Ca/Ca+Mg ratios (47.4 - 49.4), and show variations in Al₂O₃ (0.7 - 4.9 wt.%), Cr₂O₃ (0.44 - 1.3 wt.%) and Na₂O (0.5 - 2.9 wt.%) contents. They are diopsides with extremely low Ca-Tschermak component in their molecules, and jadeite varies between 2.1 and 19.2 mole % (Table IV-3).

The Na₂O content increases with increasing Al₂O₃, which is equivalent to an increase in jadeite, and decreases

with both CaO and MgO contents (Fig. IV-1 a,b).

Garnets:

The garnets are pyropes with Mg/Mg+Fe ratio varying between 64.8 and 80.6, corresponding to a decrease in FeO from 14.3 to 10 wt.%. They display a trend of calcium and iron enrichment in a Ca-Mg-Fe diagram (Fig. IV-2), similar to that observed for eclogitic garnets. Cr₂O₃ (0.4 - 3.6 wt.%) shows a positive correlation with both FeO and CaO (4.1 - 6.2 wt.%), and a decrease with increasing MgO (Fig. IV-3 c,b,a), which is contrary to the Cr₂O₃-MgO relationship observed in garnets from concentrates (Lawless, 1974; Reid and Hanor, 1970) and rocks elsewhere (e.g. Matsoku, Gurney et al., 1975).

Orthopyroxenes:

The orthopyroxenes are quite iron rich (5.0 - 9.9 wt.%), and have low Al₂O₃ and Cr₂O₃ contents (0.38 - 0.69 and 0.06 - 0.19 wt.%, respectively). An increase in the Mg/Mg+Fe ratio (85.7 - 93) is accompanied by a slight decrease in CaO.

2.1.4 Discussion:

A study of the chemical behaviour of some oxides within individual minerals and between coexisting phases in Type I pyroxenites, has revealed many unique features, contrary to those found in rocks elsewhere. For example, and as

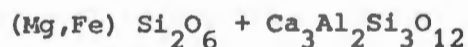
already pointed out, there is a sympathetic variation between Cr_2O_3 and FeO in garnets, and besides, an increase in their grossular components is accompanied by an increase in the amount of coexisting modal orthopyroxene.

The partition of elements between coexisting phases, if independent of bulk composition, reflects the environmental conditions prevailing at the time of their formation. This principle forms the basis of geothermometry/geobarometry methods, and their application to Type I pyroxenites resulted in conflicting and very different estimates of their temperatures of equilibration.

Because of the unique characteristics and difficulties encountered in the chemical study of these xenoliths, they will be discussed in point form below, in an attempt to make them more easily understood.

- (i) The garnets from the Koffiefontein Type I pyroxenites have grossular components ranging between 10.4 and 17 mole % (Fig. IV-2). The grossular increase is actually accompanied by an almost systematic increase in the modal amount of coexisting orthopyroxene (and a decrease in the modal amount of garnet).

In contrast, elsewhere, a general characteristic of garnets occurring in lherzolites and websterites, is a low and almost constant value of grossular component (~13 mole % - O'Hara and Mercy, 1963; MacGregor, 1967; Reid and Hanor, 1970), because the presence of orthopyroxene seems to prevent CaO enrichment in garnets, according to the buffer reaction:



(after Hatton, 1978).

Therefore, garnets coexisting with both clino- and orthopyroxene should have a greater Mg/Mg+Ca ratio than those coexisting with clinopyroxene alone (Kushiro and Aoki, 1968). However, here the garnet from the only "eclogite" found at Koffiefontein, has the highest Mg/Mg+Ca ratio. This suggests that the orthopyroxene buffering effect referred to above did not take place at the time of crystallisation of these assemblages.

- (ii) A study of the chemistry of the garnets as a function of the variation of the Na₂O content of coexisting clinopyroxenes, has been attempted (Kushiro and Aoki, 1968; Hatton, 1978; Shee, 1978). It is observed that as the clinopyroxene becomes more jadeitic, there is a decrease in CaO, FeO and Cr₂O₃, and an increase in the MgO contents of the garnets (Fig. IV-4 a,b,c,d).

The Na₂O content of clinopyroxenes in eclogites can sometimes be used as a differentiation index (Hatton, 1978; Shee, 1978), and with progressive fractionation, Na₂O will become concentrated in the more evolved liquid and coexisting pyroxenes, causing CaO to enter the garnet structure. If orthopyroxene is present, garnets will become enriched in FeO with differentiation, but CaO enrichment will be prevented according to the buffer reaction referred to in (i) Hatton, 1978). However, at Koffiefontein it has already been pointed out that this buffering effect did not take place in Type I pyroxenites.

Alternatively, increasing amounts of Na₂O in the clinopyroxene, coexisting with orthopyroxene and garnet, can also

cause a decrease in the amount of CaO in the garnets (Banno, 1967; Sobolev, 1977). However, it should be noted that simultaneous with the CaO decrease, enrichment in the MgO content of the garnet also took place, and this is contrary to what is expected from fractional crystallisation.

In Type I pyroxenites, if the garnets and orthopyroxenes are exsolved phases, then the original bulk and chemical compositions of the clinopyroxenes were the controlling factors in determining the chemistry of the garnets in Type I pyroxenites. The re-equilibrated clinopyroxenes have attained almost constant Ca/Ca+Mg ratios, and MgO is preferentially concentrated in orthopyroxene relative to garnets, and the reverse applies to FeO and CaO. Depending on the original bulk composition, exsolution of progressively greater modal proportions of orthopyroxene, would have caused a CaO enrichment in the small amount of exsolved garnets, towards the Ca-rich end of the trend described in (1) (refer to Fig. IV-2). The enrichment of Cr_2O_3 in garnets with progressive CaO and FeO enrichment could also be explained on the same basis. For example, bulk rocks PC22, PC25 and PC34 have very similar Cr_2O_3 contents (~0.4 wt.%). Cr_2O_3 is usually concentrated in garnets relative to either clino- or orthopyroxene, and upon exsolution Cr_2O_3 has been concentrated in the small modal proportion of garnet exsolved in PC22 and PC25 (3.2 and 2.7 wt.% Cr_2O_3), whereas it has been "diluted" in the large modal proportion of garnet exsolved in PC34 (~0.4 wt.% Cr_2O_3).

(iii) The Ca/Ca+Mg ratios of coexisting clino- and orthopyroxene are a function of their equilibration temperatures (e.g. Davis and Boyd, 1966; Boyd and Nixon, 1973; Akella, 1976). There are problems associated with the application of the above geothermometers to natural minerals, mainly because of the presence of Fe^{2+} (Lindsley and Munoz, 1969) and to a smaller extent to that of Al^{3+} (O'Hara and Schrairer, 1963; Boyd, 1970), and also because there is now wide evidence that they are also dependent on pressure (Hensen, 1973; Mori and Green, 1975; Nehru, 1976). The pressure dependence of the enstatite solvus, especially on Fe-bearing systems, is greater than that of the diopside solvus (Hensen, 1973; Mori and Green, 1975), but this pressure effect seems to decrease at temperatures around 900°C (Mori and Green, 1975). On the other hand, at these temperatures the geothermometers also become less sensitive.

Calculation of temperatures of equilibration for Type I pyroxenites based on the mutual solubility of the two pyroxenes, yielded almost constant results, around the 900°C region (Wood and Banno, 1973; Wells, 1977 - Table IV-4, columns 1 and 2), and are therefore not reliable. The Ca/Ca+Mg ratios of the clino- and orthopyroxenes (47.7 - 49.6 and 0.31 - 0.66, respectively) fall outside the calibration ranges of the empirical geothermometers of Davis and Boyd (1966) and Boyd and Nixon (1973), but also yield temperature estimates $\leq 950^{\circ}\text{C}$. (Columns 3 and 4 in Table IV-4). Despite shortcomings, these ratios can still be taken as "qualitative" reflections of

temperatures of equilibration for these rocks.

Although the Ca/Ca+Mg ratios of both pyroxenes are almost constant, the variations observed are greater than the analytical errors resulting from counting statistics, especially for the orthopyroxenes (see Fig. IV-5). A plot of the Ca/Ca+Mg ratios of the clinopyroxenes versus those of the orthopyroxenes (Fig. IV-5), shows that the clinopyroxenes with the highest ratios (indicative of a lower temperature) coexist with orthopyroxenes also having the highest Ca/Ca+Mg ratios (indicative of a higher temperature), which is indicative of a lack of equilibrium between these two phases.

- (iv) The distribution of Mg/Fe^{2+} between clinopyroxene and garnet, and orthopyroxene and garnet is a function of temperatures and pressures of equilibration (Banno, 1970; Akella and Boyd, 1974; Raheim and Green, 1974).

The K_D values for clinopyroxene-garnet pairs ($K_D = (Fe/Mg)_{gt} / (Fe/Mg)_{cpx}$) are generally assumed to be independent of their bulk rock chemistry ($6.2 < Mg/Mg+Fe^{2+} < 85$, Raheim and Green, 1974), but are known to be a function of the Na_2O content of the clinopyroxene and of the CaO content of the garnet as well (Banno, 1970; Ellis and Green, 1979). The distribution of Fe^{2+} and Mg between clinopyroxene and garnet in the Koffiefontein Type I pyroxenites is clearly affected by these compositional variables, as illustrated in Fig. IV-6.

Temperatures of equilibration for these xenoliths were calculated using the equations of Akella and Boyd (1974)

$$T(^{\circ}K) = \frac{4620}{2.31 + \ln K_D}$$
 and Ellis and Green (1979) $T(^{\circ}K) = \frac{3104 X_{Ca}^{gt} + 3030 + 10.86P (Kb)}{\ln K_D + 1.9034}$ and results are given in Table IV-4 (columns 5 and 6). The latter takes into account the CaO content of the coexisting garnet and is also dependent on a pre-estimation of the equilibration pressure. Pressures were first determined according to the method of Wood and Banno (1974) (Table IV-4, column 8) as a function of the Al^{VI} content of orthopyroxene coexisting with garnet. The two geothermometers yielded very different estimates. Those obtained according to Akella and Boyd (1974) are lower (865 - 992^oC) than those estimated according to Ellis and Green (1979) (1028 - 1161^oC).

- (v) Fig. IV-7 (a,b,c) shows a plot of the Mg/Fe²⁺ ratios for coexisting garnet-orthopyroxene, garnet-clinopyroxene and clinopyroxene pairs, respectively, in the Koffiefontein Type I pyroxenites. In Fig. IV-7 (a) the plotted points fall between two lines defining an almost constant K_D value, ranging between 3.2 and 3.4 ($K_D = (Mg/Fe^{2+})_{gt} / (Mg/Fe^{2+})_{opx}$). However, on the basis of different K_D values, the clinopyroxene-garnet and the ortho-clinopyroxene pairs define two population groups : 1 and 2 (see Fig. IV-7 (b) and (c) - Group 1 has a greater amount of modal orthopyroxene whereas group 2 has a greater modal proportion of garnet). (Note: (a) In Fig. IV-7 xenolith PC34 falls outside the ranges of the K_D values of either groups, and this is the only "eclogite" studied. (b) PC21 does not follow the same trend as the other xenoliths, but as mentioned before, it

has not attained chemical equilibrium).

From the above, the clinopyroxene-orthopyroxene and clinopyroxene-garnet pairs indicate slightly different equilibration environments for these xenoliths. Akella and Boyd's (1974) temperatures for Group 1 are slightly lower (865 - 905°) than for Group 2 (946 - 992°C), whereas Ellis and Green's (op. cit.) equation yields similar and overlapping results for both groups (Group 1 - 1095 - 1121°C; Group 2 - 1028 - 1161°C). On the other hand, the orthopyroxene-garnet pairs suggest that they have all equilibrated under the same conditions or alternatively, that the partition of Fe²⁺-Mg between these minerals was "blocked" at a certain temperature, and did not respond to further changes (Fraser and Lawless, 1978). This will be discussed at a later stage.

- (vi) The Cr/Cr+Al ratios of coexisting orthopyroxene-garnet and clinopyroxene-garnet pairs in Type I pyroxenites from Koffiefontein are positively related, as has been reported for other xenoliths elsewhere (Sobolev, 1970, 1977). The K_D values between garnet and clinopyroxene pairs ($K_D = \frac{(\text{Cr/Cr+Al})_{\text{gt}}}{(\text{Cr/Cr+Al})_{\text{cpx}}}$) increase with increasing temperatures (Sobolev, 1970) and these K_D values in Type I pyroxenites are almost constant, ranging from 0.20 - 0.28, with one value at 0.12 ($2\sigma = \pm 0.04$), suggesting a uniform equilibration temperature:

$$(\text{Cr/Cr+Al})_{\text{gt}} / (\text{Cr/Cr+Al})_{\text{cpx}}$$

PC22 = .28	PC35 = .22
PC25 = .24	PC54 = .22
PC33 = .26	PC55 = .24
PC34 = .20	PC58 = .17

Mysen (1976) found that the partition of Al^{VI} and Cr between clino- and orthopyroxenes in natural peridotites can be used as a geothermometer, yielding temperature estimates comparable to those obtained by the Davis and Boyd (1966) geothermometer. Mysen points out that misleading results may be obtained, if his equation ($1/T = (0.26 \pm 0.01) \ln K_D + (0.67 \pm 0.01)$; $K_D = (\text{Al}^{\text{VI}}/\text{Cr})_{\text{opx}} / (\text{Al}^{\text{VI}}/\text{Cr})_{\text{cpx}}$) is applied to different assemblages, but Mysen and Boettcher (1976) suggest that their method is also applicable to websterites. It yielded temperature values of 1093 - 1304°C for the Koffiefontein Type I pyroxenites. (Table IV-4 - column 7). Although Mysen's (op. cit.) calibration range is below 1200°C, the overall temperature values are higher than those obtained by other geothermometers already mentioned (refer to Table IV-4) and are only comparable to temperatures obtained by Ellis and Green's (1979) equation (with the exception of PC25, they are within $\pm 100^\circ\text{C}$).

- (vii) It has been illustrated how the application of different geothermometers to Type I pyroxenites from Koffiefontein, revealed a lack of consistency in the results obtained. Wide discrepancies are observed in temperatures derived from both the equilibration of clino- and orthopyroxenes (e.g. Wood and Banno, 1973; Mysen, 1976; Wells, 1977) and clinopyroxene and garnet (e.g. Ellis and Green, 1979; Akella and Boyd, 1974) within each xenolith, suggesting that the geothermometers are out of phase.

Fraser and Lawless (1978) suggest that re-equilibration of pyroxenes and garnets with respect to the distribution of Fe^{2+} -Mg, takes place at high temperatures, but that the partition of these elements ceases to be effective below $\sim 1100^\circ\text{C}$, while temperature changes are still recorded in the Ca/Ca+Mg ratios of the pyroxenes. This suggestion has been disputed by Carswell (1978) who claims that the above observations are due to combined temperature and pressure effects on the xenoliths studied by Fraser and Lawless (op. cit.).

Fig. IV-8 (a,b,c) is a plot of $\ln K_D$ ($K_D = (\text{Mg}/\text{Fe}^{2+})_{\text{px}} / (\text{Mg}/\text{Fe}^{2+})_{\text{gt}}$) as a function of pyroxene variables reflecting their equilibration temperatures.

In Fig. IV-8 (a) ($K_{D_{\text{cpx/gt}}}$ vs. $(\text{Al}^{\text{VI}}/\text{Cr})_{\text{opx}} / (\text{Al}^{\text{VI}}/\text{Cr})_{\text{cpx}}$) a linear relationship is observed, but the temperature trends defined by the two variables are opposite to each other, showing that the two geothermometers are out of phase. The temperatures defined by the equilibration of $\text{Al}^{\text{VI}}/\text{Cr}$ between ortho- and clinopyroxenes may represent "relict" temperatures from an earlier stage in the cooling history of these rocks. The residual refractory behaviour of Cr was shown for Cr in garnets in Matsoku pyroxenite veins and in adjacent peridotite (Harte et al., 1977). If the diffusion and re-equilibration of Al^{3+} and/or Cr between these phases was slower than that of other components (e.g. Carmichael, 1969; Fraser and Lawless, 1978), then it is likely that the Al^{VI} content of the orthopyroxene will also reflect an earlier stage of

re-equilibration between orthopyroxene and garnet. Therefore, equilibration pressures determined by Wood's equation (1974), where components such as $(\text{Fe}/\text{Fe}+\text{Mg})_{\text{opx}}$ and $(\text{Fe}, \text{Mg}, \text{Ca}, \text{Mn}, \text{Na})_{\text{gt}}$ are taken into account, may be incorrect.

In Fig. IV-8 (b) (K_D versus $\text{Ca}/\text{Ca}+\text{Mg}_{\text{cpx}}$) there is a range in K_D despite the almost constant $\text{Ca}/\text{Ca}+\text{Mg}$ ratio of the clinopyroxene, and again the geothermometers are out of phase. This can be interpreted as being due to either:

- (i) lack of equilibration of the clinopyroxene and garnet with respect to all components as the temperature decreased.
- (ii) if there was equilibration, then the different K_D values may reflect different pressures of equilibration and/or dependency on original bulk compositions.

In contrast, in Fig. IV-8 (c), (K_D versus $\text{Ca}/\text{Ca}+\text{Mg}_{\text{opx}}$) the K_D values remain constant regardless of a slight change in the $\text{Ca}/\text{Ca}+\text{Mg}$ ratio of the orthopyroxene. Because of the small range in the latter, it is difficult to be conclusive about the implications of this trend, but similar ranges elsewhere (see Fig. IV-13) reflect K_D variations. Therefore, the partition of Fe^{2+} -Mg between orthopyroxene and garnet may have been "blocked" below a certain temperature ($\sim 1000^\circ\text{C}$, Fraser and Lawless, 1978), or again may just reflect a dependency on pressure and bulk compositions.

2.1.5 Bulk rock chemistry:

The clinopyroxenite bulk chemical compositions, as determined by XRF, are given in Table IV-5, where they have been recalculated to a pyroxene formula based on 6 oxygens. They show a slight cation excess, which could be due to several reasons:

- 1) analytical error
- 2) any ferric iron present (Fe_2O_3 obtained on total rock analyses is not relied upon, due to some evidence of introduction of foreign material during ascent to the surface)
- 3) initial garnet/orthopyroxene that may have been present in some of these rocks.

Although the Mg/Mg+Fe ratios are relatively restricted (85.6 - 90), the chemical variation shown by other oxides is very wide, especially the Al_2O_3 contents (1.4 - 10.4 wt.%). A positive correlation between Na_2O and Al_2O_3 contents is observed, but otherwise they show a discontinuous change in composition (e.g. Fig. IV-9).

Bulk rock compositions and coexisting minerals in each rock are plotted in a Ca-Mg-Fe ternary diagram (Fig. IV-2). Tie lines between coexisting clinopyroxene and garnet in rock PC34, and clino- and orthopyroxene ($\sim 3\%$ garnet present) in PC22, almost intersect their bulk compositions, whereas in all others these fall within the field defined by their respective 3 coexisting phases.

2.1.6 Discussion:

The occurrence of garnet-pyroxenites similar to Type I pyroxenites found at Koffiefontein, has been reported from several localities in the world, as lenses and dykes

in alpine peridotites (Carswell, 1973) and as inclusions in basalts (Green, 1966; Beeson and Jackson, 1970; Lovering and White, 1970; Shervais et al., 1973; Wilkinson, 1973) and in kimberlites (Borley and Suddaby, 1973; Boyd, 1973a; Harte and Gurney, 1975).

They are regarded as representing either:

- 1) basaltic liquids crystallised at high pressure and temperature (Yoder and Tilley, 1962);
- 2) residues from which basalt has been extracted (Beeson and Jackson, 1970);
- 3) high pressure cumulates from basaltic magmas (Tilley and Yoder, 1964; Green, 1966; O'Hara, 1969, 1973; Harte and Gurney, 1975), and
- 4) as samples of unmodified layered upper mantle (Wilkinson, 1973).

Regardless of their origin, it is widely agreed that in general they have undergone subsolidus re-equilibration at lower temperatures or higher pressures with some exsolution of garnet and/or orthopyroxene (Green, 1966; Beeson and Jackson, 1970; Lovering and White, 1970; Boyd, 1973; Wilkinson, 1973; Shervais et al., 1975), although the amount of garnet that can be accommodated in clinopyroxene as solid solution prior to re-equilibration remains highly speculative.

The textures of Type I pyroxenites indicate a

metamorphic history, with exsolution of garnet and orthopyroxene. There is evidence of coarsening, coalescence and recrystallisation of the exsolved phases, and therefore it is not always possible, on a textural basis alone, to decide whether or not all the garnet/orthopyroxene represent products of exsolution. For example, in PC35 and PC58 all garnet looks "primary", whereas in PC33, PC34 and PC54, both exsolved and primary garnet could be present. In PC22, although most of the orthopyroxene seems to be exsolved, some could have been primary. If not, coarsening of these phases has obliterated any evidence of exsolution. On chemical grounds, the garnet chemistry and the compositional relationships of the different phases in these xenoliths, discussed in the previous section, also indicate that the defined chemical trends may be a function of the original bulk compositions, re-equilibrated under similar temperature conditions, and therefore be at least in part due to exsolution.

Experimental work, for example, by O'Hara (1969), Boyd (1970) and Irving and Green (1970), has attempted to place some compositional limits on the amount of garnet that can be accommodated in aluminous pyroxene. The bulk and individual phase compositions of the Koffiefontein Type I pyroxenites are illustrated in Fig. IV-10, which represents Boyd's (1970) experimental system at 1200°C and 30 kb. This plot reveals a reasonably good agreement

with Boyd's (op. cit.) results, and even though bulk compositions of PC21, PC22, PC25 and PC55 fall below this theoretical three-phase field, they fall above the Al_2O_3 limit, which is considerably lowered, for two natural assemblages (Fig. 14 in Boyd, 1970). Considering that Boyd's system does not take into account important chemical components such as FeO , Cr_2O_3 and Na_2O , the above deviations do not seem to be significant. The bulk chemistry of these xenoliths also fall below the maximum solubility of garnet in clinopyroxene at 30 kb., determined by Green and Ringwood (1967) and O'Hara (1969) (Fig. 2 in O'Hara, 1969). Additional evidence in favour of exsolution is that the pyroxenites under discussion have a bulk $\text{Mg}/\text{Mg}+\text{Fe}^{2+}$ ratio ranging from 85.6 to 90, and it is suggested that total exsolution phenomena occur in rocks in which this ratio is >85 (Irving and Green, 1970).

Bulk composition of clinopyroxenites from other localities, which exsolved garnet and/or orthopyroxene on cooling are shown in Table IV-6, and these are broadly similar to the most Al_2O_3 rich Type I pyroxenites from Koffiefontein. These latter xenoliths also show some resemblance to aluminous pyroxenes crystallised from olivine-rich alkali basalt at high pressure (>10 kb. - Thompson, 1974; see Table IV-7). The xenoliths with lower Al_2O_3 contents (e.g. PC21, PC22, PC25, PC55) are more silica saturated and this may have inhibited the entry of Al^{3+} into their structures. Alternatively they may have

crystallised at lower pressures than the Al_2O_3 -rich ones. The relative re-equilibration pressures determined by Wood's (1974) equation, reflects a slightly lower pressure for the more Al_2O_3 -rich xenoliths (33 - 38 kb.) than for the ones with lower Al_2O_3 (40 - 46 kb.), at $\sim 900^\circ\text{C}$.

After consideration of the features described, it is concluded that Type I pyroxenites represent high- Al_2O_3 clinopyroxenes formed at high temperatures and at pressures of 30 - 40 kb. The discontinuous change in their bulk compositions indicates a cumulate origin (Presnal, 1969) most probably from a basaltic magma. On subsequent cooling they have exsolved garnet and/or orthopyroxene (\pm chromite) and the lack of chemical zoning and homogeneous composition of individual minerals suggests that individual xenoliths represent equilibrated assemblages. However, application of available geothermometry methods to individual specimens revealed conflicting results, which are interpreted as indicating small-scale disequilibrium.

The most likely magmatic association for these pyroxenites is the Karroo volcanism active in the vicinity of Koffiefontein as recently as 70 m.y. before the pipe emplacement. If Type I pyroxenites were derived from a basaltic magma associated with this volcanism, then diffusion rate studies could potentially test whether or not the large garnet/orthopyroxene crystals are also exsolved

phases. However, at present diffusion data on the rate of exsolution can only be applied to "coarsening of coherent lamellae in iron-free pyroxenes" (Huebner, pers. comm.) and cannot therefore be applied to the Koffiefontein pyroxenites.

2.2. Type II Pyroxenites

2.2.1 Introduction:

These xenoliths comprise a group of small greyish-green orthopyroxene megacrysts (size range : 1,5 - 2,5 cm.) with minor garnet and occasional clinopyroxene and chromite. They have a slightly turbid appearance in thin section, denoting alteration. Texturally it seems that the garnet, most of the clinopyroxene and the Cr-spinel are exsolved phases, from originally homogeneous orthopyroxenes. Texturally primary metasomatic phlogopite is found in PC24A.

Both calculated (see p. 18) and observed modes are given in Table IV-8, and brief petrographic descriptions of the individual samples are given below.

2.2.2 Petrographic Descriptions:

PC20A, PC20B : opx + cpx ± gt

Single orthopyroxene crystals with well developed cleavage, straight extinction and with green clinopyroxene lamellae exsolved parallel and along cleavage planes (e.g. Plate 8). In PC20A, small garnets are seen as elongated lamellae, showing kelyphitic rims, which are also exsolved along cleavage planes. The clinopyroxene also occurs as larger bands along one of the crystal margins. Both samples show signs of slight alteration, with cloudy patches. The wider lamellae in PC20B, permitted chemical studies.

PC24A, PC24B, PC27 and PC71 : opx + gt ± cpx

These samples are megacrysts of orthopyroxene, with small vein-like inclusions of pyrope. In hand specimen they resemble an ultrabasic nodule from Matsoku reported by Boyd et al. (1973 - Plate 23B). In thin section, these orthopyroxenes look slightly altered, are optically positive, have poorly developed cleavage, uneven extinction and occasional kink bands. In PC27 (Plate 10) recrystallisation along the latter has developed, indicating a more advanced stage of the deformation recrystallisation cycle. The original crystal is readjusting to a coarse grained rock with similar grain size to coarse peridotite xenoliths commonly seen in most kimberlites. As such it is an important transitional type.

The garnets in these samples occur as small roundish inclusions (Plate 10) or elongated narrow veinlets (0.25 - 0.5 mm.) (Plate 9). They are surrounded by kelyphitic rims in which small spinels can rarely be identified. These garnets are interpreted as products of exsolution. PC27 contains three small inclusions of clinopyroxene (Plate 10), with two of them showing twinning (deformation?). These two clinopyroxene grains have different extinction, which does not suggest exsolution from the orthopyroxene host. If they were exsolved, no evidence of such remains.

PC24 has three very fresh grains of phlogopite which are not associated with garnet alteration, and are interpreted

as primary metasomatic (Harte and Gurney, 1975).

PC28 - opx + cpx + gt + chromite

This sample is a single orthopyroxene crystal enclosing small (0.07 - 0.25 mm.) dark brown spinels, garnets and blebs of clinopyroxene. The latter extinguish simultaneously throughout the rock. Where elongated they are parallel to the spinels which also show a strong preferred orientation throughout the crystal. The garnets occur as round grains along fracture planes and as thin blebs within the orthopyroxene, also parallel to the spinels (note small colourless inclusions on left hand side of Plate 11). Some of the garnets and spinels are under the surface of the thin section.

The preferred orientation of all the inclusions and the simultaneous extinction of the clinopyroxene suggest structural control by the host orthopyroxene. The latter has undergone minor deformation, as evidenced by slight undulose extinction.

2.2.3 Mineral Chemistry:

Microprobe analyses of the individual minerals in these rocks are presented in Table IV-9. Where a mineral is homogeneous, only an average composition is given, with the number of analyses in brackets.

Orthopyroxenes:

The orthopyroxenes are MgO-rich (En₉₂ - En_{93.8}) (Fig.

IV-11) and have low and restricted concentrations of Al_2O_3 (0.58 - 0.77 wt.%), Cr_2O_3 (0.17 - 0.32 wt.%) and CaO (0.24 - 0.60 wt.%) contents.

Rock PC20A has not attained chemical equilibrium. This is particularly reflected in the variations of the Al_2O_3 content of the orthopyroxene. In PC20B, difficulty was experienced with analysis due to the lamellae size, but analyses of three lamellae revealed uniform compositions, which fell within the orthopyroxene compositional range referred to above; these will be plotted as the "minimum" composition attained by the orthopyroxene in this megacryst.

Calculation of end member molecules (Table IV-10) shows that very small amounts of Mg-Tschermak component are present (~1.0 - 1.7 mole %, with the highest value in PC20A). A plot of the CaO, Al_2O_3 and Cr_2O_3 versus the MgO contents of these pyroxenes reveals a scatter of points. (Fig. IV-12 a and b).

Garnets:

The garnets have Mg/Mg+Fe ratios varying between 80.4 and 86.4, and grossular contents between 10.8 and 12.9 mole % (Fig. IV-11). The Cr_2O_3 content of the garnets (3.2 - 4.9 wt.%) increases with increasing MgO, while the CaO content (4.1 - 5.0 wt.%) remains almost constant (see Figs. IV-12 a and b).

Clinopyroxenes:

The clinopyroxenes do not always indicate equilibration

with their hosts (e.g. PC20A, PC20B). They have high Mg/Mg+Fe ratios (~96 - 97) and high contents of Al₂O₃ (2.2 - 4.3 wt.%), Na₂O (1.7 - 3.7 wt.%) and Cr₂O₃ (1.4 - 2.4 wt.%), when compared to clinopyroxenes from Type I pyroxenites. TiO₂ is present (0.10 - 0.17 wt.%). The Ca/Ca+Mg ratios vary between 44.5 and ~51, the lowest value being found in PC27.

Chromite:

The chromite in PC28 is Cr₂O₃ rich (54.5 wt.%), but when compared with chromites from the concentrate it has less Cr₂O₃, MgO and more Al₂O₃ (see Figs. VII-12 and VII-13). In these Figs. PC28 chromite plots inside the field defined by chromites occurring in ultramafic rocks (Sobolev, 1977) and in kimberlite xenoliths elsewhere (Basu and MacGregor, 1975).

Phlogopite:

The phlogopite in PC24A, which looks texturally primary, has low Cr₂O₃ (0.08 wt.%) and TiO₂ (0.2 wt.%) contents, and plots in the field defined by primary metasomatic phlogopites from Matsoku (Harte and Gurney, 1975 - see Fig. IV-17).

2.2.4 Discussion:

The petrographic observation of extensive exsolution of garnet, chrome spinel and chrome diopside in these orthopyroxenites is interpreted as clear evidence that the

assemblages have cooled from a higher thermal regime to lower temperatures and/or pressure. The exsolution phenomena is an attempt to re-equilibrate to these lower grade sub-solidus conditions.

The conditions of re-equilibration of Type II pyroxenites can be estimated on the basis of

- (i) the mutual solubility of the coexisting pyroxenes (e.g. Boyd and Nixon, 1973; Wells, 1977)
- (ii) the distribution of FeO and MgO between clinopyroxene and garnet (e.g. Akella and Boyd, 1974), and
- (iii) the amount of potential garnet in the orthopyroxenes (Wood and Banno, 1974).

Although some of these specimens have not reached chemical equilibrium in the sense that minerals may be zoned it is assumed in the ensuing section that equilibrium between two points in different minerals in close proximity to each other will approximate equilibrium compositions.

Temperature estimates for these pyroxenites are illustrated in Table IV-11 (methods have been discussed in section 2.1.4 of this chapter, dealing with Type I pyroxenites) and with few exceptions there is good agreement between the values obtained for individual samples, regardless of the geothermometry method used. However, Mysen's (1976) equation yields a higher temperature estimate for PC27, and this again may indicate lack of re-equilibration

of Al^{3+} and/or Cr^{3+} between the pyroxene phases, with falling temperature. Ellis and Green's (1979) equation also yields much higher temperature values for the two samples where it is applicable (PC27 and PC28), and it seems out of phase with the other geothermometers.

Strictly speaking temperature estimates cannot be made for PC24A, PC24B and PC71, where clinopyroxene is not observed. However, their orthopyroxenes have Ca/Ca+Mg ratios intermediate between PC20A, PC20B and PC27, which indicate a re-equilibration temperature range from $\sim 900^{\circ}C$ up to $1070^{\circ}C$ (Boyd and Nixon, 1973). If it is assumed that the orthopyroxenes PC24A, PC24B and PC71 are saturated with calcium, then they have re-equilibrated at $\sim 1030^{\circ}$, 970° and $1050^{\circ}C$, respectively (Boyd and Nixon, 1973).

Following the same approach as in Type I pyroxenites, the Ca/Ca+Mg ratios of the orthopyroxenes have been plotted as a function of the distribution of Fe^{2+} and Mg between coexisting orthopyroxenes and garnets (Fig. IV-13). This is a function of temperature and pressure of equilibration (e.g. Fraser and Lawless, 1978). There is a decrease in $\ln K_D$ as the Ca/Ca+Mg ratios of the orthopyroxenes increase, and if the latter is a reflection of temperature, then the distribution of Fe^{2+} and Mg^{2+} between the two phases has been sensitive to temperature changes between $\sim 1070^{\circ}$ and $<900^{\circ}C$. This is in contrast with the relationship observed for these two variables in the garnets and orthopyroxenes

from Type I pyroxenites, and does not support Fraser and Lawless's (1978) suggestion that re-equilibration of Fe^{2+} and Mg between garnet and orthopyroxene is "blocked" below $\sim 1100^\circ\text{C}$.

Re-equilibration pressures have been calculated using Wood and Banno's (1974) geobarometer and are also given in Table IV-11. Pressure values obtained using temperature estimates determined by Well's (1977) equation seem unrealistically low to account for the formation of the original high- Al_2O_3 pyroxenes, and those obtained using Boyd and Nixon's (1973) temperatures are preferred (~ 37 to 43 kb., av: 40 kb. ± 3 kb.).

2.2.5 Bulk rock chemistry:

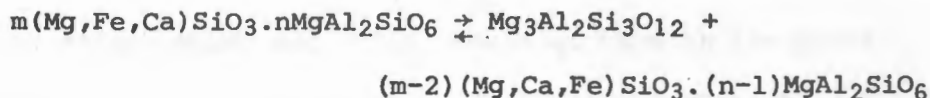
The bulk rock chemistries of Type II pyroxenites, determined by XRF, are given in Table IV-12. Due to the particularly small size of PC71, sufficient material for a bulk analysis was not available. Therefore only a calculated analysis on the basis of mineral compositions and modal abundances is given in Table IV-12. The analyses have been recalculated to a pyroxene formula (the small cation excesses are attributed to the reasons discussed in a previous section - IV-2.5) and are characterised by restricted Mg/Mg+Fe ratios ($\sim 92 - 94.2$) and high Al_2O_3 (1.6 - 3.6 wt.%) and CaO (0.9 - 2.3 wt.%). Small amounts of TiO_2 (0.06 - 0.17 wt.%) Na_2O ($\sim 0.1 - 0.5$ wt.%) and

K₂O (0.07 - 0.24 wt.%) are indicated, but these concentrations may have been affected by slight alteration. Also given in Table IV-12 is an analysis of the bulk composition of a garnet-websterite from Norway (Carswell, 1973), in which all the clinopyroxene and most, if not all garnet were derived by exsolution from a primary, high temperature orthopyroxene. Except for its slightly higher Al₂O₃ content this high temperature orthopyroxene bears a strong resemblance to the bulk compositions of Type II pyroxenites.

2.2.6

Discussion:

If these xenoliths represent original orthopyroxene megacrysts which have exsolved garnet and/or clinopyroxene, they can be represented by an equation of the form:



(after Green and Ringwood, 1967), which has moved to the right, due to decreasing temperature. An increase in pressure would have the same effect on this reaction, but a pressure change is regarded as unlikely.

With cooling, the compositions of the re-equilibrated orthopyroxene and the exsolved phases will therefore be strongly dependent on the original bulk compositions, and on the conditions of re-equilibration.

The amount of garnet and clinopyroxene exsolved seem to be dependent on the ratio of Mg-Tschermak to CaSiO₆

(Wollastonite) and Na end-member molecules (mainly ureyite and jadeite (Table IV-12(a))). For example, PC20A and PC20B, have the highest Mg-Tschermak molecular contents, but they also have the highest ureyite, jadeite and diopside contents, and have preferentially exsolved clinopyroxene. These two samples also have almost identical bulk compositions, but garnet exsolution was only observed in PC20A. The absence of garnet in PC20B could indicate that the reaction has not progressed as far as in PC20A.

The bulk compositions of these Koffiefontein megacrysts are illustrated in a Ca-Mg-Fe ternary diagram (Fig. IV-11) and in Fig. IV-12 (a and b) where CaO, Cr₂O₃ and Al₂O₃ are plotted as a function of their MgO contents. Theoretically, tie lines between orthopyroxene and garnet in PC24A, PC24B and PC71, should go through the points where their respective bulk compositions plot, because they are the only phases observed in these samples. Generally, the bulk compositions plot very close to tie lines with the exception of composition PC24A in Fig. IV-12(a), which shows a significant deviation. This can be attributed to the presence of an additional phase or alteration. If another phase was present, it could have been easily missed due to the small size of the xenoliths, their fragmentary nature and the availability of only one thin section per sample. Bulk rock compositions of

these pyroxenites in Fig. IV-12 (a and b), show well developed trends of increasing CaO, Al₂O₃ and Cr₂O₃ with decreasing MgO. The nature of these trends could be interpreted in two ways:

- 1) they represent mixing lines, relating varying proportions of orthopyroxene, garnet and clinopyroxene. However, there was no evidence, from hand specimens observation, of garnet and/or clinopyroxene other than that attributed to exsolution. Besides, PC20A and PC20B, which have the highest Al₂O₃ content also have the lowest amount of modal garnet. This option is therefore disregarded in favour of the following;
- 2) the above trends suggest a genetic relationship between high temperature pyroxenes which have crystallised in a closed system magma chamber, with increasing amounts of CaO, Al₂O₃ and Cr₂O₃.

Following this model, crystallisation of orthopyroxene from a magma would result in an increase in CaO and Al₂O₃ in the residual liquid, which in turn would tend to cause an enrichment of these elements in the more evolved pyroxenes. Although the enrichment of Cr₂O₃ with decreasing MgO is contrary to that predicted by crystal field theory effects (Curtis, 1963; Burns, 1973) and to that commonly observed in kimberlite nodules

(e.g. Gurney, 1975) and in pyroxenite/websterite nodules in basalts (Kuno and Aoki, 1970), it is consistent with a marked increase in the Cr distribution coefficient between orthopyroxene and liquid with decreasing temperature and increasing oxygen fugacity (Irving, 1978 - this is illustrated in Fig. IV-14). Therefore, although the residual liquid would become depleted in Cr during crystallisation, the large increase in distribution coefficient would still result in the more evolved pyroxenes having a greater Cr content than those crystallising at an earlier stage. This mechanism clearly implies an igneous origin for these orthopyroxene megacrysts. They have then subsequently experienced modification influenced by falling temperature.

2.3 Type III Pyroxenite

2.3.1 Introduction:

Type III pyroxenites (PC29, PC30, PC31, PC39, PC41, PC50), from Koffiefontein comprise a group of six small (~1,5 to 2,5 cm. in hand specimen) coarse grained rocks in which the main constituent is orthopyroxene. Clinopyroxene is always present in subordinate amounts, garnet is observed in four of these xenoliths and one is chromite bearing.

The orthopyroxene is coarse grained (~1,5 - 8 mm.) and two of these xenoliths (PC30 and PC39) are single

crystals (up to 1,7 cm.) enclosing clinopyroxene or garnet inclusions. Clinopyroxene varies in habit from small blebs (~0.2 mm.) to large crystals (up to 4 mm.) adjacent to or poikilitically enclosed within the orthopyroxenes. Garnet occurs as discrete crystals (up to 4 mm.) although they do in addition occur as small inclusions in the orthopyroxenes of PC50. Most garnets show strong signs of alteration.

On a textural basis, although a small modal percentage of clinopyroxene in a few xenoliths may have resulted from exsolution from the orthopyroxene, most of the clinopyroxene and all the garnet and chromite seem to be primary phases. This distinguishes these pyroxenites from Type II, discussed in the previous section.

Modal percentages are presented in Table IV-13 and brief petrographic descriptions of individual samples are given below.

2.3.2

Petrographic Descriptions:

PC29 : opx, cpx, gt

This xenolith consists of an aggregate of coarse orthopyroxene (up to 5 mm.) and clinopyroxene (up to ~4 mm.), with minor garnet. The sample shows signs of alteration. Introduction of foreign material has taken place mainly along grain boundaries, and has preferentially affected the garnet. This mineral is now present

as a few small grains completely surrounded by kelyphite.

The orthopyroxene is fractured and irregularly shaped and the grain boundaries vary from irregular to smoothly curved. Numerous small, parallel inclusions of a colourless to very pale-brown mineral with rhombic shape (rutile), occur under the surface of the orthopyroxene.

The clinopyroxene has mineral inclusions similar to those occurring in the orthopyroxene, but with a long needle-like shape. Under polarised light the clinopyroxene shows a series of bands (lamellae), often coincident with the needle-shaped inclusions but a quantitative microprobe scan revealed constant clinopyroxene composition.

PC30 : opx, cpx

Single orthopyroxene crystal (~1.7 cm. long) poikilitically enclosing clinopyroxene. The clinopyroxene varies in shape and size from small blebs (~0.2 mm.) through small elongated grains, to large grains up to 4 mm. in size. A few of the smaller clinopyroxenes and a large crystal (~3 mm.) extinguish simultaneously (~10% of total clinopyroxene present), whereas others have different extinction angles. This suggests that ~10% of the clinopyroxene may have resulted from exsolution from the orthopyroxene host. The clinopyroxene is partly altered to a brown, patchy mineral

(chlorite).

PC31 : opx, gt, cpx

This sample consists of several large orthopyroxene crystals (~3 - 7 mm.), with small amounts of garnet and clinopyroxene. The garnets (up to 4 mm.) occur as discrete grains, are fractured, surrounded by kelyphite, and a few have spongy altered centres. Bright green clinopyroxene, occasionally slightly altered, is present as small grains mainly concentrated along the boundaries between the orthopyroxene and the garnet. A few secondary phlogopite grains are present.

PC39 : opx, gt, cpx

This sample comprises a single fresh orthopyroxene crystal (~8 mm. long), with a large garnet (~4 mm.) partially enclosed on one edge. This garnet is highly fractured and altered along the margins (kelyphite). A small area of the orthopyroxene crystal contains very small (~0.4 to <0.1 mm.), rounded to elongated inclusions of green clinopyroxene. Two sets of these inclusions can be distinguished on the basis of different extinction angles. It is possible that one or both sets of these clinopyroxenes may represent products of exsolution.

PC41 : opx + cpx + chromite

PC41 comprises several large orthopyroxene crystals

(~1,5 - 8 mm.), with occasional signs of deformation, i.e. individual crystals are being separated into smaller grains across sharply defined lines, which give the crystal uneven extinction. Clinopyroxene occurs as small blebs (~.2 mm.) within the orthopyroxene, and as larger irregularly shaped discrete grains (up to 1,5 mm.). The clinopyroxene has cloudy patches, mainly along the edges, and in places has been completely altered and replaced by chlorite.

Small grains of chromite occur poikilitically enclosed by the orthopyroxene and as discrete grains. One of these chromites has a very small inclusion of orthopyroxene.

PC50 : opx + cpx + garnet

This sample is similar in many respects to PC41 (please refer), with the exception that clinopyroxene is more abundant, slightly coarser grained (1 - 2 mm.) and does not occur as blebs. In contrast to PC41, the orthopyroxene has a cloudy appearance, looks slightly altered, and encloses small roundish garnets. The garnets are highly altered but occasionally a pinkish-purple colour can still be recognised.

2.3.3

Mineral chemistry:

Microprobe analyses of individual minerals in Type III pyroxenites are presented in Table IV-14.

Minerals are homogeneous and have uniform compositions, and therefore only average compositions are given, with the number of analyses in brackets.

Orthopyroxenes :

The orthopyroxenes and enstatites (Mg/Mg+Fe : 91.8 - 93.8, Fig. IV-15) with low contents of CaO (0.2 - 0.66 wt.%), Cr₂O₃ (0.2 - 0.5 wt.%) and Al₂O₃ (0.5 - 0.83 wt.%). Fig. IV-16 (a,b,c) illustrates a plot of Cr₂O₃, CaO and Al₂O₃ contents versus the Mg/Mg+Fe ratios. The most Cr₂O₃ and CaO-rich and Al₂O₃-poor pyroxenes have the lowest Mg/Mg+Fe ratios, and they also have the highest TiO₂ (0.05 - 0.14 wt.%).

The small orthopyroxene inclusion in a chromite grain in PC41 (see hand specimen description) has higher Cr₂O₃ and FeO, and lower MgO contents than the other orthopyroxenes in this sample. (Table IV-14-PC41, analysis 2).

Clinopyroxenes:

The clinopyroxenes are diopsides with variable contents of Al₂O₃ (1.1 - 4.3 wt.%), Cr₂O₃ (1.1 - 2.8 wt.%), Na₂O (1.5 - 4.1 wt.%) and TiO₂ (0.07 - 2.4 wt.%). Their Mg/Mg+Fe and Ca/Ca+Mg ratios vary between 91.1 - 95.1 and 43.2 - 48.7 respectively (Fig. IV-15).

Garnets:

The garnets (Fig. IV-15) in xenoliths PC29, PC31

and PC39 are pyropes ($Mg/Mg+Fe$: 80.7 - 84.1) with almost constant Cr_2O_3 contents (2.2 - 2.8 wt.%), and with 3.8 to 4.8 wt.% CaO. The garnet in xenolith PC50 has a very distinctive composition in view of its high Cr_2O_3 (12.3 wt.%) and CaO (8 wt.%) contents.

Chromite:

The chromite in PC41 is Cr_2O_3 -rich (59.1 wt.%), and has the lowest Al_2O_3 (5.6 wt.%) and highest TiO_2 (2.3 wt.%) contents of all chromites found in mantle rocks in Koffiefontein. It is similar in composition to chromites from the Koffiefontein concentrate and plots near the fields defined by chromites occurring in ultramafic rocks and kimberlite xenoliths (see Figs. VII-12 and 13).

2.3.4

Discussion:

The pyroxenes in Type III xenoliths form two slightly different compositional groups defined by PC29, PC31 and PC39, and PC30, PC41 and PC50, respectively. In the latter group, the absence or presence of garnet/chromite may be due to differences in bulk chemistry, or in PC30, the absence of either of these phases may again be due to the small size and fragmentary nature of these rocks.

Type III pyroxenites are texturally and chemically distinct from both Types I and II. Chemically the orthopyroxenes in Type III have broad similarities to

the re-equilibrated orthopyroxenes in Type II, with respect to their CaO, Al₂O₃ and Cr₂O₃ compositional ranges, but on average they have slightly lower Mg/Mg+Fe ratios.

Estimated conditions of equilibration of Type III pyroxenites are presented in Table IV-15 (methods were discussed in previous sections). The temperatures obtained by Mysen's geothermometer are much higher than those obtained by other clinopyroxene-orthopyroxene geothermometers, but since they fall outside his calibration range, they cannot be relied upon. However, in PC31 and PC39 they are also high but similar to temperatures defined by garnet-clinopyroxene geothermometers (i.e. Akella and Boyd, 1974; Ellis and Green, 1979). Wells' geothermometer yields temperature results that seem to be too low, with the exception of those obtained for the two garnet-free xenoliths (PC30 and PC41). Although the several geothermometers seem to be out of phase, they all indicate a definite range in equilibration temperatures, at almost constant pressure (31 - 40 kb., Table IV-15) for Type III pyroxenites. In general, PC29, PC31 and PC39 have equilibrated at lower temperatures ($\sim 900^{\circ}\text{C}$ - 970°C) than PC30, PC41 and PC50 ($\sim 1070^{\circ}$ - 1100°C) as evidenced by the range in Ca/Ca+Mg ratios of their pyroxenes. The high Cr₂O₃ content of the garnet in PC50, and the high K_D (~ 0.7 ; $K_D =$

$\frac{(Cr/Cr+Al)_{gt}}{(Cr/Cr+Al)_{cpx}}$) for clinopyroxene-garnet pairs, also point towards a high temperature of equilibration of this xenolith (Sobolev, 1970).

The intersecting tie lines defined by coexisting phases in these pyroxenites (Fig. IV-15) suggest that if they are related and come from the same body they are not in equilibrium or, alternatively, they represent fragments derived from a number of different pyroxenite horizons. The small size and limited number of samples available allows only a very uncertain speculation about their origin, but if these rock fragments were derived from an unrelated number of pyroxenite bodies, then it would require the kimberlite to have sampled a number of different horizons on its way to the surface. If the kimberlite had sampled over an extensive depth range, it is surprising that peridotite is virtually absent in the Koffiefontein kimberlite pipe, in view of the dominantly peridotitic composition of the upper mantle. Therefore, a preferred interpretation for Type III pyroxenites is that they represent a related suite of xenoliths, which are not in equilibrium.

2.4. Type IV Pyroxenite Xenoliths

2.4.1 Introduction:

A set of small (~1 - 1,5 cm.), predominantly fine

grained pyroxenites, which constitute a small proportion of the Koffiefontein suite, form a distinctive grouping which has been designated Type IV in this study. In this category there is a gradation from orthopyroxenites (PC65, PC60) through websterites (PC23, PC66, PC43, PC26, PC68, PC53) to clinopyroxenites (PC57). Garnet and spinel are generally absent, and with one exception (PC65) they are phlogopite or amphibole bearing. Modes are summarized in Table IV-18. Type IV pyroxenites generally show signs of subsolidus readjustment of their original textures, as is manifested in the varying degrees of polygonization and deformation (kink bands, deformation bands, uneven extinction) of the individual grains.

These xenoliths are mostly fine grained (0.3 - 1.3 mm.), though occasionally individual grains reach 3 - 4 mm. Minerals vary in habit from equant, polygonally shaped to elongated grains. The former have straight or slightly curved grain boundaries, often converging at triple junctions with angles of 120° . The elongated crystals are usually larger in size (porphyroclasts?), have more irregular grain boundaries, and partially enclose or are surrounded by smaller polygonal grains; these porphyroclasts often show signs of being separated into 2 or more different grains, and seem to be reminiscent of a previous textural stage,

before polygonisation of the rest of the rock occurred. A visual estimate of the percentage of porphyroclasts present in each rock, is also presented in Table IV-16, and the two most extreme cases are illustrated in Plates 12 and 13. Only in two specimens, PC26 and PC43 do the orthopyroxenes have subhedral shape (these are the coarsest grained xenoliths).

Both uniform and uneven extinction are observed in all specimens. Some grains also show very fine lamellae (sometimes visible under plain light), while others have more widely separated parallel bands (deformation bands) only observed under polarised light. Clinopyroxenes often show two different sets of lamellae.

The fine lamellae in the orthopyroxenes are occasionally curved or disrupted by kink bands, which seems to indicate that deformation took place during and after exsolution. In a few instances the lamellae are wider along kink bands, suggesting that exsolution was activated by preceding deformation. It should be noted that all these phenomena are observed in both the polygonal grains and porphyroclasts.

In most of these xenoliths either phlogopite or amphibole (in PC26 only) are observed as accessory phases, with the exception of PC57, where phlogopite is a major phase. The phlogopite (flakes of ~ 0.4 mm. in size, up to a few grains of ~ 1.6 mm.) has curved to

straight grain boundaries, occasionally may be strained and in PC57, phlogopite and clinopyroxene often display an unusual poikilitic relationship. Both the phlogopite and the amphibole are in textural equilibrium with the surrounding phases, suggesting that they formed prior to the inclusion of the xenoliths within the kimberlite.

In two samples (PC23 and PC66) the clinopyroxene is unevenly distributed, occurring mainly on one side of the specimens. The phlogopite distribution tends to follow that of the clinopyroxene, but this is not as pronounced in PC66. Individual descriptions of these xenoliths are given below.

2.4.2

Petrographic Descriptions:

PC65 : (100% opx)

This rock consists entirely of equant orthopyroxene grains, with polygonal shape, and with a bimodal size distribution (≈ 0.6 and 1 mm.). They have straight to slightly curved grain boundaries, with triple junction points of $\approx 120^\circ$ (Plate 12). Most of the grains exhibit straight extinction, but some are slightly strained. A few have very fine lamellae (sometimes visible under crossed nicols), or more widely separated parallel bands (deformation bands?). In a few instances the orthopyroxene is exsolving material, visible under plain light, concentrated along

deformation bands (kink bands ?).

PC60 : (97% orthopyroxene, 3% phlogopite, amphibole is present).

Most of the orthopyroxenes are fresh, but a few have a turbid appearance and have a variable grain size (0.4 - 4 mm.). The larger orthopyroxene grains (porphyroclasts - ~40%) have very irregular grain boundaries, are cracked and often show undulose extinction; in some, separation of the original crystals into smaller grains can be observed, along well developed kink bands. The larger grains may surround or partially enclose smaller polygonal grains. The latter have regular, smoothly curved or straight grain boundaries, and often show triple junctions of $\sim 120^\circ$. They also show lamellae and signs of deformation (see Plate 13).

Phlogopite occurs as small flakes/grains with regular grain boundaries, and one flake has almost twinned extinction.

PC43 : (~97% opx; 3% cpx)

This sample is similar to PC26 above, except that it is much coarser grained: orthopyroxene varies in size from ~0.7 to 9 mm. and clinopyroxene from ~5 to 2 mm (Plate 14).

The larger orthopyroxene grains are elongated and have irregular grain boundaries, whereas the smaller

ones are polygonal and have straight grain boundaries joining at $\sim 120^\circ$. They both have common features such as widespread exsolution lamellae. Kink bands are observed frequently (Plates 14 and 15):

- 1) lamellae are bent at kink bands, indicating deformation after exsolution;
- 2) lamellae are often wider at kink bands and get thinner away from them, which suggests that deformation may have activated exsolution. Curved lamellae are also observed, suggesting deformation during exsolution.

Clinopyroxenes are irregularly shaped, with irregular grain boundaries; they occur interstitially between orthopyroxenes, although one grain is enclosed within the largest orthopyroxene (~ 9 mm.). Two sets of exsolution are occasionally observed (see Plate 16).

PC26 : ($\sim 89\%$ opx; 10% cpx; 1% amphibole).

Both pyroxenes in the sample are relatively fresh, and grain size is variable ($\sim 0.7 - 3$ mm.) with the orthopyroxene having an average larger size. Some of the larger orthopyroxenes tend to be elongated, with subhedral crystal shape, whereas the smaller ones have polygonal shape with well developed straight grain boundaries joining at $\sim 120^\circ$. Both types of grains may show straight extinction, or a series of deformation bands giving them uneven extinction, or abundant exsolution of very fine lamellae. In one of the orthopyroxene

grains the lamellae are bent at a kink band, and they are also slightly curved. This indicates deformation at least after and during exsolution. One clinopyroxene has two sets of exsolution lamellae (Plate 16).

PC66 and PC23 : (PC66 - ~ 87% opx; ~ 10% cpx; ~ 3% phlogopite)
(PC23 - ~ 93% opx; ~ 5% cpx; ~ 2% phlogopite)

Orthopyroxene is the major constituent of both samples, and it has a cloudy appearance, not as pronounced in PC66.

Grain size varies from ~0.4 to 2.5 mm. with the orthopyroxene having a larger average size. The smaller grains have in general polygonal shapes, with curved to straight grain boundaries, defining triple junctions (often at ~120°). A few larger elongated grains (porphyroclasts ?) have irregular shapes and grain boundaries, are highly fractured, often having uneven extinction and partially enclose or are surrounded by smaller polygonal grains. Porphyroclasts are more abundant in PC23 than in PC66, where only two are observed. They seem to be a relict of a previous textural stage, before polygonisation of the rest of the rock occurred.

Pyroxenes in both rocks show very thin lamellae (more abundant in pyroxenes from PC23), larger deformation bands, and occasional kink banding. In a few cases the lamellae are wider along the kink bands, suggesting that some of the observed exsolution was activated by deformation. Some clinopyroxenes in PC23 show two different sets of lamellae.

Phlogopite is present as small flakes, with a grain

reaching ~ 1.3 mm., with straight to curved grain boundaries. In PC66, it occasionally shows uneven extinction. In view of the textural equilibrium with the surrounding minerals, phlogopite is considered to be primary.

In both these xenoliths, the clinopyroxene is unevenly distributed, occurring mainly on one side of the rock. The phlogopite distribution tends to follow that of the clinopyroxene, but this is not as pronounced in PC66.

PC68 : ($\sim 60\%$ opx; 40% cpx + few small phlogopite grains)

Both pyroxenes have a very cloudy appearance, variable grain size (0.3 - 1.3 mm.), and irregularly shaped grains with some having a polygonal shape. The grain boundaries vary from irregular to smoothly curving and straight, occasionally joining at angles of $\sim 120^\circ$. Some of the grains with irregular boundaries have uneven extinction, across sharply defined deformation planes. The percentage of polygonal grains is smaller than in any of the other samples in Type IV xenoliths, and they may also show uneven extinction.

PC53 : $\sim 70\%$ opx; $\sim 28\%$ cpx; $\sim 2\%$ phlogopite

In thin section this rock has a cloudy appearance, denoting slight alteration. There is a variation in grain size from ~ 0.4 mm. to ~ 2.5 mm., the orthopyroxene having a greater average grain size than the clinopyroxene. Grain boundaries are predominantly regular, from gently curved to straight, occasionally also joining at $\sim 120^\circ$ triple junctions.

Very fine lamellae are observed in some grains of both pyroxenes, and two sets of lamellae are occasionally observed in the clinopyroxene. Some phlogopite flakes are altered, but a few are fresh and are in textural equilibrium with the rest of the rock.

PC57 : (~70% cpx; ~30% phlogopite)

Sample consists of an aggregate of small clinopyroxene grains of variable shape and size (up to 3 mm.), and of phlogopite (up to 1 mm.). The clinopyroxene has a very cloudy appearance in places, and it is not easy to see its relationship with phlogopite, but otherwise grain boundaries between the two phases seem to be regular. An unusual poikilitic relationship is observed between clinopyroxene and phlogopite. It looks as if originally there were a few large clinopyroxene crystals (and phlogopite ?), which have been fractured and deformed.

2.4.3 Mineral Chemistry:

A preliminary chemical study of Type IV pyroxenites has revealed a few salient features:

- 1) both the large relic pyroxene grains and some of the smaller polygonised grains have extremely fine lamellae which, with one exception (PC43) are not resolvable by electron microprobe analyses;
- 2) some of the porphyroclasts that look optically homogeneous, are chemically zoned (e.g. PC53, analyses 1 and 2, Table IV-17);
- 3) within each xenolith, optically homogeneous polygonal grains

are often chemically distinct

- 4) although some of the chemical variations observed are very small, they are significantly greater than the analytical errors resulting from counting statistics. Random variations in the Al_2O_3 , Cr_2O_3 and Na_2O contents of the clinopyroxenes and in the CaO and Al_2O_3 contents of orthopyroxenes are observed. The above features would require a large amount of detailed microprobe work on each rock. Since these Type IV xenoliths are extremely small (1 - 1.5 cm.) in hand specimen and constitute only a small proportion of the mantle material found at Koffiefontein their chemistry will be discussed in a generalised manner only (Table IV-17).

Orthopyroxenes:

The orthopyroxenes are bronzites - enstatites ($\text{Mg}/\text{Mg}+\text{Fe}$: 84.2 - 90.7) with low TiO_2 and Cr_2O_3 (0.02 - 0.43 wt.%) contents. CaO (0.13 - 1.20 wt.%) and Al_2O_3 (1.10 - 3.97 wt.%) contents are variable, the highest Al_2O_3 and CaO contents being observed in the centre of a chemically zoned, optically homogeneous orthopyroxene porphyroclast (PC53, analyses 1 and 2). The higher CaO and Al_2O_3 values are significantly greater than usually observed in mantle minerals from kimberlites, and greater than those observed in other Koffiefontein pyroxenites.

Clinopyroxenes:

The clinopyroxenes have $\text{Mg}/\text{Mg}+\text{Fe}$ ratios varying between 87.5 and 91.5, and the contents of Al_2O_3 and Cr_2O_3 contents varying between

0.37 - 4.96 wt.% and 0.08 - 1.43 wt.% respectively. TiO_2 (N.D. - 0.31 wt.%) and Na_2O (0.35 - 1.28 wt.%) concentrations are low. The Ca/Ca+Mg ratios of the clinopyroxenes vary from ~48 to 53. A value of 44.1 is found at the centre of a zoned clinopyroxene, but the grain shows at least one set of very small lamellae in the centre, which are obscured by a series of parallel deformation bands that occur throughout the grain (Table IV-17, PC68 - analysis 3).

The Ca-rich pyroxenes always have greater Mg/Mg+Fe ratios, greater TiO_2 , Al_2O_3 , Cr_2O_3 and Na_2O contents (wt.%) than the coexisting Ca-poor pyroxenes. These inter-element relationships generally apply to both porphyroclasts and to the smaller polygonal grains. But, in PC23 for example, the orthopyroxene polygonal grains have greater Al_2O_3 and Cr_2O_3 contents than the clinopyroxene porphyroclasts.

As already mentioned, the lamellae in the pyroxenes are not wide enough to be quantitatively resolved for electron microprobe analysis, with the exception of some in pyroxenes from PC43. Out of all the analysed lamellae in PC43, only in one instance (Table IV-17; analysis No. 5) was the composition (major and minor elements) observed to be the same as that of the first generation phase.

Phlogopite:

The phlogopite compositions have been plotted in Fig. IV-17, which shows the variation of Cr_2O_3 with respect to FeO and TiO_2 (after Harte and Gurney, 1975). The phlogopites have low Cr_2O_3 and TiO_2 , and plot near the compositional fields defined by primary metasomatic phlogopites found in peridotites at other localities.

Amphibole:

End members of the amphibole (in Table IV-17) have been recalculated according to the method of Papike et al. (1974) and it corresponds to an edenitic amphibole ($\text{Na, Ca}_2 \text{Mg}_5 \text{Si}_7 \text{AlO}_{22} (\text{OH})_2$). It is slightly more TiO_2 and FeO-rich than other edenites/pargasites reported from elsewhere in peridotites (Table IV-18).

2.4.4 Discussion:

Type IV pyroxenites from Koffiefontein show relicts of a higher temperature assemblage and a metamorphic imprint in their textures. They show signs of subsolidus readjustment with a reduction in grain size from coarse to very fine grained (compared to other mantle rocks), and with a considerable amount of exsolution taking place with falling temperature. Their textures developed in response to annealing and deformation, and the xenoliths were brought to the surface before equilibrium was attained.

The very high Ca/Ca+Mg ratios of the clinopyroxenes indicate that they have cooled to very low temperatures ($<900^\circ\text{C}$), but the two sets of exsolution often observed in the clinopyroxenes are relicts of previous higher temperatures.

The absence of an aluminous phase in these xenoliths does not allow calculation of their equilibration pressures. The Al_2O_3 contents of the orthopyroxenes is quite high (up to 3.96 wt.%) and of the same order of magnitude as those observed for the bulk rock analyses of Type II orthopyroxenites (1.6 - 3.6 wt.%), which have exsolved garnet on cooling. The orthopyroxenes of Type IV pyroxenites are more FeO-rich

than Type II above, and apparently they are not Al_2O_3 saturated under their prevalent equilibration conditions, which suggests a shallower origin for Type IV pyroxenites (<37 kb.).

Chemical data and textural evidence suggest that phlogopite and amphibole are primary minerals, which were present before deformation and re-equilibration of these rocks, and therefore not connected with their inclusion within the kimberlite.

According to Modreski (1972) phlogopite is stable to depths of 175 km. (~53 kb., 1125°C) under stable shields where geothermal gradients are low, and experimental work by Kushiro (1969) limits the stability of diopside and phlogopite and enstatite and phlogopite to 32 kb., at 1000°C and 33 kb. at 1100°C, respectively. The stability field of amphibole is more limited. Lambert and Wyllie (1968) found that amphibole will remain stable to a maximum depth of 80 km. (~25 kb.) under continental shields, which is in agreement with Kushiro's (1969) work. (85 km., ~27 kb. assuming Clark and Ringwood's (1964) geotherm.)

Type IV pyroxenites from Koffiefontein must have formed at low pressures in the presence of a volatile, K_2O -rich liquid and were deformed and recrystallised under moderate temperatures at a relatively shallow depth in the mantle.

2.5 Type V pyroxenites.

2.5.1. Introduction

A single olivine bearing pyroxenite (PC47) has been found at Koffiefontein. Again it is a small specimen (~2,5 cm.) consisting mainly of orthopyroxene (~83%), with smaller amounts of olivine (~8%),

clinopyroxene (~5%), garnet (~2%) and chromite (~2%). This rock consists of a single orthopyroxene crystal, which has been recrystallised and deformed. The original orthopyroxene has been subdivided into smaller crystals, either along irregular or straight deformation bands.

Discrete grains of olivine (up to 2 mm.), clinopyroxene (up to 2,5 mm.), chromite and garnet are poikilitically enclosed by the orthopyroxene. The orthopyroxene is exsolving chromite and garnet, and at least in one grain the chromite lamellae are concentrated along an incipient kink band, suggesting that exsolution was activated by deformation (Plate 17). Garnet lamellae are widespread, and the small discrete grains referred to above, may represent exsolved phases which have migrated to the boundaries of newly developed orthopyroxene crystals.

2.5.2 Mineral Chemistry:

Microprobe analyses of the individual phases in PC47 are presented in Table IV-19.

The orthopyroxene is an enstatite ($En_{88.3}$), with a low content of Al_2O_3 (~0.5 wt.%), CaO (0,2 wt.%) and Cr_2O_3 (~0.15 wt.%). The clinopyroxene has a $Mg/Mg+Fe$ ratio of 92.7, and it has low Al_2O_3 (0.99 wt.%), Cr_2O_3 (0,7 wt.%) and Na_2O (0,76 wt.%).

Both these pyroxenes and the garnet ($Mg/Mg+Fe$: ~68; ~6 wt.% CaO ; 3 wt.% Cr_2O_3) are more FeO -rich than the equivalent minerals in Type II and III pyroxenites (Fig. IV-15) and are similar to those found in Type I. The olivine ($Fo_{85.7}$) is much more FeO -rich than any of the olivines from the four peridotites (~ $Fo_{92.2}$ - $Fo_{93.5}$) found at Koffiefontein.

It should be noted that the garnets in this xenolith have not attained uniform composition, especially reflected in the variations of their CaO and Cr₂O₃ contents, which denotes a lack of equilibrium. The Ca/Ca+Mg ratios of both the clinopyroxene (~49) and the orthopyroxene (~0.46) indicate that this sample has cooled to ~900°C (Davis and Boyd, 1966 and Boyd and Nixon, 1973, respectively) and two adjacent clinopyroxene and orthopyroxenes (analyses 18 and 14 in Table IV-19) yielded a temperature estimate of ~1050°C, using Wood and Banno's (1973) geothermometer. The equilibration pressure of this xenolith, calculated from adjacent orthopyroxene and garnet crystals (analyses 14 and 2 in Table IV-19) is ~47 Kb (Wood and Banno, 1974).

3. GROUP B - KOFFIEFONTEIN PERIDOTITE XENOLITHS

3.1 Introduction

Only four small (~3cm.) peridotite xenoliths have been found at the Koffiefontein kimberlite pipe. One is a garnet lherzolite (PC 44) and three are harzburgites (PC 61, PC 64 and PC 63). Of the harzburgites one is chromite bearing (PC 63) and one has primary phlogopite (PC 61).

They are coarsely grained (up to 8mm.) rocks with no signs of deformation and vary from very fresh to slightly altered. Alteration has preferentially affected the olivine, causing serpentinization along fractures and grain boundaries.

The garnet in PC44, is concentrated along pyroxene grain boundaries (ie, between orthopyroxene-clinopyroxene and between orthopyroxene grains) but is

almost completely altered. Both the ortho- and clinopyroxene in this lherzolite have exsolution lamellae.

Modal visual estimates are presented in Table IV-20.

3.2. Mineral Chemistry

The individual minerals in the Koffiefontein peridotites are homogeneous and have uniform compositions. Microprobe analyses of the constituent phases are given in Table IV-21 (number of analyses are indicated in brackets).

The olivines are forsterites ($\text{Fo}_{92.2} - \text{Fo}_{94.2}$), similar to those from granular peridotites from Lesotho (Nixon and Boyd, 1973).

The orthopyroxenes of PC44, PC61 and PC63 are enstatites ($\text{En}_{94.2} - \text{En}_{95.2}$), also similar to those from granular peridotites from Lesotho (Nixon and Boyd, op. cit.) but with slightly lower Al_2O_3 (0.65 - 0.81 wt.%), Cr_2O_3 (0.27 - 0.31 wt.%) and CaO (0.18 - 0.22 wt.%) contents. However, the orthopyroxene from the harzburgite PC64 has a higher CaO (0.74 wt.%) and much higher Al_2O_3 (2.4 wt.%) contents. The Al_2O_3 content of this pyroxene is comparable to that observed in orthopyroxenes from Type IV pyroxenites from Koffiefontein.

The clinopyroxene from the garnet lherzolite PC44 has ~2,6 wt.% Al_2O_3 , 1,8 wt.% Cr_2O_3 and 2,00 wt.% Na_2O . The Ca/Ca+Mg ratio is high (47,8) and comparable to clinopyroxenes in granular peridotites (Nixon and Boyd, 1973). The garnet in this xenolith is a pyrope with 12,5 mole % grossular component and ~2,5 wt.% Cr_2O_3 .

The chromite in PC63 is typical of those occurring in ultramafic rocks and kimberlite nodules (Fig. VII-12 and 13) and the phlogopite

in PC61 has a composition similar to primary-metasomatic phlogopites found in peridotites elsewhere (Fig. IV-17).

3.3 Discussion

The coexisting minerals olivine-chromite in harzburgite PC63 indicate an equilibration temperature of 793°C (Roedder et al., 1979 - see Chapter V-5) and mineral assemblages in garnet lherzolite PC44 yield equilibration conditions of $\sim 940^{\circ}\text{C}$ (Davis and Boyd, 1969) and 36 kb. (Wood and Banno, 1974). The lack of clinopyroxene and garnet in the other two peridotites does not allow estimation of their equilibration conditions, but the high Al_2O_3 in harzburgite PC64 indicates a shallower depth of origin.

CHAPTER V

INCLUSIONS IN DIAMONDS FROM KOFFIEFONTEIN

1. INTRODUCTION

Diamonds are believed to form in the Earth's mantle, from igneous melts (Meyer and Boyd, 1972; Sobolev, 1977; Harris and Gurney, 1979) at depths of at least 100 km. (Kennedy and Nordlie, 1968) and are brought to the surface by kimberlites. Syngenetic mineral inclusions in diamonds provide useful information on the environment of formation of diamond, which is of both intrinsic and economic interest. They yield direct evidence on the composition of the upper mantle, and are unique in respect of their armouring in that they are surrounded by unreactive diamond and except where they touch each other they probably represent primary compositions unmodified by subsequent events and metamorphic effects.

Chemical studies of these inclusions have shown that they have an overall compositional similarity, irrespective of the age and locality of the host kimberlite (Meyer and Tsai, 1976; Sobolev, 1977; Gurney et al., 1979). They also have a compositional range broadly similar to that of eclogitic and peridotitic minerals occurring both in xenoliths and concentrates of kimberlites, but in some respects show distinctive characteristics (e.g. low CaO in peridotitic garnets, high Cr₂O₃ in peridotitic garnets, olivines and chromites, high K₂O in eclogitic clinopyroxenes - Meyer and Tsai, 1976; Sobolev, 1977; Harris and Gurney, 1979). Besides these common features, a few others

must be taken into account in any attempt to explain the origin of diamonds. With few exceptions (e.g. Orapa and Premier Mines), peridotitic inclusions in diamonds from southern Africa are much more abundant than eclogitic inclusions (Gurney et al., 1979). This distribution pattern rarely reflects the xenolith population at individual localities (e.g. at Roberts Victor, where the xenolith population is characteristically eclogitic, the diamond inclusions are predominantly peridotitic). Diamonds have relatively often been found in association with eclogites (Sobolev, 1977; Hatton, 1978; Shee, 1978) but they have rarely been found in peridotites by comparison (Dawson and Smith, 1975; Pokhilenko et al., 1977; Gurney, pers. comm.), and in general the vast majority of diamonds are recovered from the kimberlite matrix from the largest down to the smallest of sizes. Therefore, their distribution does not seem to fit a simple picture of derivation from the disaggregation of xenoliths. In addition diamonds probably originate from more than one source, as has been clearly demonstrated at Roberts Victor (Kramers, 1977).

Fesq et al. (1975) have found droplets of CO_2 , H_2O -rich melts in diamonds that looked free of inclusions, and this has given strong support to the hypothesis that most diamonds originate in magmas of kimberlitic character (e.g. Meyer and Boyd, 1972) derived by small degrees of partial melting of carbonated mantle peridotite (Harte et al., in press). This magma is also capable of crystallising minerals such as garnet, olivine, ortho- and clinopyroxene (Eggler and Wendlandt, 1977), which are found as inclusions in diamonds. The fractionation of clinopyroxene may be originally suppressed

because of the association of Ca^{2+} cations with CO_3^{2-} , resulting in the crystallisation of Ca-poor phases (e.g. low CaO garnets - Harte et al., 1979).

The most abundant diamond inclusions at the Koffiefontein pipe are sulphides, as elsewhere in S. Africa. Out of the peridotitic and eclogitic suite of minerals, the peridotitic inclusions are the most abundant (Hawthorne et al., in prep. - see Table V-1).

The Koffiefontein inclusions were removed by cracking the diamonds, and they have been briefly described by Dr. J. W. Harris. (These notes were made available by Dr. Gurney, for the purpose of this study).

To date, 78 mineral inclusions from Koffiefontein diamonds have been analysed and the results are presented in Table V-2 to V-9 (analyses by R.S. Rickard). Inclusions with the same number have been removed from the same diamond, and eighteen coexisting mineral pairs are reported: 3 garnet-olivine; 4 garnet-orthopyroxene; 7 garnet-clinopyroxene; 1 olivine-orthopyroxene; 1 olivine-clinopyroxene; 1 olivine-chromite and 1 orthopyroxene-periclase.

2. PERIDOTITIC INCLUSIONS

Garnets:

The peridotitic garnet inclusions at Koffiefontein have been sub-divided into two groups, based mainly on their CaO contents and Mg/Mg+Fe ratios.

- (a) Garnet inclusions K1, K4, K10, K11, K12, K45, K47 and K48 (Table V-2A) have the highest Mg/Mg+Fe ratios (88.2 - 92.6), very low

CaO (0.6 - 2.7 wt.%) and TiO_2 , and have Cr_2O_3 contents between 3.5 and 6.6 wt.%. They have compositions typical of peridotitic diamond inclusions, although with lower Cr_2O_3 concentrations (Gurney, 1975; Sobolev, 1977) and are chemically similar to those most commonly found at the Finsch Mine, S.A. (Gurney et al., 1979 - see fields A and B, Fig. V-1).

Garnets of similar composition have been found in a few peridotite xenoliths (e.g. Sobolev, 1977) and occasionally also in the concentrate fractions of kimberlites (Gurney and Switzer, 1973; Lawless, 1974; Sobolev, 1977), such as P.J.L. gt 1 and gt 3 from Koffiefontein (Table VII-2).

Garnets with low CaO contents (<3.5 wt.%) are believed to have formed in the absence of clinopyroxene, and are consequently thought to be derived from a dunite/harzburgite paragenesis (Sobolev, 1977; Harte et al., 1979, in press).

Three of the garnet inclusions (gts K10, K11, K48) occur with olivine and one (gt K47) with orthopyroxene, in the same diamond.

(b) The remaining peridotitic garnet inclusions at Koffiefontein (gts K2, K3, K5, K9, K44, K46) (Table V-2B) have lower Mg/Mg+Fe ratios (84 - 87.8) and higher CaO (3.3 - 5.5 wt.%) than those in group (a); Cr_2O_3 also tends to be higher (4.5 - 8.7 wt.%).

Chemically similar garnets are also occasionally found as inclusions in diamonds elsewhere (e.g. Finsch, Gurney et al. (1979) field C in Fig. V-1; Premier, Gurney, in prep.) but are not common. In contrast to group (a) however, they are widely distributed in kimberlite

concentrates (Lawless, 1974; Fig. V-1) and peridotitic xenoliths.

In fact, they are compositionally similar to a few garnets found both in Type II orthopyroxenites and concentrate of Koffiefontein (compare with Fig. VII-1).

Garnets of similar composition have been assigned to a lherzolite paragenesis by Sobolev (1977).

Three of these Koffiefontein garnet inclusions (gt K2, K9, K46) have been found to occur with orthopyroxene in the same diamond.

Olivines:

Olivine is generally the most abundant peridotitic inclusion in diamonds (Meyer and Tsai, 1976; Hawthorne et al., in prep.), and this has also been found at Koffiefontein. In general, olivine diamond inclusions, although tending towards very Mg-rich compositions, i.e. Mg/Mg+Fe : 91 - 96.1 (Meyer and Tsai, op. cit.; Harris and Gurney, 1979) have compositions overlapping with those found in xenoliths and concentrates (Meyer and Boyd, 1972).

The 15 olivines that have been analysed from Koffiefontein (Table V-3) are also very Mg-rich ($Fe_{91.6} - Fe_{95.4}$), and CaO (N.D. - 0.16 wt.%) can reach unusually high concentrations in a diamond inclusion. Although Sobolev (1977) also reports an olivine with 0.18 wt.% CaO, it is uncertain whether these high CaO values are due to alteration or are inherent in the original olivine compositions. The olivines with the highest CaO contents (0.13 and 0.16 wt.%) are described as occurring in diamonds with "black fracture flaws" (diamonds K20 and K26 respectively in notes by Harris).

The most distinctive characteristic of olivine diamond inclusions, when compared to olivines from xenoliths, is the commonly observed high concentration of Cr_2O_3 of up to 0.09 wt.% (Meyer and Boyd, 1972; Meyer and Tsai, 1976; Gurney et al., in prep.). Olivine inclusions at Koffiefontein have Cr_2O_3 contents up to 0.15 wt.% (D.L. = 0.03) and a similarly high value (0.15 wt.%) has also been reported by Prinz et al. (1975).

It has been suggested (Burns, 1975) that chromium enters the olivine structure as Cr^{2+} , due to the low oxygen fugacity and high pressures prevalent during the formation of diamonds. On the other hand the simultaneous crystallisation of chromites with diamonds, suggests that most chromium is present as Cr^{3+} , and its oxidation state in olivine seems uncertain. High magnesium olivine phenocrysts (up to Fo_{92}) which coexist with Cr-spinel in ocean floor basalts, from the Mid-Atlantic Ridge, have Cr_2O_3 contents up to 0.15wt%. (le Roex, 1980); these phenocrysts probably crystallise at higher oxygen fugacities than those required for diamond formation, and it is likely that most of the chromium is in the trivalent state. According to Arai (1978) Cr^{3+} enters the octahedral site of olivine by the coupled substitution $3 (\text{Mg}, \text{Fe}^{2+}) \leftrightarrow 2 \text{Cr}^{3+}$; this is accompanied by the substitution of the large Ca^{2+} cation for $(\text{Mg}, \text{Fe}^{2+})$ to fulfill the vacancy left in the octahedral site. Although a few of the Koffiefontein diamond inclusions have higher CaO, there is no obvious correlation. So, it seems that the oxidation state of chromium in olivines remains open to speculation, and that the presence of at least some Cr^{3+} in the structure of olivine diamond inclusions should not be ruled out.

Four of the diamonds which contain the olivine inclusions, are also hosts to other minerals: 1 olivine - 1 clinopyroxene, 1 olivine - 1 orthopyroxene, 1 olivine - 1 chromite and 3 olivine - 3 garnet inclusion mineral pairs have been found. The olivine that occurs with two clinopyroxenes in the same diamond (K18) has a Mg/Mg+Fe ratio of 92.7. It is slightly more Feo-rich (7.2 wt.%) than the 3 olivines that coexist with the 3 low CaO garnets (Feo : 5.2 - 5.7 wt.% - K10, K11 and K18).

Clinopyroxenes:

The clinopyroxene diamond inclusions from Koffiefontein (Table V-4) are similar in many respects to others reported by Sobolev (1977) and by Meyer and Tsai (1976) belonging to the peridotitic suite (Fig. V-1). They have low FeO (1.8 - 2.7 wt.%), Na₂O (0.3 - 2.4 wt.%), Al₂O₃ (0.68 - 2.14 wt.%) and TiO₂ (N.D. - 0.07 wt.%) contents and a Cr₂O₃ content ranging between 0.8 and 3.7 wt.%. However, the K₂O content of these pyroxenes is very high for peridotitic pyroxenes, and higher than that of the eclogitic diamond inclusions from Koffiefontein (Table V-9). There is the possibility that the potassium content associated with the inclusion cpx K15 (0.31 wt.%) may be due to alteration, because the host diamond is fractured, but the same does not apply to cpx K14 (0.79 wt.% K₂O) which occurs in an unfractured diamond. Inclusions cpx K18 and K18A2 have particularly high K₂O concentrations (~1.6 wt.%) and from the description of their diamond host, cpx K18A2 is a clear diopside and therefore its K₂O content should not be simply regarded as a product of alteration, even

though cpx K18 could be the altered pyroxene referred to in this diamond.

It should be pointed out that clinopyroxenes K18A2 and K18 have been included in the peridotitic suite of minerals, because they occur with olivine in the same diamond. With the exception of their K_2O contents, they have pyroxene compositions but X-ray diffraction work is required to determine positively whether their structure corresponds to that of a pyroxene.

Clinopyroxenes with relatively high potassium contents have also been reported in peridotite xenoliths (up to 0.086 wt.% - Sobolev, 1977), peridotitic diamond inclusions (up to 0.23 wt.% - Meyer and Tsai, 1976; 0.15 wt.% - Sobolev, 1977) and eclogitic diamond inclusions (0.76 wt.%, Finsch pipe, S.A. 0.55 and 1.12 wt.%, Orapa, Botswana - Rickard, unpubl. data).

The stability limits of the potassium-rich minerals phlogopite (175 km - Modreski, 1972) and richterite (30 kb at $1000^{\circ}C$ - Kushiro and Erlank, 1970) makes them unsuitable minerals to accommodate K_2O in the upper mantle at depths of diamond formation. Both Erlank (1973) and Sobolev (1977) have suggested that under these conditions K_2O will probably enter the clinopyroxene structure. So far, results from experimental work indicate that <150 ppm K_2O enter the structure of synthetic pyroxenes at pressures up to 30 kb. (Erlank and Kushiro, 1970) and that at higher pressures (100 kb., $1400^{\circ}C$) this value may increase to 2200 ppm (Shimizu, 1971). A careful determination of this oxide in homogeneous, unaltered clinopyroxenes, such as some of the diamond inclusions mentioned above, may corroborate the importance of

clinopyroxene as a source of K_2O in the deep mantle, even in peridotitic material.

Besides their high K_2O contents, inclusion K18A2 and K18 have unusually low Na_2O (~ 0.3 wt.%) and Al_2O_3 (~ 0.7 wt.%). They also have slightly different compositions, especially reflected in their Ca/Ca+Mg ratios (40.3 and 45.5), even though they occur in the same diamond. The clinopyroxene diamond inclusions have compositional similarities to a few of the most MgO-rich (Mg/Mg+Fe: 0.92 - 0.96) concentrate clinopyroxenes.

Orthopyroxenes:

The Koffiefontein orthopyroxene diamond inclusions (Table V-5) are enstatites ($En_{92.6} - En_{95.8}$) with a low CaO content (0.13 - 0.78 wt.%) which decreases with increasing Mg/Mg+Fe ratio (Fig. VII-7). They are chemically similar to most enstatite diamond inclusions (Meyer and Boyd, 1972; Sobolev, 1977; Harris and Gurney, 1979) and also to a few green orthopyroxenes found in the Koffiefontein concentrate (see Figs. VII-7, 8 and 10), except that the latter have higher average Na_2O and TiO_2 .

The orthopyroxenes that do occur with garnet in the same diamond (K2, K9, K46, K47) have a smaller Al_2O_3 compositional range (0.55 - 0.76 wt.%; av.: 0.66), but similar on average, to that of the orthopyroxenes that do not occur with garnet (0.30 - 1.16 wt.%, av.: 0.69 wt.% Al_2O_3). The latter value (1.16 wt.% Al_2O_3 - opx 262-B) is unusually high when compared to diamond inclusions elsewhere (Meyer and Boyd, 1972; Meyer and Svisero, 1975; Meyer and Tsai, 1976; Sobolev, 1977; Gurney et al., 1979, in prep.). The only known

reported high value for this oxide in a diamond inclusion, is 1.36 wt.%, in a bronzite coexisting with a subcalcic clinopyroxene (Prinz et al., 1975). The Al_2O_3 content of opx 262-B is comparable to that of orthopyroxenes from sheared lherzolites (Boyd and Nixon, 1973), but it has a much lower CaO content (0.12 wt.% CaO, versus ~0.7 - 1.2 wt.% CaO in sheared lherzolites).

Chromite:

Only one of the chromite inclusions in Koffiefontein diamonds has been analysed (Table V-6). This chromite occurs with olivine and has Cr_2O_3 and TiO_2 contents (63.3 wt.% and 0.1 wt.% respectively) typical of diamond inclusions, but with a slightly higher Al_2O_3 content (Sobolev, 1977 - see Fig. VII-13).

3. ECLOGITE INCLUSIONS

Garnets:

The Koffiefontein eclogitic garnet inclusions (Table V-7) have a very wide range in CaO, MgO and FeO contents, and display a broad trend of simultaneous calcium and iron enrichment (Fig. V-2). They are characterised by low Cr_2O_3 (N.D. - 0.85 wt.%), high FeO (13.5 - 21.3 wt.%) and the presence of both TiO_2 (up to 0.76 wt.%) and Na_2O (up to 0.34 wt.%). The presence of Na_2O is a characteristic feature of eclogitic garnet diamond inclusions and often of garnets in Type I eclogite nodules (e.g. Shee, 1978).

Seven of these garnets occur with clinopyroxene in the same diamond (K8, K16, K37, K41, K42, K43 and K56). Diamonds K19 and K37

each have two garnet inclusions, which have significantly different chemical compositions (Table V-7). The implications of this will be discussed in more detail in a latter section.

Clinopyroxenes:

The clinopyroxene inclusions (Table V-8) also show a wide variation in CaO (10 - 20 wt.%), FeO (4 - 14 wt.%) and MgO, and in their Ca/Ca+Mg ratios (36 - 48.6) (Fig. V-2). They all have TiO₂ (0.13 - 0.42 wt.%) and the Na₂O (1.4 - 4.6 wt.%) and Al₂O₃ (2.7 - 7.9 wt.%) contents are variable and in a few cases are low for eclogitic clinopyroxenes (e.g. cpx K8, K56). Nevertheless, such inclusions have been assigned to an eclogitic paragenesis because of their high TiO₂ and occurrence, in the same diamond, with garnets which have eclogitic characteristics.

The presence of K₂O in clinopyroxenes is usually characteristic of diamond inclusions belonging to the eclogitic suite of rocks (Sobolev, 1977) and the eclogitic clinopyroxene diamond inclusions at Koffiefontein have K₂O contents of up to 0.23 wt.%.

The eclogitic diamond inclusions at Koffiefontein have characteristics broadly similar to Type I eclogites from Orapa (Shee, 1978). Hatton (1978) and Shee (1978) used the Na₂O content of clinopyroxenes as a differentiation index for eclogites. Although the Koffiefontein clinopyroxene inclusions do show an increase in Na₂O with decreasing MgO, the relationships with CaO is very poorly defined (Fig. V-3 a and b). In addition, the tie lines defined by clinopyroxene-garnet

pairs in a Ca-Mg-Fe ternary diagram (Fig. V-2) intersect each other suggesting that they do not form part of the same differentiation sequence or alternatively they do not represent equilibrium assemblages.

4. "ODD" INCLUSIONS (Mg, Fe) O minerals

Four inclusions of (Mg, Fe) O oxide ferropericlase, magnesio-wüstite ?) have been found in Koffiefontein diamonds (Table V-9). They have been reported previously by Hawthorne et al. (in prep.) who state "The red/brown minerals from Koffiefontein, whose compositions approximate periclase, were found in diamonds which were fractured and these minerals may be pseudomorphs. These inclusions, however, were sufficiently crystalline to give simple crystal X-ray patterns from which cell parameters and space group data were obtained (J. Smyth, pers. comm.)" - p.5. A periclase inclusion has also been found in an Arkansas diamond (Newton et al., 1977), with an inclusion suite of Cr-diopside, a bycrystal of Cr-diopside-orthopyroxene, olivine and magnetite. Newton et al. (1977) suggested that this periclase was probably a magnesite inclusion, prior to the combustion of the diamond for the removal of its inclusions. Magnesite may form according to the reaction:

Dolomite + enstatite \rightleftharpoons Diopside + Magnesite, which takes place at temperatures and pressures similar to those at which the graphite-diamond transformation occurs (Kushiro et al., 1975) (see Fig. V-4), and the presence of carbonates in the upper mantle has also been predicted by several other workers (Wyllie and Huang, 1975; Egglar and Wendlandt, 1977).

However, the Koffiefontein inclusions were not recovered by burning the diamond, but by cracking it, and other alternatives to a carbonate origin for the inclusions should be prominently considered. For instance, recent experimental work suggests that Mg_2SiO_4 -spinel transforms to pyroxenes with perovskite structure and to rocksalt (MgO), at ~ 250 kb. (Liu, 1975). Ringwood (1975) proposes that these assemblages are important constituents of the transition zone (~ 350 to 900 km.) and lower mantle ($> 900 - 1000$ km.). If the ferropericlasite minerals found in the Koffiefontein diamonds were to represent the phases described by Ringwood (1975) this would imply that both diamonds and their host kimberlite originated at depths greater than ~ 200 km., as is currently held (e.g. Egglar and Wendlandt, 1977).

The breakdown of orthopyroxene, according to the reaction $(Mg,Fe)_2Si_2O_6 \rightleftharpoons (Mg, Fe)O + 2SiO_2$ (Gurney, pers. comm.) could also be a potential source of periclasite and quartz, which is occasionally found as inclusions in diamonds.

The origin of the periclasite inclusions at Koffiefontein seems uncertain, and their stoichiometry is currently under investigation (Boyd, pers. comm. to Gurney). They have been described as possible pseudomorphs, but the finding of 4 periclasites in a very small fraction of the Koffiefontein diamond population, and their rarity at other localities, would make their origin as secondary products highly coincidental.

Diamond K262 is a host to one of these periclasites (transparent and isotropic) and to an orthopyroxene with an abnormally high Al_2O_3 content (1.16 wt.% - see Table V-5), suggesting a somewhat unusual

origin for both the inclusions in the diamond, most probably linked to the peridotitic suite of inclusions.

5. CONDITIONS OF EQUILIBRATION OF THE KOFFIEFONTEIN DIAMOND INCLUSIONS

Syngenetic inclusions in diamonds yield direct evidence of the upper mantle conditions prevailing at the time of their formation. A wide survey of diamonds with more than one inclusion, has revealed that the inclusions in each diamond belong either to the peridotitic or eclogitic suite (Meyer and Tsai, 1976; Harris and Gurney, 1979; Hawthorne et al., in prep.), reflecting different growth environments. One tentative exception has been found by Prinz et al. (1975) where olivine, rutile, silica and clinopyroxene (omphacite??) have been extracted from the same diamond. Although diamond K19 from Koffiefontein is cracked, olivine, sulphides and an eclogitic garnet have been extracted from it, and it constitutes another potential exception, which needs confirmation (the above is based on a visual identification; a chemical analysis of the inclusion identified as olivine is not yet available). Besides, multiple inclusions of the same mineral phase in a given diamond seem to have a constant composition and it is generally assumed that different inclusions in the same diamond represent equilibrium assemblages (e.g. Meyer and Tsai, 1976; Sobolev, 1977). However, in contrast to this, multiple inclusions of the same mineral phase in three diamonds from Koffiefontein (K18, K19, K37) do not show this feature of uniform composition.

Although the range in composition could be attributed to post-crystallisation alteration, only one of the diamonds has been

described as having fractures (K19). The description of the other two diamonds are somewhat ambiguous but no fractures were reported suggesting that compositional variations cannot be attributed to post-entrapment alteration. It therefore seems possible that some of the differences in chemistry of these inclusions in the same diamond, could reflect original differences.

The apparent equilibrium between multiple diamond inclusions, observed in other studies, is often used to justify the use of inclusion compositions to determine temperatures and pressures of equilibration of co-existing minerals and hence the formation of diamond itself. For purposes of comparison with other work, this approach will be followed below, even though it has been pointed out that the Koffiefontein inclusions may not always represent equilibrium assemblages.

(1) Olivine-chromite:

Olivine K22 (Table V-3) coexists with a chromite (Table V-6), and according to Jackson (1969) the distribution of Mg and Fe²⁺ between coexisting olivine and spinel can be used to estimate their temperature of equilibration. Roeder et al. (1979) have recently re-evaluated this geothermometer using new free energy data for the FeCr₂O₄ molecule and suggest the following formulation:

$$T^{\circ}K = \frac{\alpha 3480 + \beta 1018 - \gamma 1720 + 2400}{\alpha 2.23 + \beta 2.56 - \gamma 3.08 - 1.47 + 1.987 \ln K_D}$$

where:

$$\alpha = \frac{Cr}{Cr+Al+Fe^{3+}} \quad \beta = \frac{Al}{Cr+Al+Fe^{3+}} \quad \gamma = \frac{Fe^{3+}}{Cr+Al+Fe^{3+}} \quad K_D = (Fe^{2+}/Mg)_{sp} / (Fe^{2+}/Mg)_{ol}$$

If it is assumed that inclusions found in a single diamond represent equilibrium assemblages, then the temperature obtained for the olivine-chromite pair above (Koffiefontein diamond K22), is 974°C (using Jackson's (1969) equation the value obtained is 1604°C , which is considered unrealistic). Although Roeder et al. (1979) point out that application of this geothermometer to Cr-rich spinels will probably give the most reliable results, the largest uncertainty at present, seems to be in the choice of the free energy data for FeCr_2O_4 .

(ii) Orthopyroxene-garnet pairs:

The compositions of coexisting orthopyroxene and garnet, can be used to determine their pressure of equilibration (MacGregor, 1974), provided a previous determination of temperature can be made. It is only possible to estimate a temperature from an orthopyroxene composition, if it has crystallised with clinopyroxene, but no ortho-clinopyroxene pairs have been found in a single Koffiefontein diamond. However, the garnets from orthopyroxene-garnet pairs found in diamonds K9 and K46, have grossular components of 11.8 and 13.3 mole % respectively, and garnets with ~ 13 mole % grossular are assumed to have crystallised in the presence of two pyroxenes (O'Hara and Mercy, 1963; MacGregor, 1967; Sobolev, 1977). Under this assumption, the Ca/Ca+Mg ratios of the orthopyroxenes K9 and K46 can be used for geothermometry and reflect temperatures of $\sim 1080^{\circ}\text{C}$ ($\pm 50^{\circ}\text{C}$) using Boyd and Nixon's (1973) empirical geothermometer. Calculated pressures, for K9 and K46 orthopyroxene-garnet pairs, are 42 and 38 kb. ($\pm 3\text{Kb}$) respectively,

using equation 12 of Wood, 1974:

$$P = \frac{1.9871 \times T}{\Delta V} \times \ln \frac{(X_{Al}^{Mg})_{opx} \times (1 - X_{Al}^{Mg})_{opx}}{(1-Y)_{gt}^3} + \frac{7012 - 3.89T}{\Delta V} - 10450 \times (X_{Fe})_{opx} (1 - 2 X_{Al}^{Mg})_{opx}$$

The grossular components of the garnets of the two other orthopyroxene-garnet pairs, K2 and K47, are 9.9 and 6.3 mole% respectively, and therefore estimates of temperature cannot be made on the same assumption as before (even though according to Sobolev (1977) garnet K2, with CaO content >3.5 wt.%, may be attributed to a lherzolite paragenesis).

Different pressure-temperature relationships can be obtained, by inserting different temperature values in equation 12 of Wood (1974). The lines drawn through the points obtained in a P versus T diagram, represent lines of constant K_D , along which the 4 orthopyroxene-garnet pairs could have equilibrated. These are illustrated in Fig. V-4, together with the graphite-diamond stability curve (Bundy et al., 1961).

Minimum temperatures and pressures of equilibration for all four mineral pairs can be estimated by the intersection of the line of constant K_D for each pair, with the line separating the stability fields of graphite and diamond:

opx/st pair	T °C	PKb	at T (43 Kb)
K47	900°	39	1030
K2	950	40	1060
K9	1130	45	1130
K46	1250	48	1250

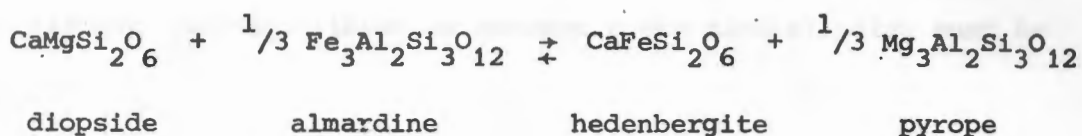
Comparison of the calculated temperatures and pressures of equilibration obtained for mineral pairs K9 and K46 (1080°C, 38 Kb., respectively) with the above values, shows that pair K46, would have equilibrated in the graphite stability field (see Fig. V-4). This discrepancy may be due to:

- 1) large errors in the geothermometer and geobarometer used,
- 2) the original assumption that temperature can be estimated from the Ca/Ca+Mg ratio of orthopyroxene coexisting with garnet containing ~13 mole % grossular component may be invalid,
- 3) if this assumption is valid, then mineral pairs included in diamonds do not necessarily represent equilibrated assemblages, as already suggested in the introduction to this section.

Another inconsistency is that garnet-orthopyroxene pairs K9 and K46, yield higher minimum temperature estimates than pairs K2 and K47. The garnets from the first two pairs have a greater CaO content, and if this is indicative of their crystallisation in the presence of clinopyroxene, then they should have crystallised at a later stage (lower temperature) during the crystallisation sequence. If a minimum crystallisation temperature of 1250°C would be assumed for orthopyroxene-garnet pair K47 (garnet with lowest CaO content) then this would require a minimum pressure of formation order of 65 Kb. (refer to Fig. V-4).

(iii) Clinopyroxene-garnet:

The distribution of iron and magnesium between garnet and clinopyroxene, represented by the equation:



has been used as potential geothermometer (Banno, 1970; Akella and Boyd, 1974; Raheim and Green, 1974; Ganguli, 1979) but is dependent on pressure (Banno, 1970; Raheim and Green, 1974) and other chemical components such as CaO in garnets (Ganguli, 1979; Ellis and Green, 1979), Na₂O and Al₂O₃ in the clinopyroxenes, and the amount of Fe³⁺ present in both minerals (Ganguli, 1979). The above geothermometer has been discussed and applied to diamond inclusions elsewhere (e.g. Gurney et al., in prep.), and the results obtained for Koffiefontein garnet-clinopyroxene diamond inclusions are given in Table V-10.

The equations of Raheim and Green (1974)

$$(T = \frac{3686+28,35P_{ks}}{2,33+\ln K_D}) \text{ and Ellis and Green (1979) } (T = \frac{3104X_{Ca}^{gt}+3030+10.86P}{1.9034+\ln K_D})$$

were combined with that defining the graphite-diamond stability curve

$$(Bundy et al., 1961 - PKb = 7,1 + 0,027 T^{\circ}K), \text{ to yield } T = \frac{3887}{\ln K_D + 1,56}$$

and $T = \frac{3104X_{Ca}^{gt} + 3107}{1.61018 + \ln K_D}$, respectively. In this way, minimum temperatures and pressures of equilibration for these mineral pairs and their

host diamonds were obtained (see Table V-10). Inclusion pairs in diamond K37 (1 cpx - 2 gts) indicate a wide range of minimum temperatures and pressures of equilibration, because the two garnets have different compositions. Even though they occur in an uncracked diamond, it has been suggested that garnet K37 D may be a product of alteration. If this garnet reflects alteration, then it is not possible to decide with which garnet the clinopyroxene should be paired with. If it is

not altered, non-equilibration between these mineral pairs must be assumed.

Without taking into consideration the problematic case of diamond K37, the range in minimum equilibration pressures is 18 and 10 Kb. (columns (3) and (4) respectively, of Table V-10). If these diamonds and their inclusions crystallised from an eclogitic melt, this corresponds to a minimum depth range of ~33 km.

As mentioned before, the tie-lines defined by the eclogitic clinopyroxene-garnet inclusion pairs do not define a regular pattern, which was interpreted as suggesting that they do not form part of the same differentiation sequence or alternatively, that they do not represent equilibrated assemblages. This is in contrast to the Premier and Orapa Mines eclogitic assemblages (Gurney: pers. comm.).

(iv) Olivine-garnet:

An interesting exercise would be the application of the olivine-garnet geothermometer (O'Neil and Wood, 1979) to the three low CaO garnets and their olivine pairs (in diamonds K10, K11 and K48). However, it has recently been pointed out that there are a few errors in the published method (JJG pers. comm.), and calculations of temperatures of equilibration for these assemblages would be irrelevant at this stage.

6. DISCUSSION

The chemical study of the diamond inclusions at the Koffiefontein kimberlite pipe, has revealed the features summarised below:

- 1) The diamond inclusions at Koffiefontein have chemical compositions broadly similar to those reported from other localities.
- 2) Some of these compositions are occasionally matched by equivalent phases found in the Koffiefontein mineral concentrate.
- 3) The diamond inclusions do not reflect the xenolith population at the pipe. The most abundant xenoliths are pyroxenites and websterites, and only a few of the peridotitic garnet inclusions (group (b)) have compositions broadly similar to exsolved garnets occurring in Type II orthopyroxenites. No genetic link is suggested.
- 4) A total of eighteen diamonds have multiple mineral inclusions, which have been analysed. Three of these diamonds have more than one inclusion of the same mineral, and in all three cases these discrete grains have different compositions. One diamond seems to have inclusions belonging to different paragenetic suites (i.e. peridotitic and eclogitic).
- 5) Tie lines between eclogitic mineral inclusions do not define a regular pattern, and cross each other.
- 6) Calculation of temperatures and pressures of equilibration of mineral pairs often resulted in inconsistent results.
- 7) In view of (4), (5) and (6) above, the assumption that multiple inclusions in a single diamond always represent equilibrated assemblages, is questioned by the writer. If it is assumed that both diamonds and their inclusions crystallise from melts, then these are continuously changing in composition, as reflected in

the compositional ranges observed in the mineral inclusions from different diamonds. The occurrence of discontinuous growth layers in diamonds, and inclusions of diamond in diamond (e.g. Sutton, 1928) suggest a multistage growth process. The inclusions trapped at successive growth stages could be expected therefore to reflect any changes in magma composition, and separate inclusions are unlikely to equilibrate through the diamond matrix, but this might occur if they are in physical contact (e.g. rare polymineralic inclusions). This would explain the lack of equilibrium found at Koffiefontein, and some of the differences in chemistry of the same phase in a single diamond.

A chemical study of inclusions in larger diamonds may substantiate this suggestion. A handicap of this study is the small and constant size range of the diamonds studied, and this seems to be the case elsewhere (see Hawthorne et al., in prep.).

- 8) The relationship of diamonds containing eclogitic and peridotitic inclusions is unknown. They may not be related, and may be derived from different sources (e.g. at Roberts Victor they have different ages). However, the two diamonds with mixed assemblages (Prinz et al., 1975 and this work) may eventually be seen to be the direct indication of a common origin for some.
- 9) The occurrence of periclase inclusions in four of the diamonds, may indicate a deeper origin for kimberlite and diamonds, than that currently favoured.

CHAPTER VI

KOFFIEFONTEIN MEGACRYSTS

1. INTRODUCTION

Relatively few megacrysts were found at the Koffiefontein pipe and these include 15 garnets, 3 orthopyroxenes and 2 clinopyroxenes. Their sizes range from 1,5 to 2,5 cms., and they are usually partially covered with a greyish alteration coating. The crystals are very fresh, although irregular fractures across the garnet megacrysts are often observed, and these are filled with alteration products (kelyphyte). Both rims and cores of the megacrysts were analysed to test for compositional zoning, but they were all homogeneous.

The megacrysts were cracked to look for inclusions. The majority were inclusion free, but one clinopyroxene was found to contain one roundish inclusion of serpentine (Table VI-3) and one orthopyroxene contained a phlogopite (Table VI-2).

2. GARNET MEGACRYSTS

These megacrysts are red to reddish-brown in colour, and eleven of them have been analysed (Table VI-1). They are high-TiO₂ garnets (0.78 - 1.1 wt.%), with a remarkably constant calcium content (~10,3 - 11,1 mole % grossular), and Mg/Mg+Fe ratio between ~75 and 81 (Fig. VI-1); they all have traces of Na₂O (0.11 - 0.23 wt.%, av. 0.14).

The compositions and inter-element relationships of the Koffiefontein garnet megacrysts illustrated in Fig. V-21 are similar to those

found for some garnet megacrysts from Northern Lesotho (Nixon and Boyd, 1973), Orapa (Shee, 1978) and Monastery (Jakob, 1977). They show a slight decrease in Cr_2O_3 with increasing TiO_2 and FeO contents, and TiO_2 increases with decreasing Mg/Mg+Fe ratio. The garnets from Koffiefontein display lower average TiO_2 and Cr_2O_3 , and a more limited compositional variation than those from Monastery, and are restricted to the more Mg-rich end of the trend found at that locality. No garnet-ilmenite associations, as present at Monastery (garnets with Mg/Mg+Fe : 68.4 - 73.6), have been found.

3. ORTHOPYROXENE MEGACRYSTS

Three orthopyroxene megacrysts, with a grey-green glassy appearance have been found (Table VI-2). They are enstatites ($\text{En}_{88.7} - \text{En}_{91.9}$) with low calcium (0.48 - 0.78 wt.%) and Al_2O_3 (0.49 - 0.71 wt.%). They have a greater Mg/Mg+Fe ratio than the glassy orthopyroxene megacrysts found at Monastery (Jakob, 1977), and are more similar in this respect, to the observed orthopyroxene compositions that have exsolved clinopyroxene at that locality. They all have TiO_2 (0.1 - 0.16 wt.%) and Na_2O (0.19 - 0.23 wt.%).

4. CLINOPYROXENE MEGACRYSTS

Only two deep-green subcalcic clinopyroxene (Ca-Ca+Mg : 30 and 36.3) megacrysts were found at Koffiefontein. They are similar to the most Mg-rich Monastery megacrysts (Jakob, op. cit.), but PC69 (Table VI-3) has a lower Al_2O_3 (1.63 wt.%) content (the lowest value observed at Monastery is 2.3 wt.%). TiO_2 varies between 0.22 and 0.28 wt.%.

5. DISCUSSION

The megacrysts found in kimberlites have been interpreted as mantle cumulates formed from a magma (Nixon and Boyd, 1973), rich in TiO_2 , K_2O , Na_2O , H_2O and CO_2 , derived by partial melting of metasomatised peridotite (Gurney et al., 1977). As cooling takes place, phenocrysts (olivine, orthopyroxene, clinopyroxene, garnet, ilmenite, phlogopite) crystallise from this magma enriching it in volatiles and incompatibles (protokimberlite ?), and are later brought up to the surface during the kimberlite emplacement.

At Koffiefontein, no megacryst of olivine or ilmenite, nor any silicate-ilmenite associations have been found, and even pyroxenes are very scarce.

The garnet megacrysts display the typical differentiation trend of increasing TiO_2 with increase in FeO, found at other localities (Nixon and Boyd, op. cit.; Jakob, op. cit.) and have a constant calcium content. Following O'Hara and Mercy (1963) and MacGregor (1967) this is taken as indicative of their concurrent crystallisation with ortho- and clinopyroxene. A reconstruction of the crystallisation sequence (Jakob, 1977) for the Koffiefontein megacrysts is not possible due to the few samples available, but if megacrysts represent coexisting equilibrium assemblages (Nixon and Boyd, 1973; Gurney et al., 1977) the few pyroxenes can be used to evaluate temperatures of crystallisation.

Estimated temperatures for the orthopyroxenes range from $\sim 1055^\circ$ to 1150°C and for clinopyroxenes from $\sim 1285^\circ\text{C}$ to 1390°C . These values have been derived from the empirical geothermometers of Davis

and Boyd (1966) and Boyd and Nixon (1973) respectively. Bearing in mind the limitations of the Ca/Ca+Mg ratios of ortho- and clinopyroxene as geothermometers, due to their compositional and pressure dependency (Chapter IV, Section 2.4), the above temperatures should be regarded as approximations. The above temperature ranges are compared below, with those observed at Monastery:

	Monastery ⁺ (°C)	Koffiefontein (°C)
orthopyroxene	1190 - 1410	1055 - 1150 ^o
orthop. - ilmenite	1190 1300	-
clinopyroxene	1220 - 1385	1285 - 1390
clinopy. - ilmenite	1130 - 1270	-
garnet - clinop.	1175 - 1427	-

+ (Jakob, 1977)

Although all the megacrysts from Koffiefontein have compositions equivalent to the most Mg-rich members of the Monastery series, the overall crystallisation temperature as indicated by the few pyroxene megacrysts is greater at Koffiefontein (maximum range : 345^oC) than at Monastery (maximum range : 297^oC). Also, with the exception of Fe-rich olivines the crystallisation of megacrysts at Monastery ceased at ~1150^oC, but the temperatures indicated by the Koffiefontein orthopyroxene megacrysts are below this value.

If the Koffiefontein megacrysts had a cumulate origin similar to that of those from the Monastery kimberlite, they must have crystallised from a melt undergoing a slower rate of cooling, and poorer in TiO₂, as suggested by the low abundance of ilmenite in the concentrate and rarity of such megacrysts.

CHAPTER VII

KOFFIEFONTEIN HEAVY MINERAL CONCENTRATE

1. INTRODUCTION

The heavy mineral concentrate that is obtained during the processing of kimberlites for the extraction of diamonds represents fragments of megacrysts, crystals associated with the evolution of kimberlites, and disaggregated crustal and mantle nodules broken during the explosion phase of kimberlite emplacement.

A study of the chemistry of the concentrate minerals can therefore yield important information on the type of mantle xenoliths expected to be found in a given pipe; this could be useful at Koffiefontein because mantle nodules are rare or difficult to find at this locality.

In addition, the presence of minerals with characteristics similar to those usually associated with diamonds can also be used as a diamond prospecting aid, and it is useful to know their distribution in known economic deposits.

To obtain a statistically representative estimate of the abundance of individual minerals, a random sample of the Koffiefontein concentrate was arbitrarily size-graded using a set of sieves (cf. Pettijohn, 1975) at 0.5 phi. intervals, and each fraction was then passed through a bulk sample splitter (Carver, 1971) to separate a suitable quantity for microscopic observation. A total of 2808 grains were point-counted and classified as in Table VII-1; without taking into

account "accessory minerals" (these include sulphides, quartz, magnetite, phlogopite flakes and a variety of unidentified fragments) which are of no particular interest to this study, garnet was the most abundant mineral found, followed by orthopyroxene, opaque minerals (chromite and ilmenite) and clinopyroxene respectively. No attempt was made to distinguish between the relative abundance of chromite and ilmenite, but the former proved to be more abundant in the random sample of opaques analysed, in the proportion of 28 to 6.

An abundant mineral with a green, glassy appearance and "conchoidal" fracture which was visually identified as olivine, was however found to be orthopyroxene during a preliminary chemical survey. Since olivine is usually more abundant than the latter mineral, an intensive search for it was undertaken; further selected mineral grains were analysed semi-quantitatively in a Siemens energy dispersive spectrometer by comparing 200 seconds total count ratios for Si and Ca, and Si and Al, with those of a kimberlitic olivine and two orthopyroxenes from Koffiefontein, and once again no olivine was found.

A number of different minerals from the Koffiefontein kimberlite pipe were selected for chemical analysis, including clinopyroxene, chromite and ilmenite, orthopyroxene and garnet. The grains of garnet, clino- and orthopyroxene were selected for analysis on the basis of the following criteria: colour and lack of alteration, and in the case of the latter, fracture and absence or presence of cleavage.

Lawless (1974) carried out a study of the garnets and orthopyroxenes of the Koffiefontein pipe, and his data has been included with the present results to provide as complete a study of the

concentrate minerals as possible.

2. ANALYTICAL RESULTS

2.1 Garnets

The xenocrysts of garnet were sorted on the basis of their colour into the following categories: purple, orange, red and reddish-brown. The separation was carried out in bright daylight and with the aid of a sorting lamp. Sobolev (1977) has reported that low calcium, high chromium garnets similar to inclusions in diamond change colour from purple to grey/green under these conditions. Lawless (1974) reported the presence of garnet showing this "alexandritic effect" at Koffiefontein but none were found by the author.

Although colour sorting does not provide a clear cut separation of the garnet grains into chemical groups and a gradation between them is observed, this criterion still reflects some broad chemical differences. Colour sorting is very subjective, particularly for garnets of differing dimensions, and it was found that the grains described as red and orange by Lawless (op. cit.) have chemical characteristics similar to those described as orange and red, respectively, by the writer, and it should be noted that these garnets therefore will be presented below according to the latter classification.

2.1.1 Purple garnets:

Three of these, KF44, 45 and 47 (Table IV-2), have a very high FeO (>32 wt.%) and probably are of crustal origin and will therefore not be considered further.

(a) High-chromium, low-calcium garnets:

Three garnets (PJL1,2 and 3; see Lawless, 1974) differ from the others by their low CaO (≤ 3.5 wt.%) and highest Mg/Mg+Fe ratio (87.2 - 89.8). Cr_2O_3 varies between 4.3 and 7.3 wt.%. These garnets are compositionally similar to group (a) peridotitic garnet inclusions in Koffiefontein diamonds and plot within the fields typically found for garnet inclusions in diamonds at other localities (see Fig. VII-1 and refer to fields A and B of Fig. V-1).

(b) High-chromium garnets:

A further set of purple garnets (Table VII-2) have CaO contents greater than 4 wt.%, ranging up to ~ 7 wt.%, and Cr_2O_3 values between 1.8 and 8.3 wt.% (with three exceptions, with < 1.1 wt.% Cr_2O_3). Both Na_2O (N.D. - 0.10 wt.%) and TiO_2 (< 0.2 wt.%, with two values at 0.36 - Fig. VII-2) are low, and the Mg/Mg+Fe ratio is lower than in (a) above, varying between 86.9 - 77.2. There is an overall decrease in FeO with increasing Cr_2O_3 (Fig. VII-3). The grossular component is higher (~ 10 -15 mole %, one value at 18.7) than that reported by Reid and Hanor (1970) for pyropes from Kimberley concentrates (4 - 11%).

Since the garnets from Type II pyroxenites (Chapter IV) fall within the compositional range of these purple garnets, it is possible that some of these xenocrysts might be relict grains of the Koffiefontein orthopyroxenites (Fig. VII-1 and 3) but the majority of the purple garnets fall outside the compositional range observed for garnets from any of the Koffiefontein xenoliths. These purple garnets also show chemical similarities to group (b) peridotitic garnet

inclusions from Koffiefontein diamonds.

2.1.2 Orange garnets:

With a few exceptions, the orange garnets (Table VII-3) can be chemically distinguished from the others, in terms of the variation of Cr_2O_3 and $\text{Mg}/\text{Mg}+\text{Fe}$ ratio with respect to TiO_2 (Figs. VII-4 and VII-2 respectively). They have lower $\text{Mg}/\text{Mg}+\text{Fe}$ ratios (71 - 82, with one value at 60.2) and Cr_2O_3 (<1.2 wt.%) contents than the purple garnets, and lower TiO_2 (<0.42 wt.%), Cr_2O_3 , and grossular components (Figs. VII-2 to 5) than the red and red-brown garnets. In the ternary Ca-Mg-Fe diagram (Fig. VII-5) the grossular component (7.7 - 13.8%, av. ~10%, with two values at 19 and 27%) of the orange garnets does not vary with changing $\text{Mg}/\text{Mg}+\text{Fe}$ ratio, plotting within the field defined by the Kimberley pyropes (Reid and Hanor, 1970) and along the peridotite-pyroxenite trend (Gurney, 1975). They also plot at the low Cr end of the peridotite-pyroxenite trend (Gurney, op. cit.) in a Mg-Ca-Cr ternary plot.

The orange garnets do not resemble any of the garnets from the xenoliths, found and studied so far, at the Koffiefontein pipe.

O'Hara and Mercy (1963), MacGregor (1967), Boyd (1970) and Sobolev (1977) report that the amount of grossular component in garnets from natural four-phase garnet peridotites is almost constant, over a wide range of P, T and FeO content. This almost constancy of grossular component is observed for both the purple and orange garnets from the Koffiefontein concentrate, with slightly different values for the two groups. Orange garnets from other localities

often belong to the eclogitic suite, but it was seen above that at this locality they follow peridotite-pyroxenite garnet trends.

2.1.3 Red and reddish-brown garnets:

These grains (Table IV-5) are characterised by high TiO_2 (0.6 - 1.2 wt.%), Cr_2O_3 values between, 0.7 and 2.0 wt.%, and constant CaO (4.1 - 4.8 wt.%) with varying Mg/Mg+Fe ratio (Fig. VII-5). With the exception of a few grains, which in terms of their low TiO_2 and/or high Cr_2O_3 contents (e.g. 2.9 - 4.5 wt.% Cr_2O_3 , Table VII-5) are similar to orange and purple garnets, the red and reddish-brown garnets plot within or near the fields defined by the garnet megacrysts (Figs. VII-2, 3, 4 and 5). The Na_2O concentration (0.05 - 0.20 wt.%) and the trends of increasing TiO_2 with decreasing Mg/Mg+Fe ratio and decreasing Cr_2O_3 with increasing FeO displayed by the red and reddish-brown garnets are also similar to those of the megacrysts of the Koffiefontein pipe. It is likely that these garnets are fragments of the megacrysts.

2.2 Orthopyroxenes

The orthopyroxenes were sorted into green and brown categories, some showing cleavage and an elongated shape whereas others have a glassy, clear appearance and are roundish sometimes with fracture.

Lawless (1974) presented data for brown orthopyroxenes from the Koffiefontein concentrate and his results are broadly similar to those

found here for the brown orthopyroxenes (Fig. VII-7 to 10).

A total of 37 grains were analysed (Table VII-6A to E). They lie in the range $En_{95.1} - En_{85.2}$ which is wide for kimberlitic orthopyroxenes (Fig. VII-7), and they also show a wide variation in other components: CaO (0.2 - 1.4 wt.%), Al_2O_3 (0.3 - 3.4 wt.%) and Cr_2O_3 (N.D. - 0.93 wt.%). TiO_2 is low and Na_2O ranges from 0.02 - 0.30 wt.%. There is a broad increase in Cr_2O_3 and decrease in TiO_2 and CaO with increasing MgO (Figs. VII-8, 9 and 10).

Although the chemistry of the green and the brown orthopyroxenes overlap to some extent, colour variation is a relatively good reflection of their compositional differences (Figs. VII-7 to 10). No relation to presence or absence of cleavage is observed.

Based on colour, they are well separated by their Mg/Mg+Fe ratios (green: 91.9 - 95.1; brown: 85.2 - 92, with three values at 93 - 94). Also, the majority of the green orthopyroxenes have lower average contents of TiO_2 , Al_2O_3 , CaO and Na_2O and greater Cr_2O_3 , than the brown ones.

Five of the green orthopyroxenes (KF 5, 7, 23, 24 and 25) differ from the others by their high Al_2O_3 contents (~2 - 3.4 wt.%). Lawless (1974) also reports a similarly high-Al orthopyroxene (2.49 wt.% Al_2O_3 , PJL opx 2). If stoichiometry is assumed (following Lawless, 1974) then there is significantly more Al than necessary to fill the tetrahedral site in these aluminous pyroxenes; in contrast, the lower Al pyroxenes have in most cases insufficient Al, when combined with Si, to fill the tetrahedral site. Alternatively, if end members are calculated according to the method of Papike et al. (1974) by equally

dividing Al between the tetrahedral and 6-fold co-ordinated site, after allocation to the Na-Ti and jadeite molecules, then there is still significantly more Al^{VI} in the high-Al pyroxenes.

As mentioned above green orthopyroxenes have lower average contents of Al₂O₃ than the brown ones, but this is reversed if the five high-Al pyroxenes are taken into account. The five high-Al pyroxenes have similar compositions to orthopyroxenes from some xenoliths found at the Koffiefontein pipe (e.g. Type IV pyroxenites: PC 26, 43, 53, 60, 66, 68 and peridotite PC64) with the exception of their FeO and MgO contents. In general the aluminous pyroxenes from the concentrate are more Mg-rich (\sim En₉₃) than the orthopyroxenes from the xenoliths (En_{84.2} - En_{93.9}). Fragmentation of such xenoliths may constitute a potential source for the high-Al pyroxenes.

The green orthopyroxenes with the highest Mg/Mg+Fe ratios have compositional ranges similar to orthopyroxene inclusions in Koffiefontein diamonds, in terms of their CaO, Cr₂O₃ contents and Ca-Mg-Fe variation (see dotted fields in Figs. VII-7, 8 and 10), but TiO₂ is lower (N.D.) in the inclusions. These green orthopyroxenes also bear some similarities to those in Type I pyroxenites.

2.3 Clinopyroxenes

Clinopyroxenes are rare, with colour varying from tones of lighter to deeper bright-green, and not readily separated into colour groupings; cleavage is not observed. Twenty-two grains were analysed and the results are shown in Table VII-7. They are diopsides, with Ca/Ca+Mg ratios varying between 43 and 49 and Mg/Mg+Fe ratios between 92 and 96.

This is illustrated in a ternary Ca-Mg-Fe diagram (refer to Fig. V-1) where the compositional variation of clinopyroxene inclusions in diamonds and of those found in Type I pyroxenites from Koffiefontein are also shown: the clinopyroxenes from the concentrate show a slight overlap with the diamond inclusion clinopyroxenes but with few exceptions they are clearly distinguished in terms of the variation of TiO_2 (wt.%) with respect to Mg/Mg+Fe ratio (Fig. VII-11). The concentrate clinopyroxenes plot outside the field defined by those in Type I pyroxenites, and they also differ from clinopyroxenes found in other Koffiefontein xenoliths. These clinopyroxenes have Cr_2O_3 contents (0.6 - 3.6 wt.%) comparable to some from the concentrate of the Newlands kimberlite pipe, as reported by Lawless (1974). In other respects they have similar compositions to clinopyroxenes from granular lherzolites from Lesotho (Nixon and Boyd, 1973), although such rocks are very rare, if present at all at Koffiefontein.

2.4 Chromites

Sobolev et al. (1975) and Sobolev (1977) have emphasised the importance of the chemical study of chromite grains from the kimberlite concentrate. The average Cr_2O_3 content of chrome-spinels from diamond-bearing pipes is higher (~45 - 52 wt.%) than that observed in chrome-spinels in non-diamondiferous types (~28 wt.%) (Sobolev, 1977). Sobolev (1977) also found that in the U.S.S.R. diamondiferous pipes, 12 to 20% of the chromite grains from the concentrate have compositions similar to those associated with diamonds, either as inclusions or as intergrowths. Chromites, together with pyrope garnet, which have crystallised

simultaneously with diamond have very distinctive chemical characteristics and the finding of grains with similar compositions, may be used as a prospecting aid. With few exceptions (see Meyer and Boyd, 1972), these chromites are characterised by high Cr_2O_3 (>61 wt.%), low TiO_2 (<1 wt.%), $\text{Mg}/\text{Mg}+\text{Fe}^{2+}$ between ~44 and 84, and usually well differentiated from other chromites in terms of the relationship between Cr_2O_3 and Al_2O_3 (Sobolev et al., 1975; Sobolev, 1977; see Fig. VII-13B).

Twenty-eight chromite grains from the Koffiefontein concentrate have been analysed (Table VII-8) and are plotted in Figs. VII-12 and 13, where the compositional variations of other chromites from other localities and environments are also shown for comparison. The Koffiefontein chromites are Cr_2O_3 -rich (52.6 - 67.1 wt.%) and $\text{Mg}/\text{Mg}+\text{Fe}^{2+}$ varies between 49 and 68. This and the $\text{Fe}^{3+}/\text{Fe}^{3+}+\text{Cr}+\text{Al}$ ratios are almost identical to those shown by chromites from kimberlite xenoliths (Basu and MacGregor, 1975), but these have slightly lower $\text{Cr}/\text{Cr}+\text{Al}$ ratios than the Koffiefontein chromites. The relationship between the Al_2O_3 and Cr_2O_3 contents, as shown in Fig. VII-13B, indicates a wide compositional variation, similar to that found by Sobolev et al. (1975) for chromites from concentrates of Yakutian kimberlite pipes.

A few of the chromite grains from the Koffiefontein concentrate plot inside the compositional fields defined by chromites associated with diamonds (Fig. VII-13A and B). With one exception, these all have <1 wt.% TiO_2 . On average, these few chromites have lower $\text{Fe}^{3+}/\text{Fe}^{3+}+\text{Al}+\text{Cr}$ ratios than the others (Fig. VII-12), which may suggest that they formed under lower oxygen fugacities. These chromites may have

crystallised simultaneously with diamonds, although only one chromite diamond inclusion from Koffiefontein has been found so far, for comparison. Most of the other chromites presented here, may be derived from xenoliths, or be associated with the kimberlite.

Discussion:

It has been shown that in terms of chemical composition most mineral grains from the Koffiefontein kimberlite concentrate do not in general match the minerals found in mantle derived rocks at this locality. Exceptions are the few high- Al_2O_3 orthopyroxenes which may be derived from disaggregated Type IV pyroxenites, and a few high Cr_2O_3 garnets which have compositions similar to those occurring in Type II pyroxenites. However, the garnet concentrate grains are much bigger than those observed in these pyroxenites, which makes a genetic relationship unlikely.

The chemistry of the red and reddish-brown garnets suggests that they represent fragments of garnet megacrysts. The high Cr_2O_3 , low CaO garnets and some of the high Cr_2O_3 garnets resemble garnet inclusions in diamonds from Koffiefontein and other localities. Some of the concentrate chromites are also similar to diamond inclusions from elsewhere, although there are not enough analyses available to compare them to the Koffiefontein diamonds. However, this still indicates a common origin for both the concentrate minerals and diamond inclusions which probably crystallised from a kimberlitic liquid during a period of diamond growth.

Both the clinopyroxenes and orthopyroxenes from the concentrate

differ in their TiO_2 contents from those found as diamond inclusions, even though the two groups of orthopyroxenes are otherwise similar. Although they may represent fragments of xenoliths which have not been found so far at Koffiefontein, their inter-element relationship suggests rather a related origin for each suite of minerals.

A preferred interpretation for the origin of most of the concentrate pyroxenes and garnets is that they crystallised from a kimberlitic magma (Eggler and Wendlandt, 1977).

CHAPTER VIII

SUMMARY

1) Mantle derived xenoliths in the Koffiefontein kimberlite pipe are extremely rare, and in contrast to other kimberlite localities in southern Africa, they are predominantly pyroxenites (including garnet free and garnet bearing varieties). Peridotites are extremely rare.

In general, the pyroxenites at Koffiefontein show a clear metamorphic textural history, with widespread evidence of exsolution, polygonisation and deformation, indicating readjustment to new pressure and/or temperature conditions. On the basis of texture, mineralogy and chemistry these pyroxenites have been subdivided into 5 types. Types I and II are characterized by unmixed textural features, from originally aluminous clino- and orthopyroxene, respectively. In Type I pyroxenites, it was illustrated how the process of migration, coalescence and recrystallisation of exsolved phases, can lead to obliteration of earlier textures formed under previous conditions of equilibration. On a basis of texture alone, it is not possible to decide whether or not all the orthopyroxene and/or garnet are also present as primary phases. However, comparison of their bulk rock chemistry with experimental work, does not rule out the possibility that all the garnet and/or orthopyroxene may represent exsolution products only. Although individual minerals in Types I and II pyroxenites are chemically unzoned, detailed chemical studies revealed small-scale disequilibrium, and application of different goethermometers yielded conflicting results for individual samples.

Type IV pyroxenites vary from orthopyroxenites, through websterites to clinopyroxenites, *sensu stricto*, and garnet spinel are absent. They are characterised by varying degrees of polygonisation and

deformation of the individual minerals, and generally have accessory primary phlogopite or amphibole. The pyroxenes have high Al_2O_3 contents, and have not attained equilibrium as illustrated by the chemical inhomogeneity of individual crystals.

Type V comprises a single olivine-bearing pyroxenite, and once again garnet and chromite occur as both discrete grains and exsolved phases.

Peridotites at Koffiefontein are relatively rare, and with one exception they are chemically broadly similar to granular peridotites from Lesotho (Nixon and Boyd, 1973).

The small size and limited number of pyroxenite and peridotite allows only an uncertain speculation about their origin. In view of the chemical variation of individual samples and bulk rock composition in Type I and II pyroxenites, they have individually been interpreted as representing related crystallisation products from basaltic magma. Individual samples from Types III, IV and V pyroxenites did not allow any conclusive genetic interpretation.

In view of the predominantly peridotitic composition of the upper mantle, and the lack of peridotite at the Koffiefontein pipe, it is suggested that this kimberlite sampled over a small depth range, involving one or more, possibly unrelated pyroxenite bodies.

2) Mineral inclusions in diamonds from Koffiefontein are chemically similar to diamond inclusions elsewhere. They have peridotitic and eclogitic compositions and so do not reflect the xenolith population at this pipe and are only occasionally compositionally similar to equivalent phases in the heavy mineral concentrate.

The assumption that multiple inclusions in the same diamond always represent equilibrated assemblages, is questioned in view of the following:

- (i) The analyses of multiple inclusions of the same mineral in a single diamond at Koffiefontein has revealed in 3 instances that they have different compositions.
- (ii) One Koffiefontein diamond seems to have mineral inclusions of different paragenesis (i.e. peridotitic and eclogitic).
- (iii) Tie lines between eclogitic mineral included in the same diamond do not define a regular pattern and intersect each other.
- (iv) Calculation of temperatures and pressures of equilibration of mineral pairs often yielded inconsistent results.

It is suggested that the apparent disequilibrium between inclusions is in accord with crystallisation and entrapment from a magma that is continuously changing in composition, coupled with the slow growth rate of the host diamond.

Diamonds containing eclogitic and peridotitic inclusions may not be related and may be derived from different sources. However, the rare occurrence of diamonds with mixed assemblages (this work and Prinz et al., 1975) may eventually be taken as direct evidence for a common origin. The occurrence of periclase inclusions in four of the Koffiefontein diamonds, may indicate a deeper origin for kimberlite and diamonds, than that currently favoured.

3) The study of the megacryst suite at Koffiefontein was very limited because only 15 garnets, 3 orthopyroxenes and 2 clinopyroxenes were

found. However, the garnet megacrysts display typical differentiation trends as found for those at other localities (e.g. Northern Lesotho, Monastery; Nixon and Boyd, 1973; Jakob, 1977) where megacrysts are abundant.

Assuming that the megacrysts represent coexisting assemblages (Nixon and Boyd, *op. cit.*; Jakob, *op. cit.*) the few pyroxenes available indicate a greater crystallisation temperature range (1390 to 1055°C) than that observed at Monastery, although the compositions of the Koffiefontein megacrysts are more Mg-rich. It is concluded that if the megacrysts from the Koffiefontein kimberlite had a cumulate origin similar to those from Monastery, they must have crystallised from a magma undergoing a slower rate of cooling, and poorer in TiO_2 . This is suggested by the rarity of ilmenite megacrysts, ilmenite-silicate associations and low abundance of ilmenite grains in the concentrate.

4) In general, the chemical compositions of most of the grains from the heavy mineral concentrate from the Koffiefontein kimberlite do not match that found in minerals from mantle xenoliths or megacrysts at this locality. Exceptions are a few high- Al_2O_3 orthopyroxenes, which may be derived by disaggregation of Type IV pyroxenites, and the red and reddish-brown garnets which seem to represent fragmented megacrysts.

The high Cr_2O_3 , low CaO garnets, some of the high Cr_2O_3 garnets and some chromites from the concentrate have similar chemistry to mineral inclusions found in diamonds at Koffiefontein and elsewhere, suggesting a common origin. In view of the scarcity of mantle xenoliths at Koffiefontein it is unlikely that the concentrate derived by

disaggregation of such xenoliths. A preferred interpretation is that the pyroxenes and garnets crystallised from a kimberlitic magma or magmas (Eggler and Wendlandt (1977) under varying physical and chemical conditions.

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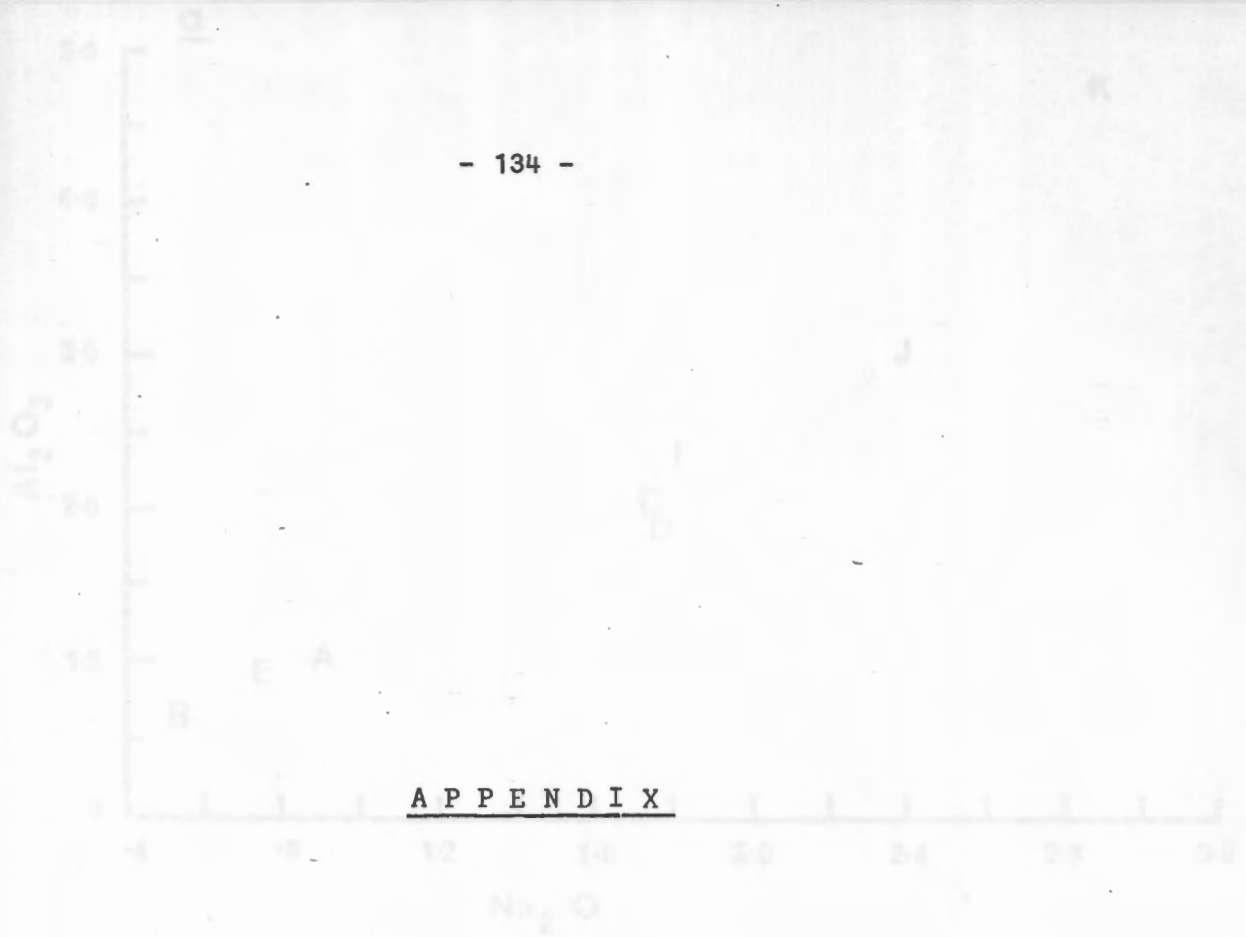


Fig. IV-1. Variation of Na_2O (wt%) with respect to (a) Al_2O_3 (wt%) and (b) CaO (wt%) and MgO (wt%) (encircled) contents for all amphiboles from Type 1. Symbols: A-FC22, B-FC23, C-FC33, D-FC14, E-FC31, F-FC31, G-FC31, H-FC34.

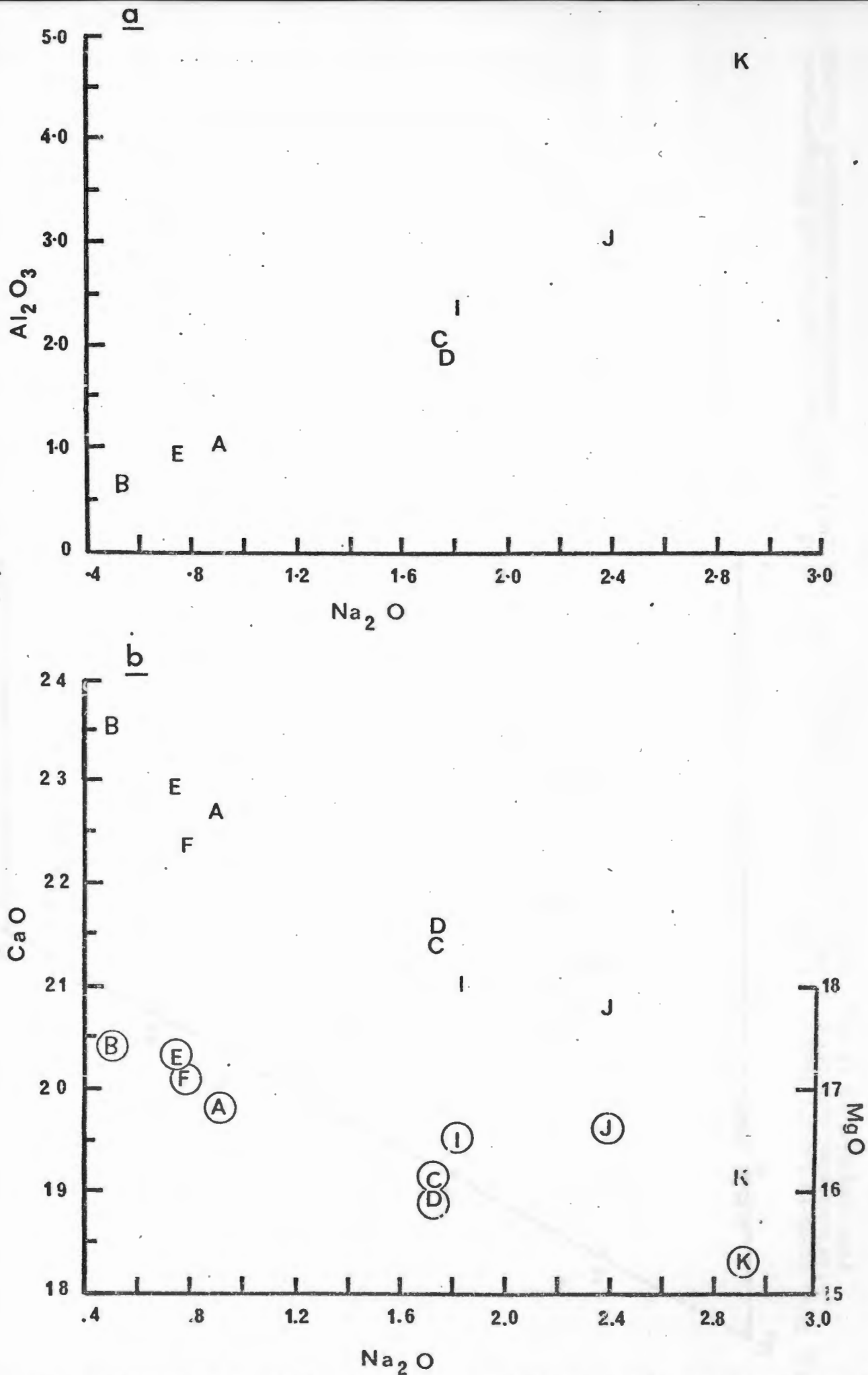


Fig. IV-1. Variation of Na₂O (wt%) with respect to (a) Al₂O₃ (wt%) and (b) CaO (wt%) and MgO (wt%) (encircled) contents for clinopyroxenes from Type I pyroxenites. Symbols: A-PC22; B-PC25; C-PC33; D-PC54; E-PC55; F-PC21; I-PC35; J-PC58; K-PC34.

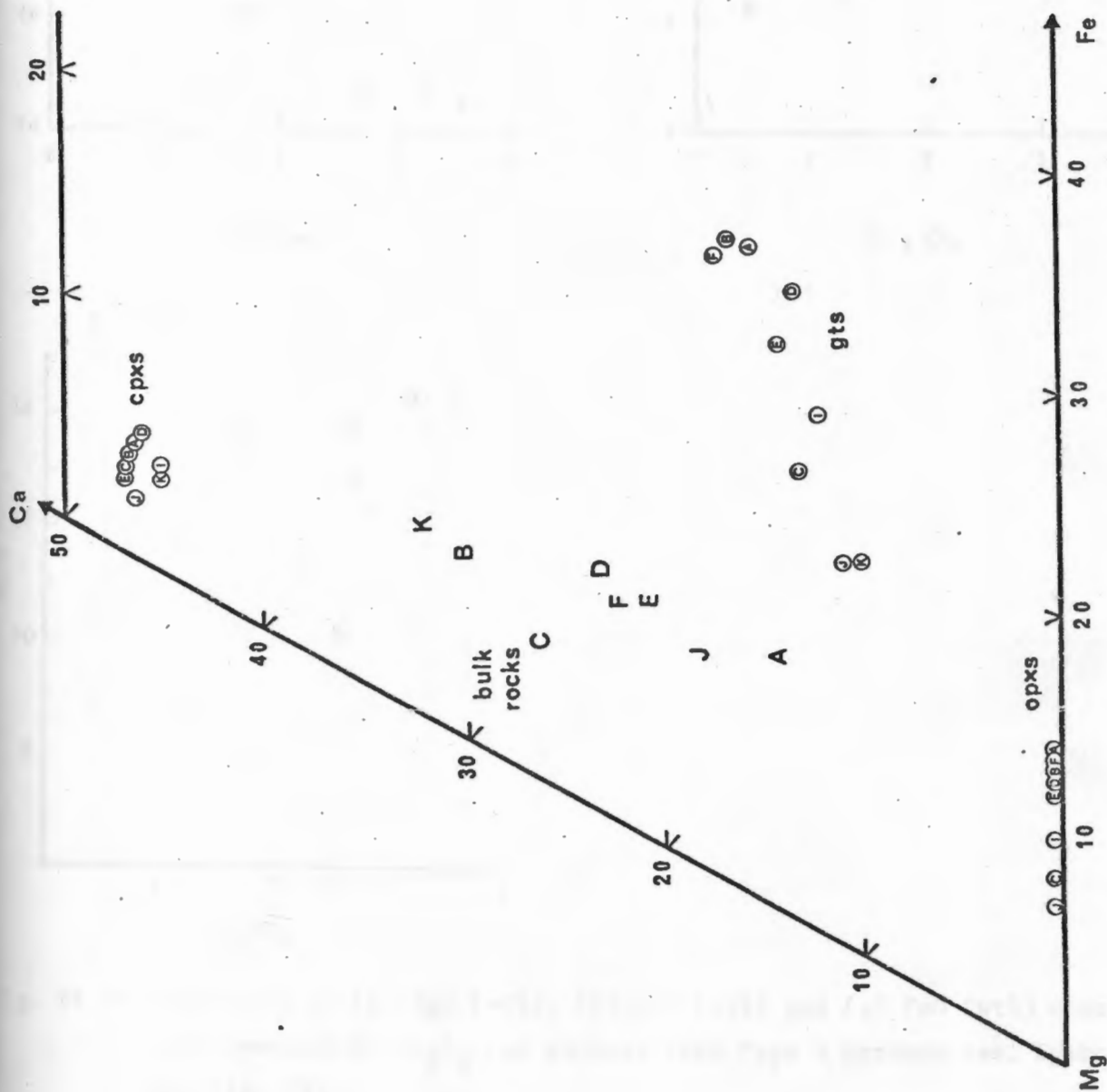


Fig. IV-2. Ca-Mg-Fe ternary diagram illustrating the compositional variation of clinopyroxenes, garnets and orthopyroxenes (in circled symbols) from Type I pyroxenites. Symbols as for Fig. IV-1. The compositional variation of the bulk rock compositions of these xenoliths are also illustrated.

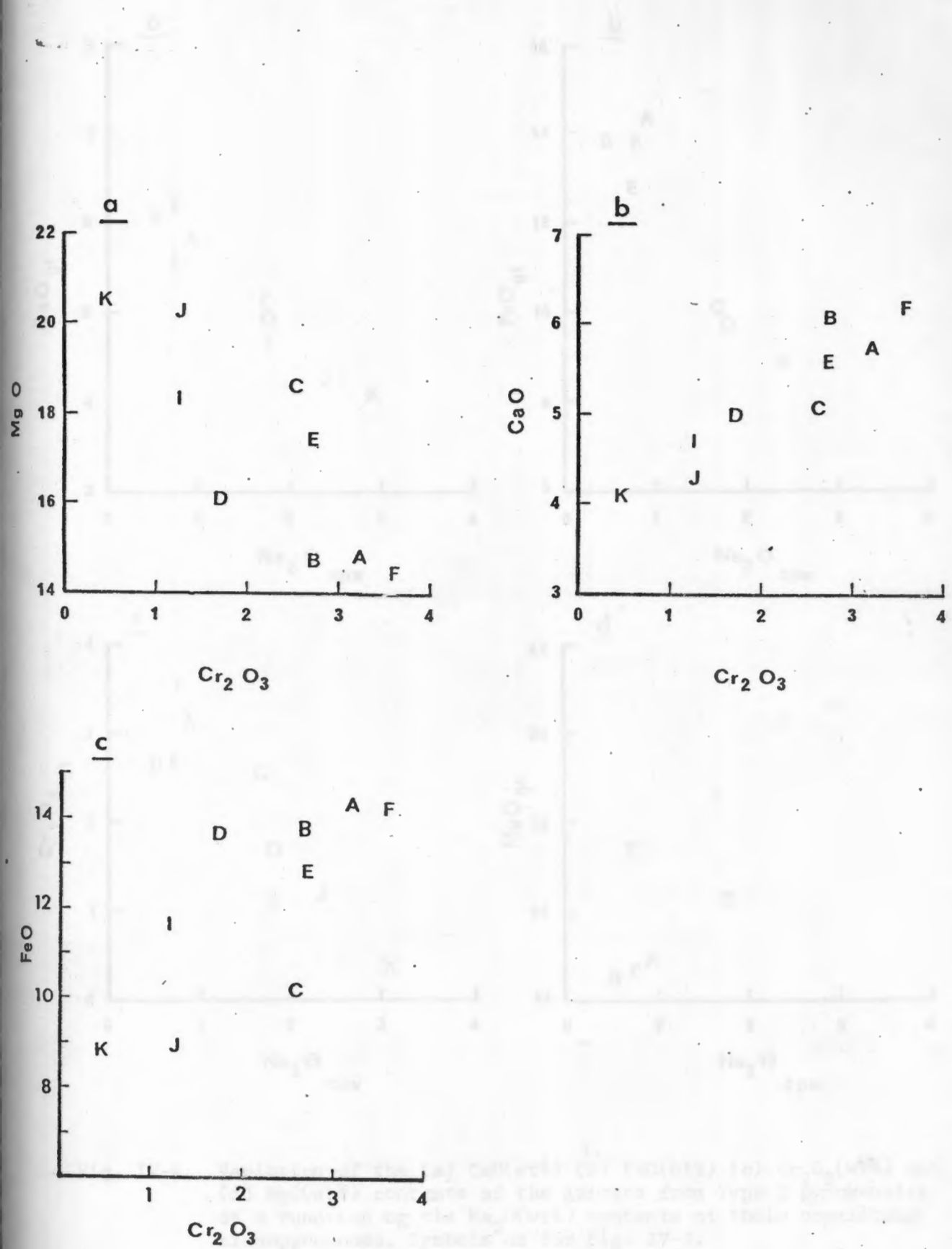


Fig. IV -3. Variation of (a) MgO (wt%), (b) CaO (wt%) and (c) FeO (wt%) contents with respect to Cr_2O_3 for garnets from Type I pyroxenites. Symbols as for Fig. IV-1.

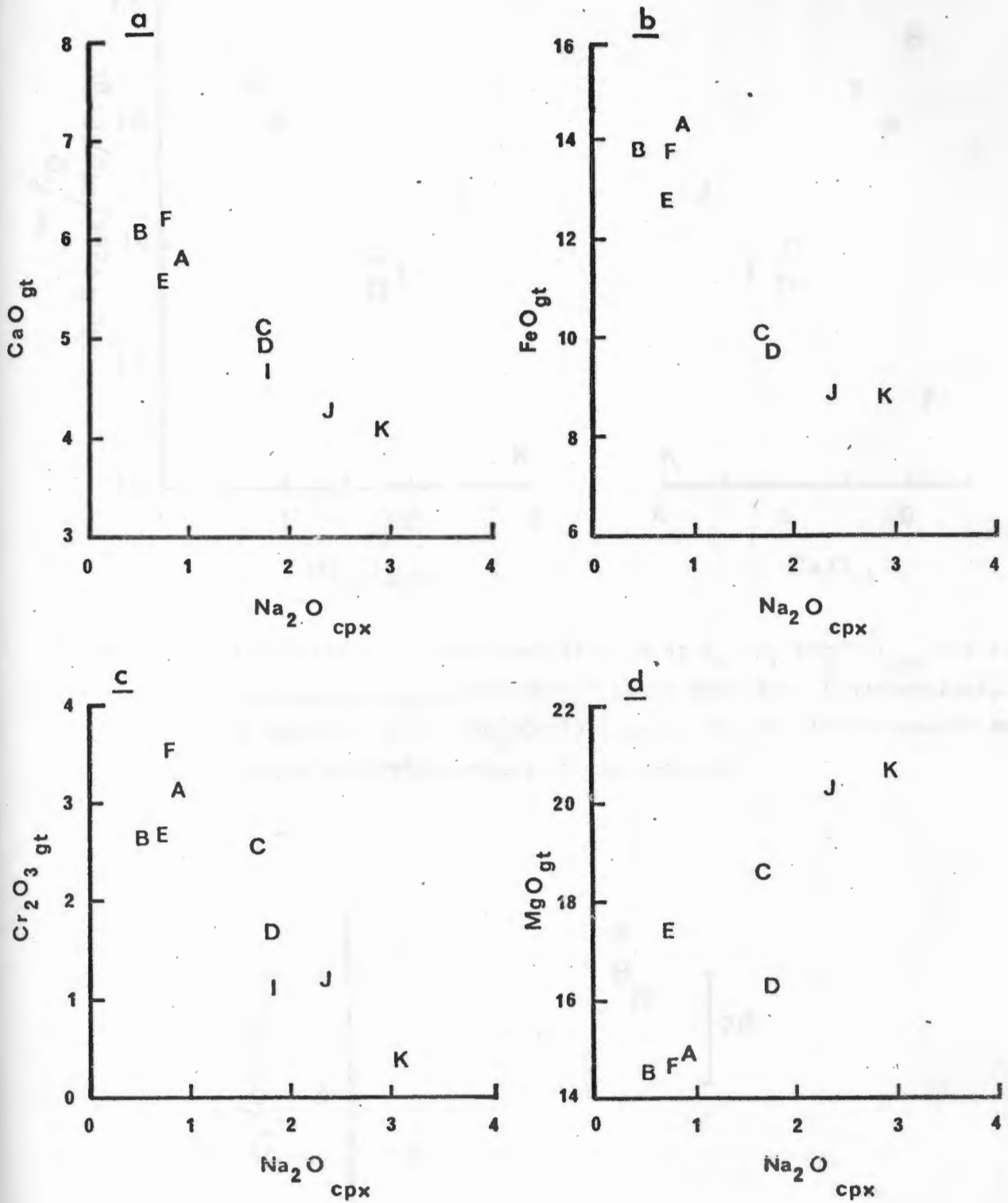


Fig. IV-4. Variation of the (a) CaO(wt%) (b) FeO(wt%) (c) Cr₂O₃(wt%) and (d) MgO(wt%) contents of the garnets from Type I pyroxenites as a function of the Na₂O(wt%) contents of their coexisting clinopyroxenes. Symbols as for Fig. IV-1.

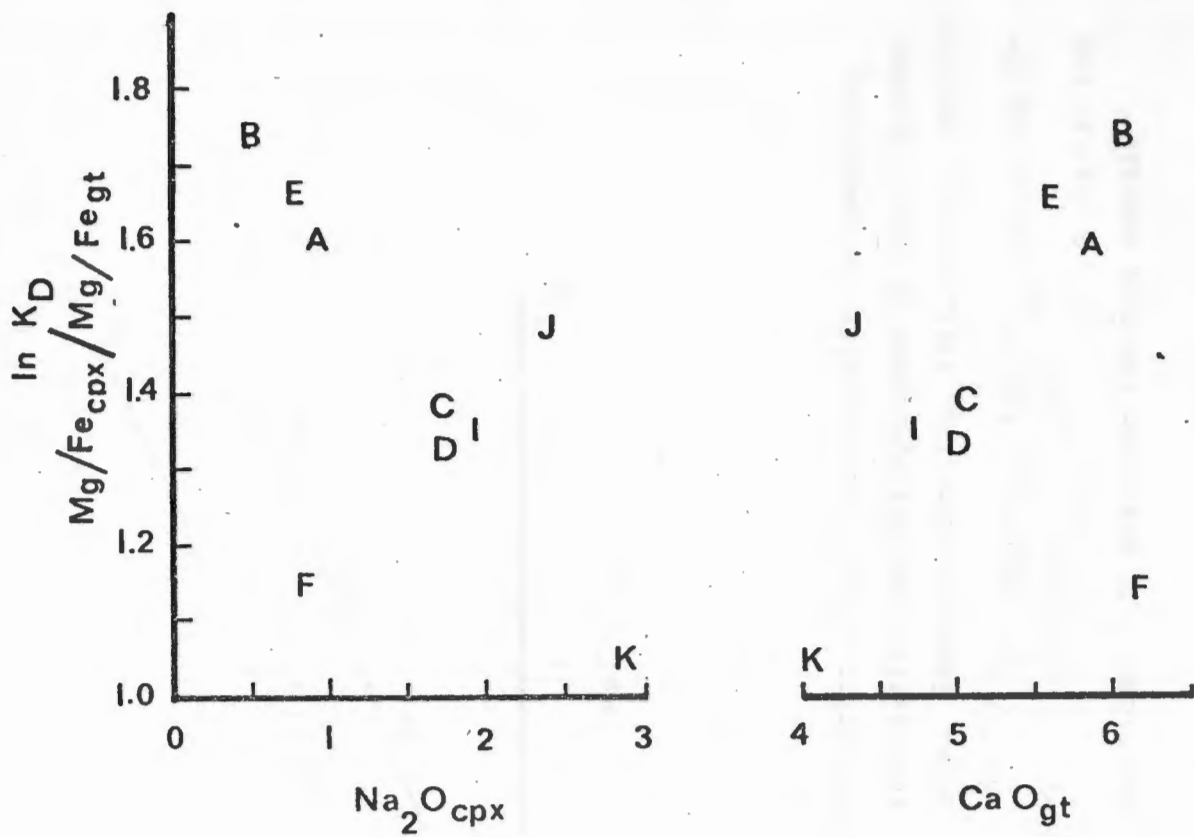


Fig. IV-6. Illustration of the variation of $\ln K_D$ ($K_D = (Mg/Fe)_{cpx} / (Mg/Fe)_{gt}$) between clinopyroxene-garnet pairs from Type I pyroxenites, as a function of the Na_2O (wt%) content of the clinopyroxenes and of the CaO (wt%) content of the garnets.

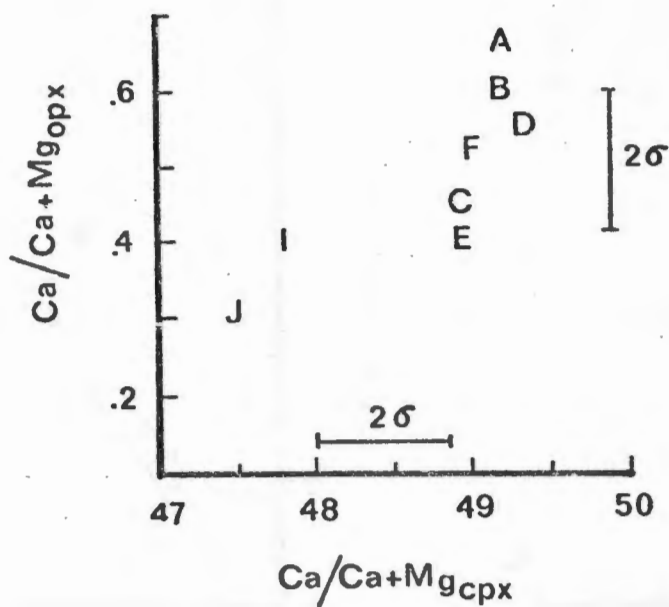


Fig. IV-5. Illustration of the variation of the $Ca/Ca+Mg$ ratios of coexisting ortho and clinopyroxenes from Type I pyroxenites. Symbols as for Fig. IV-1.

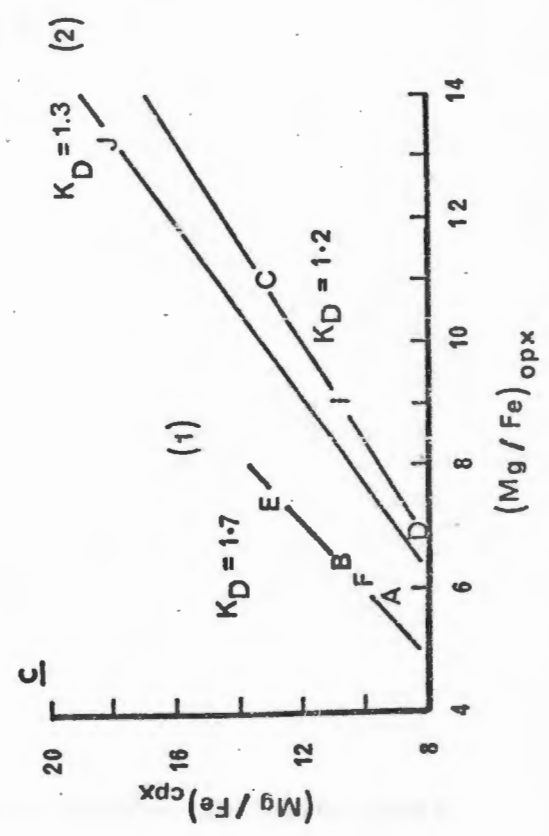
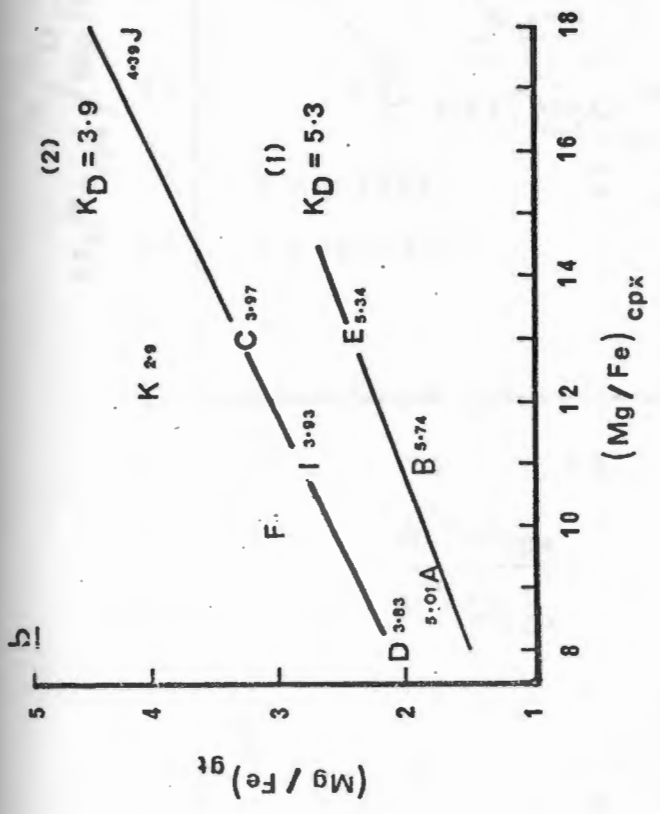
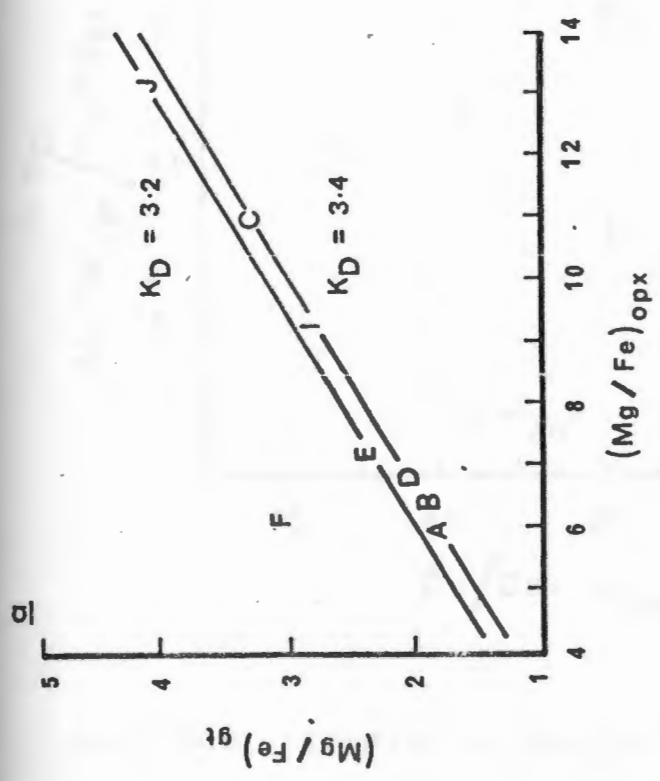


Fig. IV-7. Variation of Mg/Fe atomic ratio for coexisting garnet, clinopyroxene and orthopyroxene in Type I pyroxenites. Symbols as for Fig. IV-1. In Fig. IV-7 (a) and (b) $K_D = (Mg/Fe)_{px} / (Mg/Fe)_{gt}$ and in Fig. IV-7 (c) $K_D = (Mg/Fe)_{cpx} / (Mg/Fe)_{opx}$. In Fig. (b) the individual K_D 's are given for each sample.

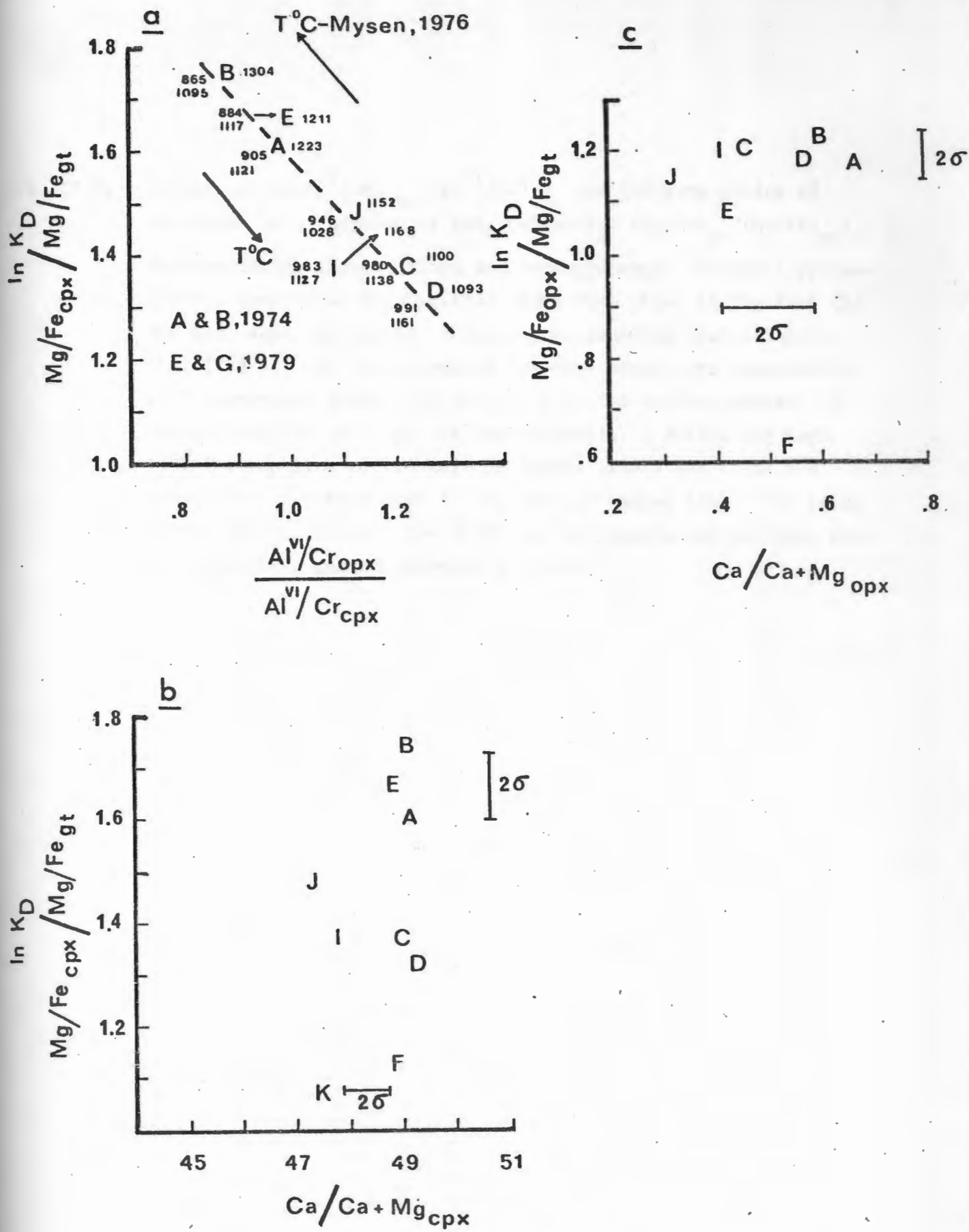


Fig. IV- 8. (caption to this Fig. is given in the following page).

Fig. IV-8. Variation in $(Al^{VI}/Cr)_{opx} / (Al^{VI}/Cr)_{cpx}$ and Ca/Ca+Mg ratios of pyroxenes as a function of $\ln K_D$ (where $K_D = (Mg/Fe)_{px} / (Mg/Fe)_{gt}$) for coexisting garnet, clino and orthopyroxenes in Type I pyroxenites. Symbols as for Fig. IV-1. 2σ errors shown in Fig. IV-8 (b) and (c) were calculated according to counting statistics. In Fig. IV-8 (a) the values quoted for each sample are temperature ($^{\circ}C$) estimates determined according to the geothermometers of Mysen (1976) (to the right of dashed line), Akella and Boyd (1974) (top line to the left of dashed line) and Ellis and Green (1979) (bottom line to the left of dashed line). The large arrows $\rightarrow T^{\circ}C$ indicate the direction of temperature increase when the respective geothermometers are used.

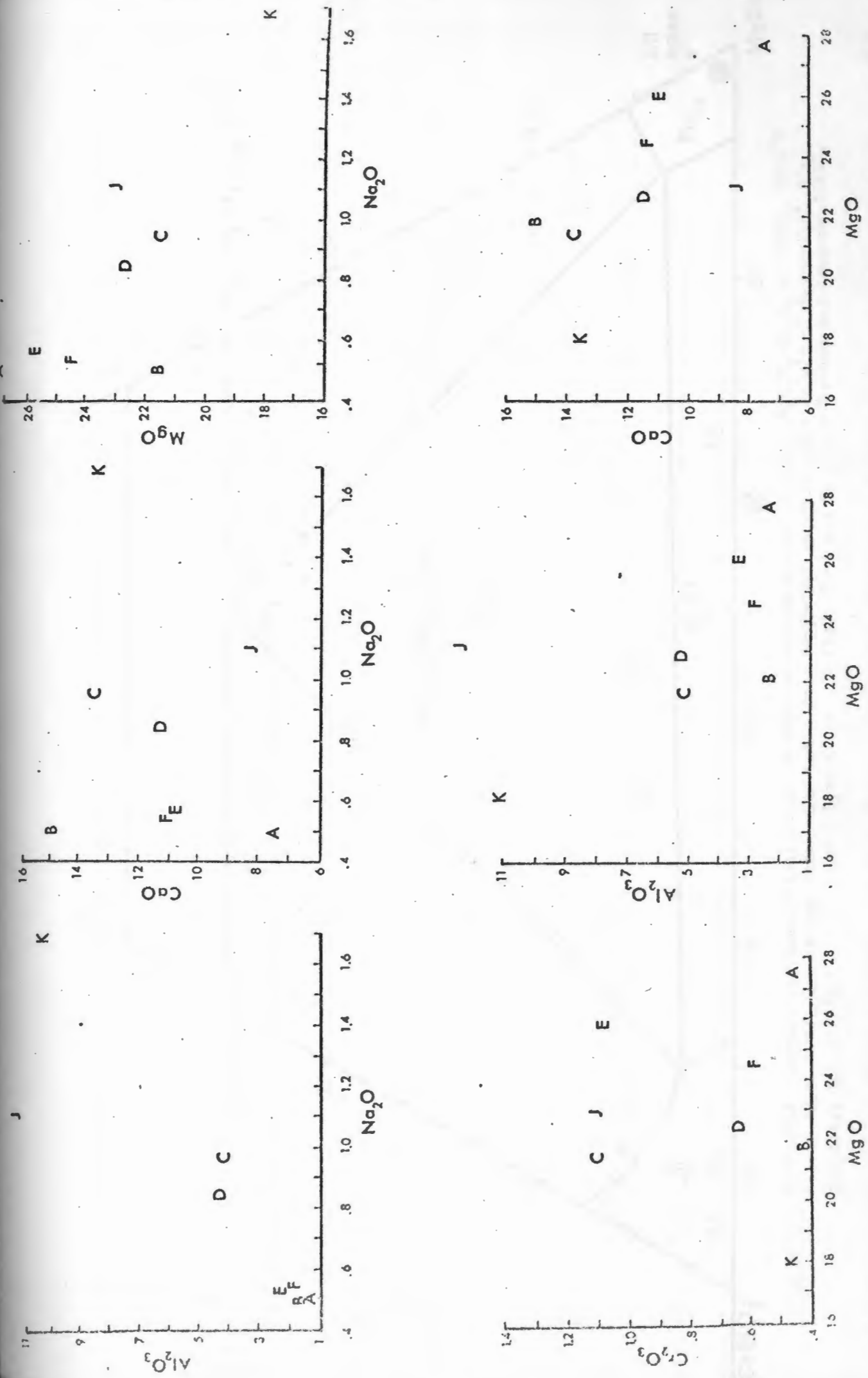


Fig. IV.-9. Illustration of the variation of Al_2O_3 (wt%), CaO (wt%) and MgO (wt%) as a function of Na_2O (wt%) and of the variation of Cr_2O_3 , Al_2O_3 and CaO (wt%) as a function of MgO (wt%) for Type I pyroxenites (bulk rocks)

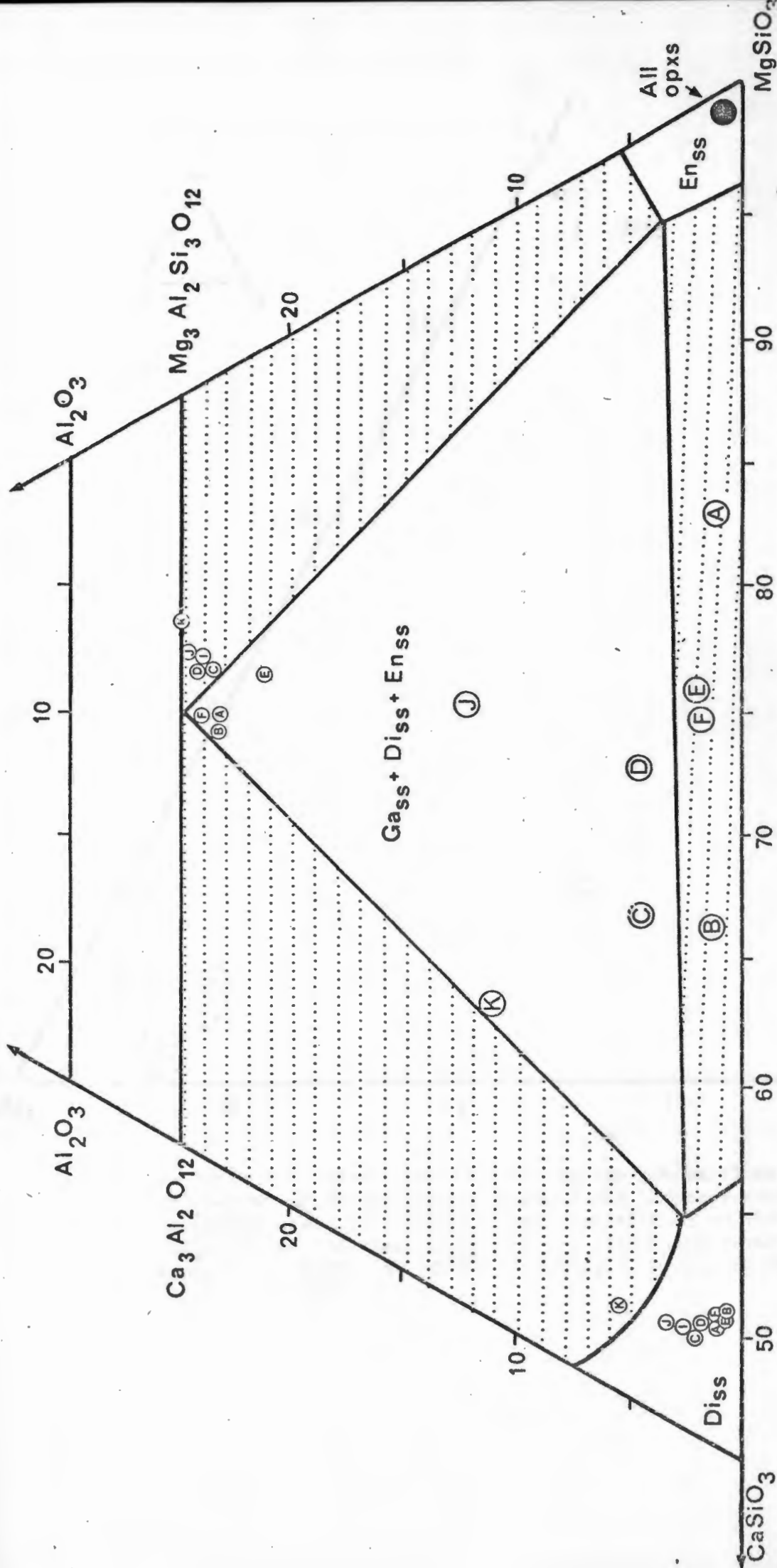


Fig. IV-10. Synthesis diagram for phase relations in a portion of the system CaSiO_3 - MgSiO_3 - Al_2O_3 at 30Kb, 1200°C (after Boyd, 1970). Weight per cent, with total iron expressed as equivalent weight of magnesium. Di- diopside; En- enstatite; Gt- garnet. Symbols as in Figs. IV-1 and 2. (After Beeson and Jackson, 1973).

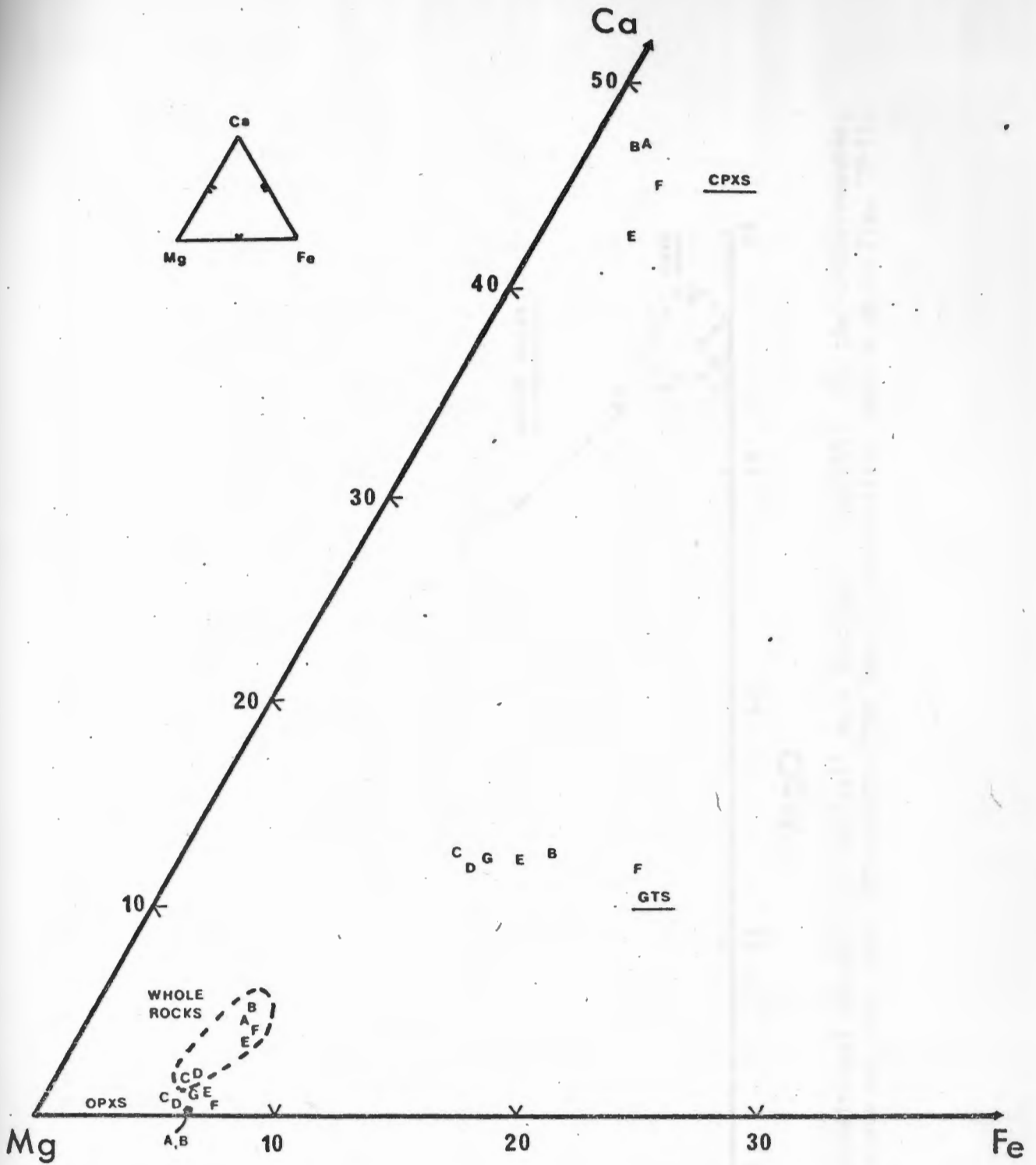


Fig.IV-11. Ca-Mg-Fe ternary diagram illustrating the compositional variation of coexisting orthopyroxenes, garnets and clinopyroxenes from type II pyroxenites. The Compositional variation of the bulk rock compositions of these xenoliths are also illustrated. Symbols: A- PC20A; B- PC20B; C- PC24A; D- PC24B; E- PC27; F-PC28; G- PC71.

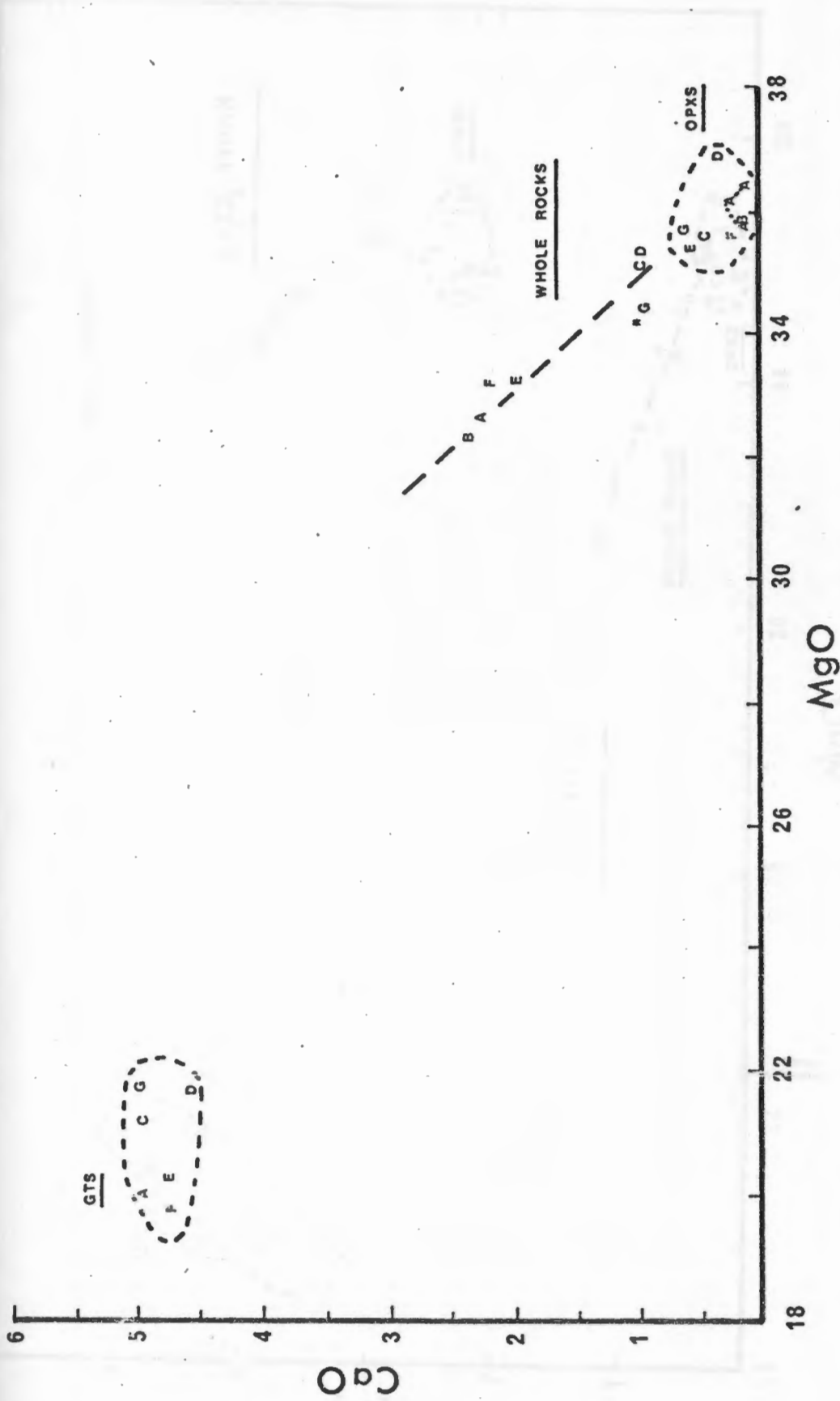


Fig. IV-12 (a). Compositional variation of CaO(wt%) as a function of MgO(wt%) for the orthopyroxenes, garnets and bulk rock compositions from Type II pyroxenites. Symbols as in Fig. IV-11.

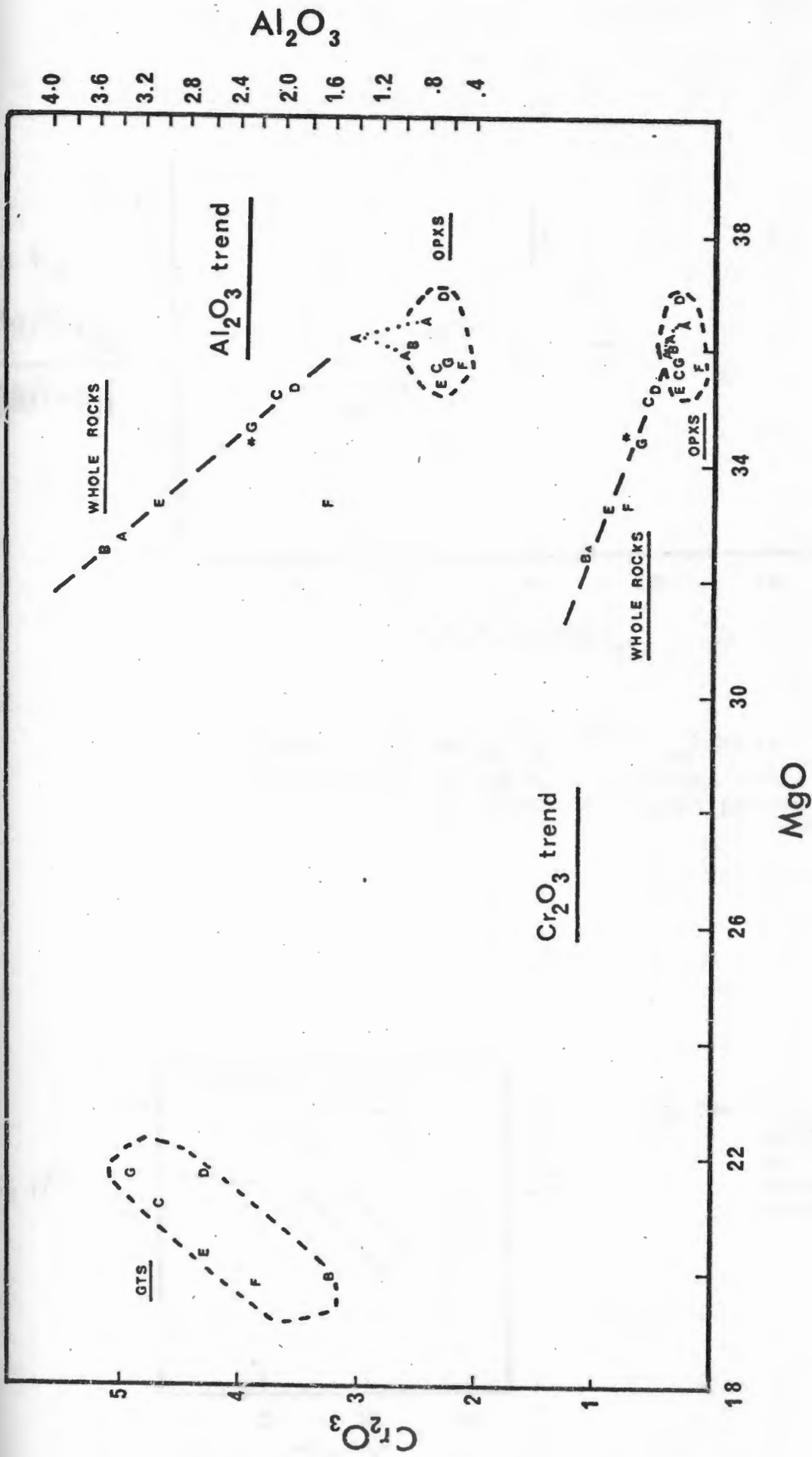


Fig. IV-12 (b). Compositional variation of Cr₂O₃ (wt%) and Al₂O₃ (wt%) contents of orthopyroxenes, garnets and bulk rock compositions as a function of their MgO (wt%) contents, for Type II Pyroxenites. Symbols as in Fig. IV-11.

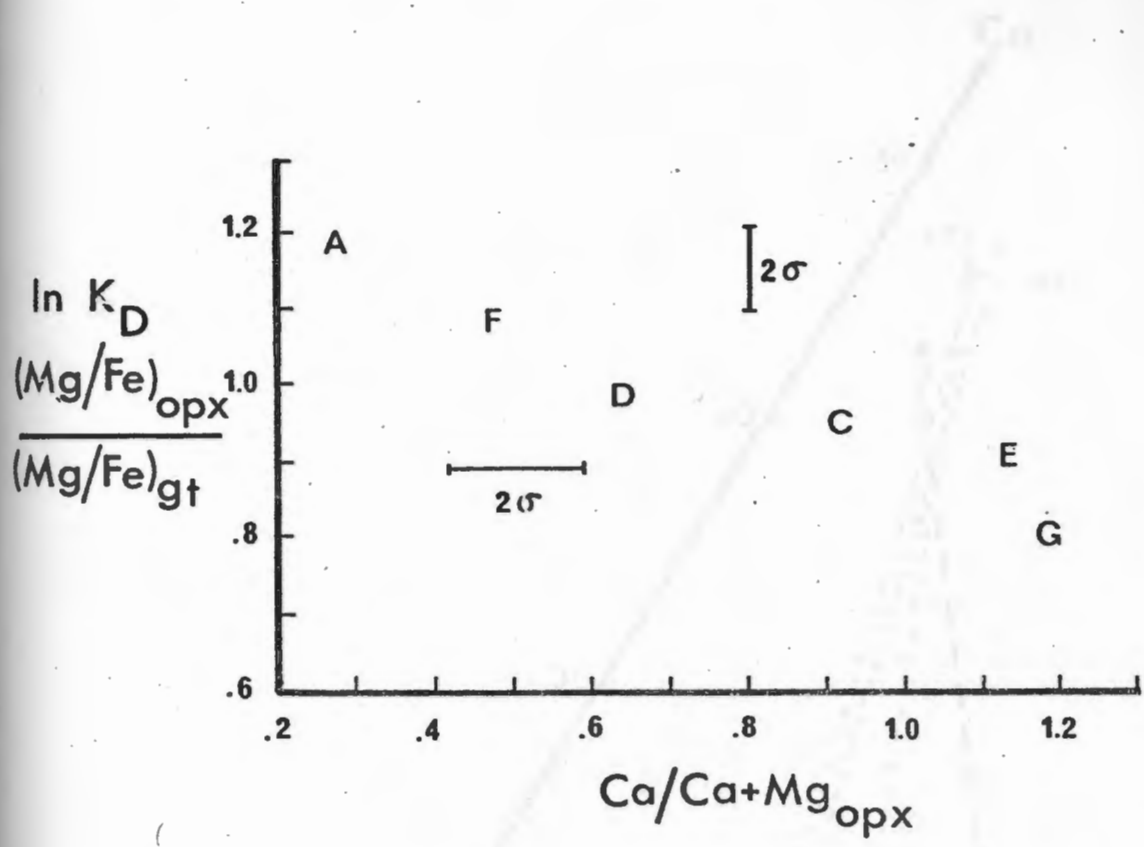


Fig. IV-13. Variation of the $\ln K_D$ ($K_D = (Mg/Fe)_{opx} / (Mg/Fe)_{gt}$) between orthopyroxene-garnet pairs as a function of the Ca/Ca+Mg ratio of the orthopyroxenes, for Type II pyroxenites.

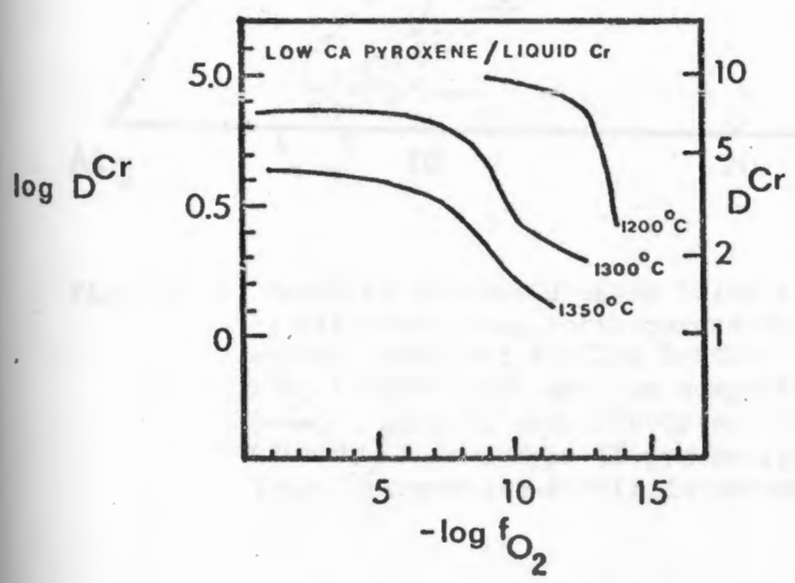


Fig. IV-14. Plot of $\log(D_{Cr})$ for orthopyroxenes (or sub-calcic clinopyroxene) versus \log oxygen fugacity (after Irving, 1978).

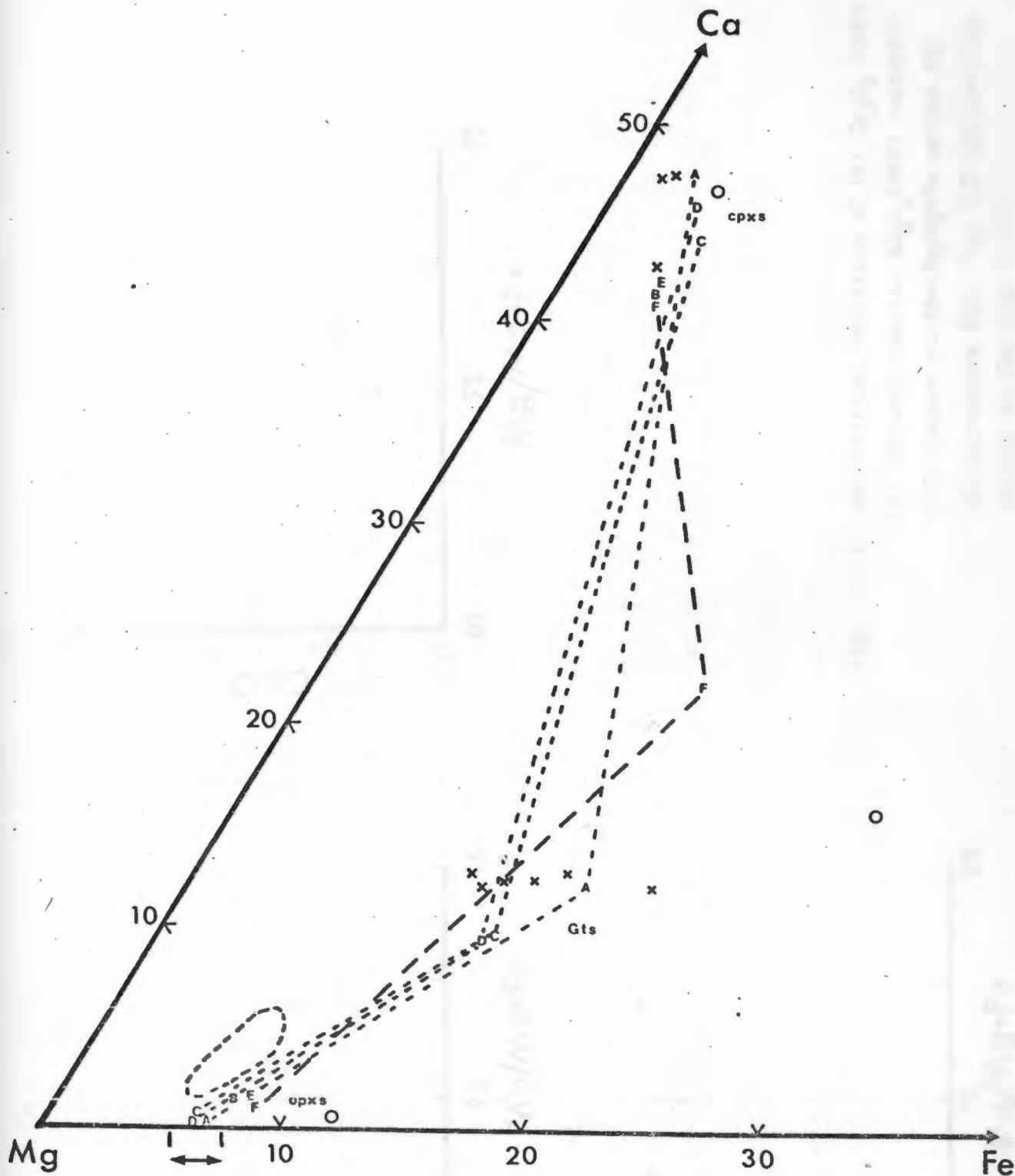


Fig. IV-15. Ca-Mg-Fe ternary diagram illustrating the compositional variation of clinopyroxenes, orthopyroxenes and garnets from Type III pyroxenites. Symbols: A-PC29; B-PC30; C-PC31; D-PC39; E-PC41; F-PC50. Also illustrated are the compositional variations of orthopyroxenes (\longleftrightarrow), garnets and clinopyroxenes (*) and bulk rock compositions (field) from Type II pyroxenites. \circ Mineral assemblages from Type V pyroxenite-PC47 (olivine-bearing pyroxenite).

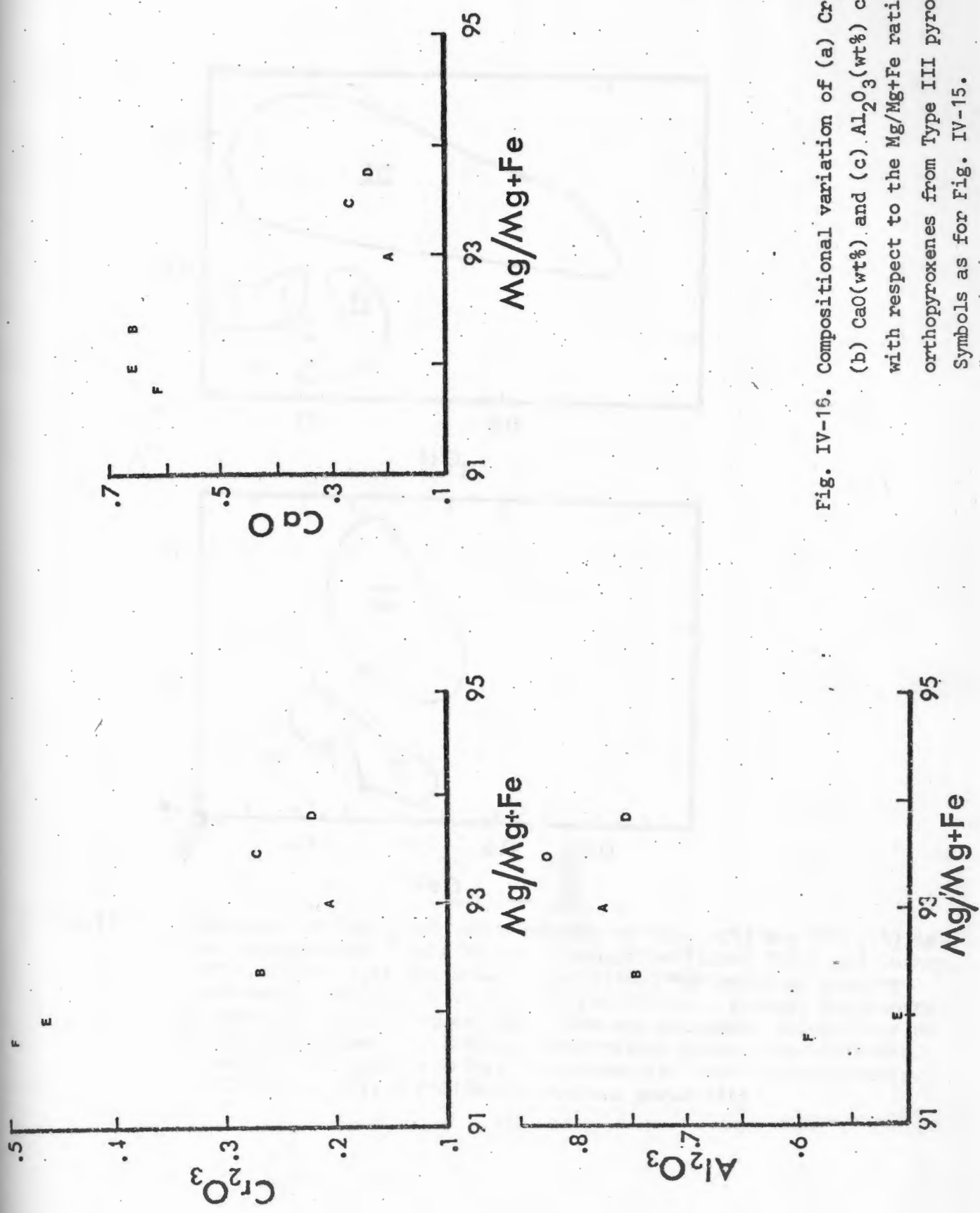


Fig. IV-15. Compositional variation of (a) Cr₂O₃ (wt%) (b) CaO (wt%) and (c) Al₂O₃ (wt%) contents with respect to the Mg/Mg+Fe ratios for orthopyroxenes from Type III pyroxenites. Symbols as for Fig. IV-15.

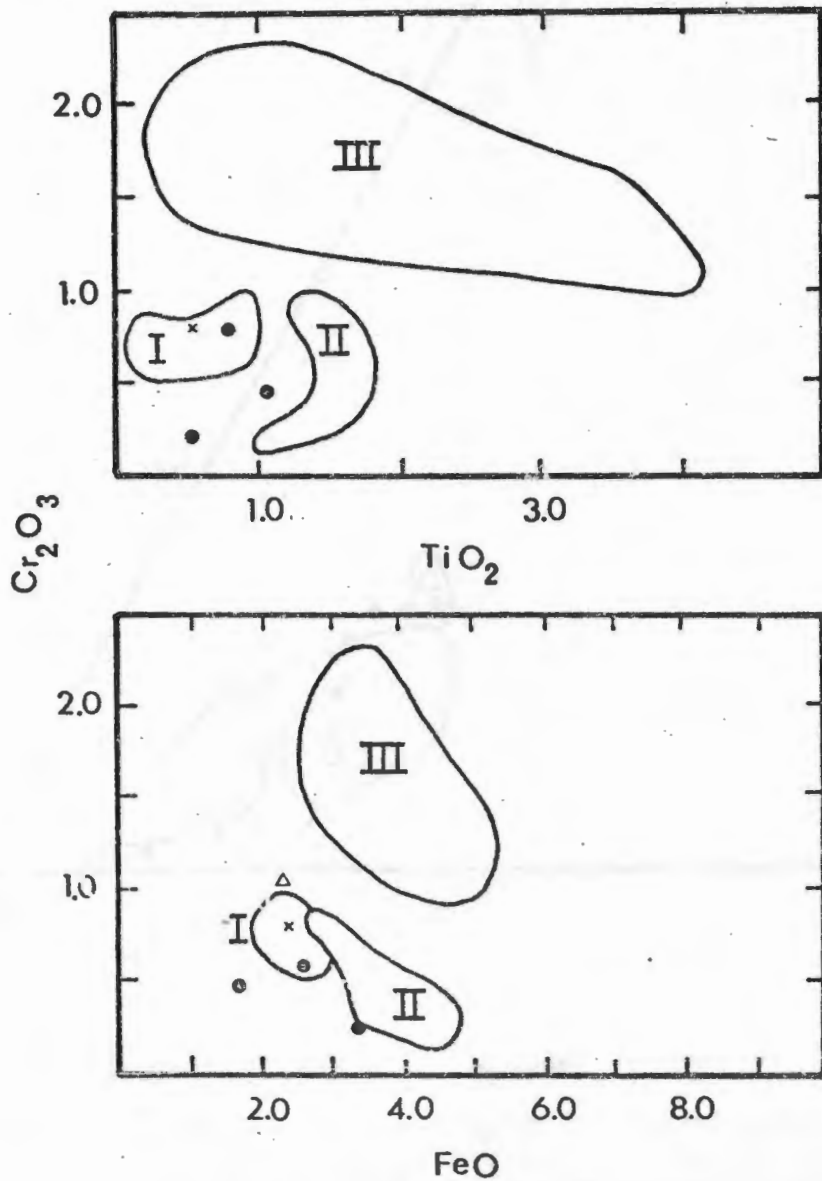


Fig.IV-17. Variation of Cr_2O_3 (wt%) with respect to TiO_2 (wt%) and FeO (wt%) in some phlogopites from kimberlite xenoliths (after Harte and Gurney, 1975). Fields I, II, III show compositional variation of primary-metasomatic phlogopite in Matsoku peridotites, primary phlogopite in peridotites from other localities and secondary phlogopites at Matsoku and other localities, respectively (data from Harte and Gurney, 1975). Symbols: ● Type IV pyroxenites from Koffiefontein; × PC24A (type II); △ PC61 (Koffiefontein peridotite).

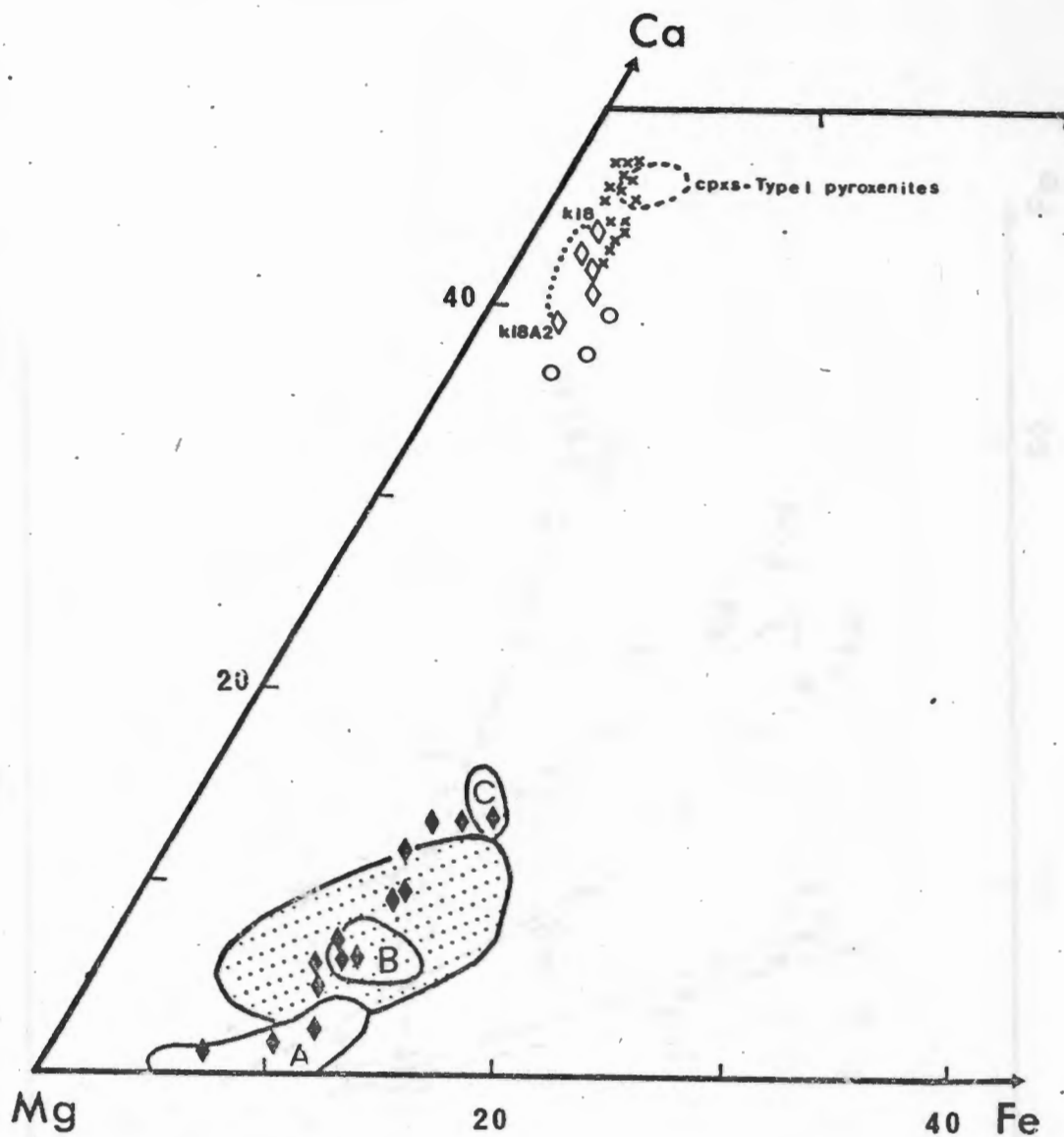


Fig. V-1. Ca-Mg-Fe ternary diagram illustrating compositional variation in peridotitic garnet and clinopyroxene inclusions in Koffiefontein diamonds. Symbols: \blacklozenge garnets; \diamond clinopyroxenes; \circ diopside diamond inclusions (Meyer and Tsai, 1976); \times clinopyroxenes from the Koffiefontein concentrate. Compositional fields designated A, B, C define the variations in peridotitic garnet inclusions found in diamonds from the Finsch Mine, S.A. (Gurney et al, 1979). stippled field Field of diamond inclusions from several kimberlite localities, as defined by the data of Lawless (1974).

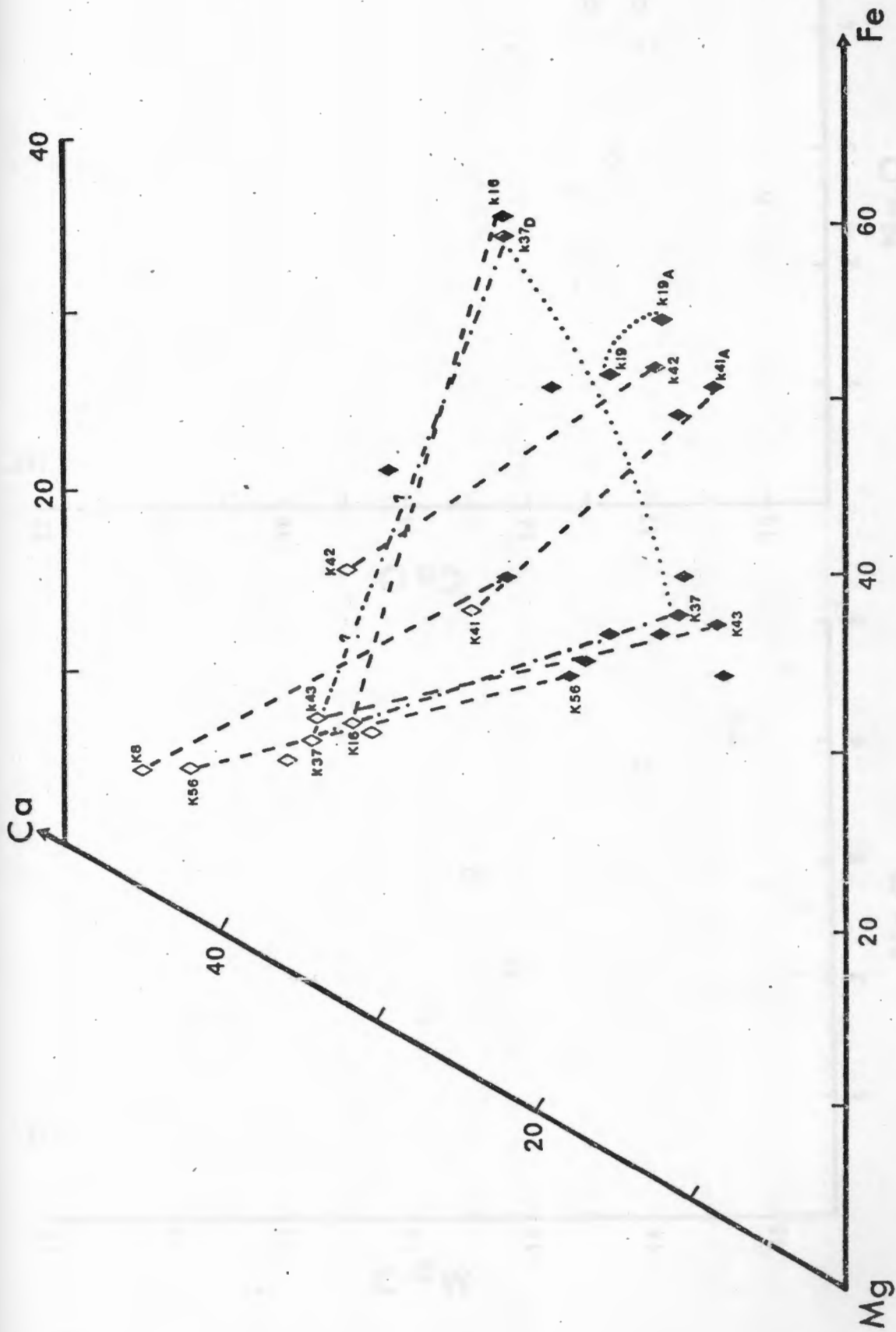


Fig. V-2. Ca-Mg-Fe ternary diagram illustrating compositional variation in eclogitic garnet and clinopyroxene inclusions in Koffiefontein diamonds. Symbols: \blacklozenge garnets; \diamond clinopyroxenes.

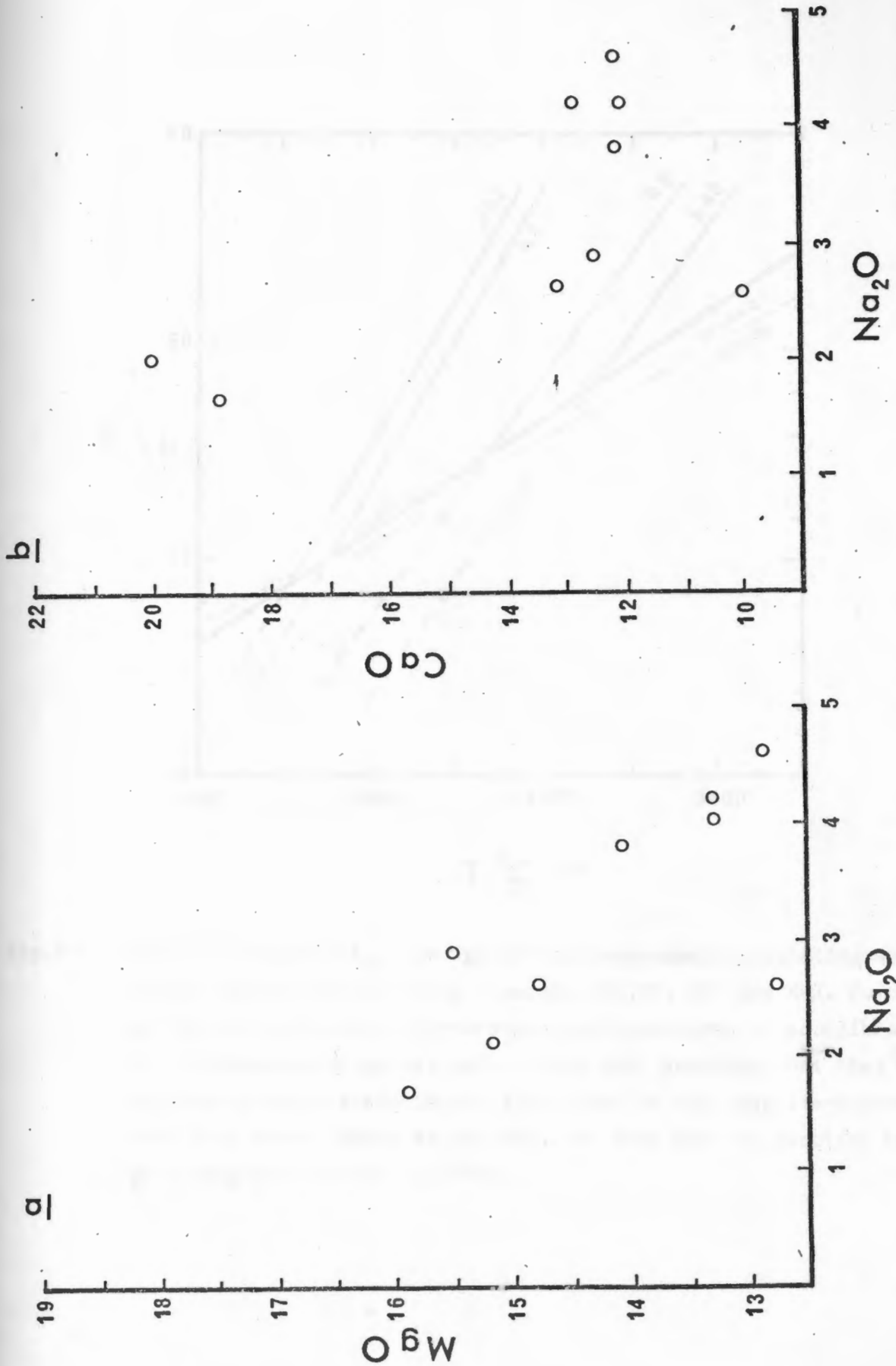


Fig. V-3. Variation of (a) MgO(wt%) and (b) CaO (wt%) with respect to Na₂O in eclogitic clinopyroxene inclusions in Koffiefontein diamonds.

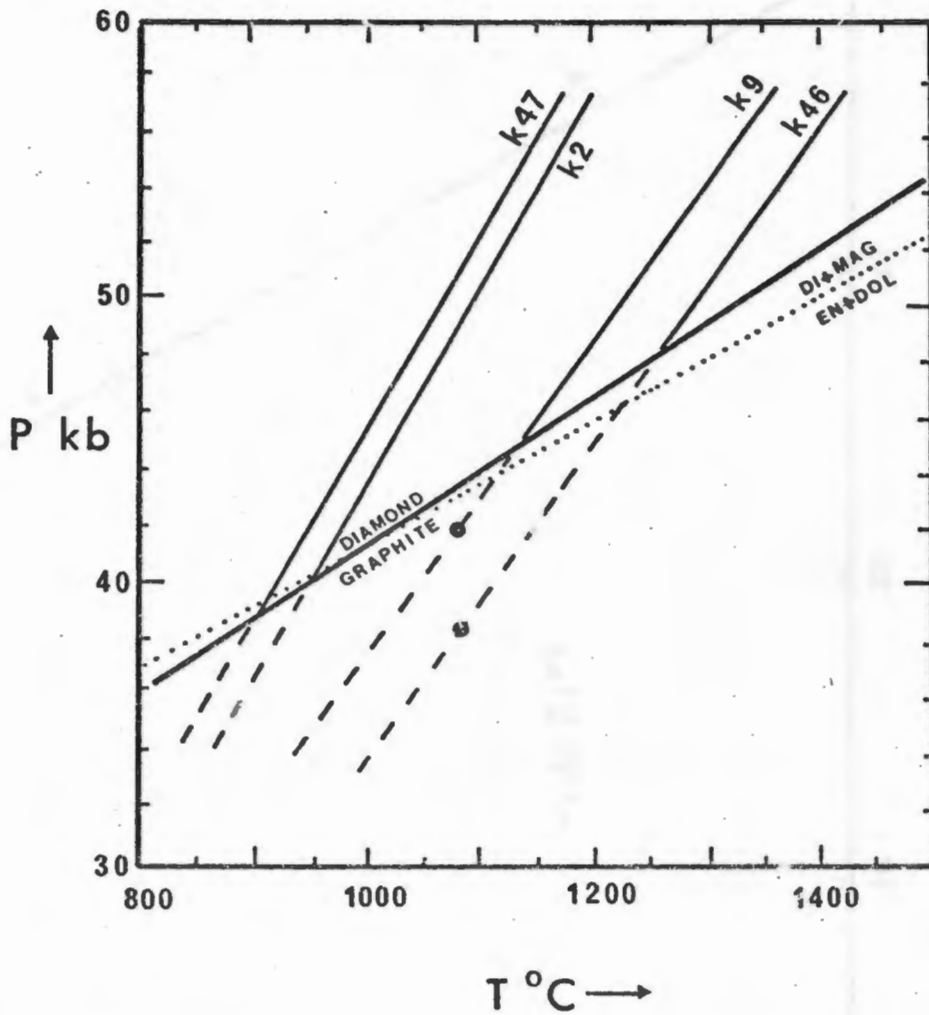


Fig.V-4. Lines of constant K_D for garnet-orthopyroxenes coexisting as inclusions in the following diamonds: K2, K9, K46 and K47. Points ● indicate calculated temperatures and pressures of equilibration for orthopyroxene-garnet pairs K9 and K46, assuming that they represent equilibrium assemblages. Also shown is the graphite-diamond stability curve (Bundy et al, 1961) and that for the reaction $En+Dol \rightleftharpoons Di+Mag$. (Kushiro et al, 1975).

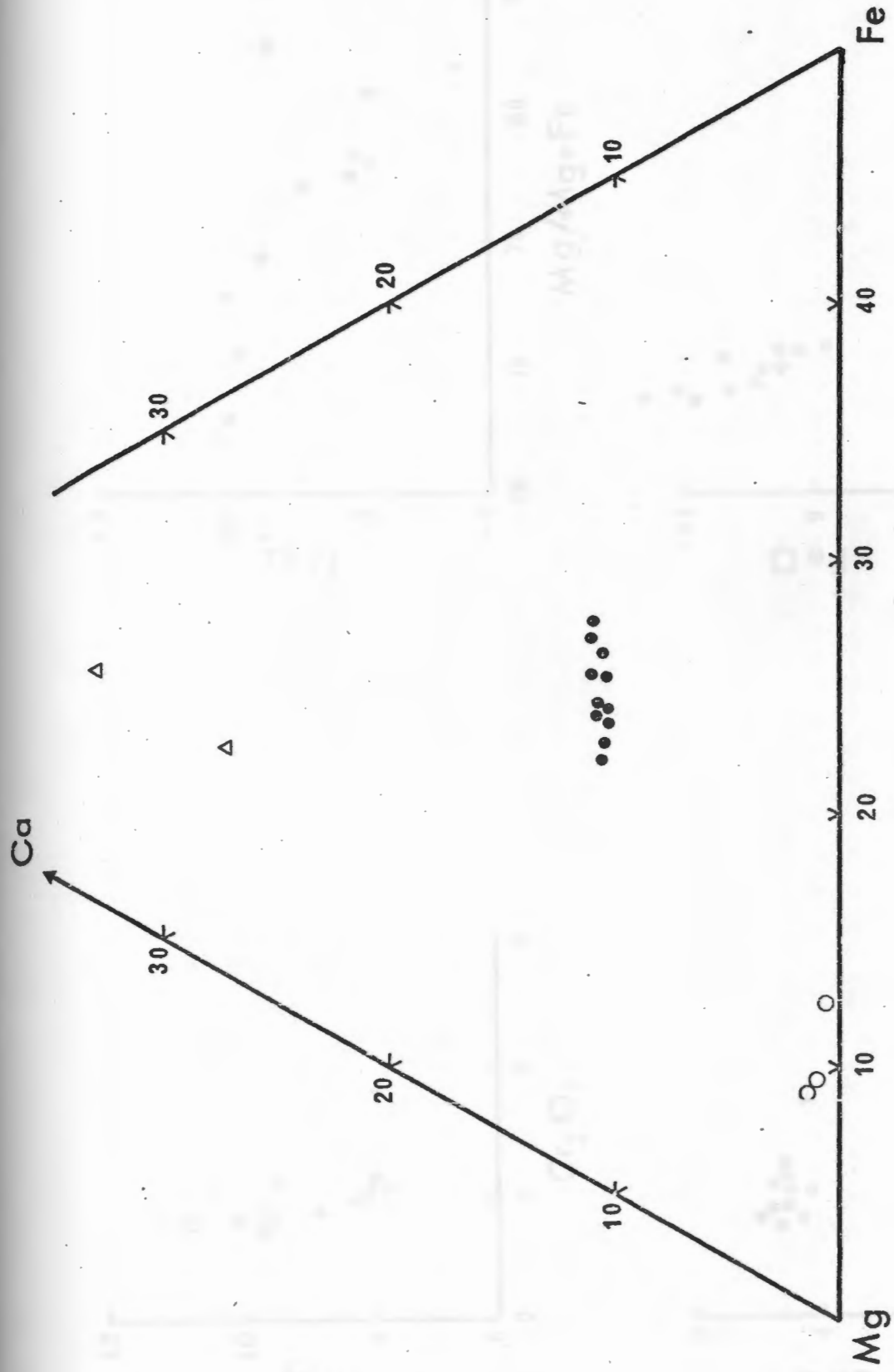


Fig. VI-1. Compositional variation of Koffiefontein megacrysts in terms of Ca-Mg-Fe.

Symbols: ● garnets; ○ orthopyroxenes; △ clinopyroxenes.

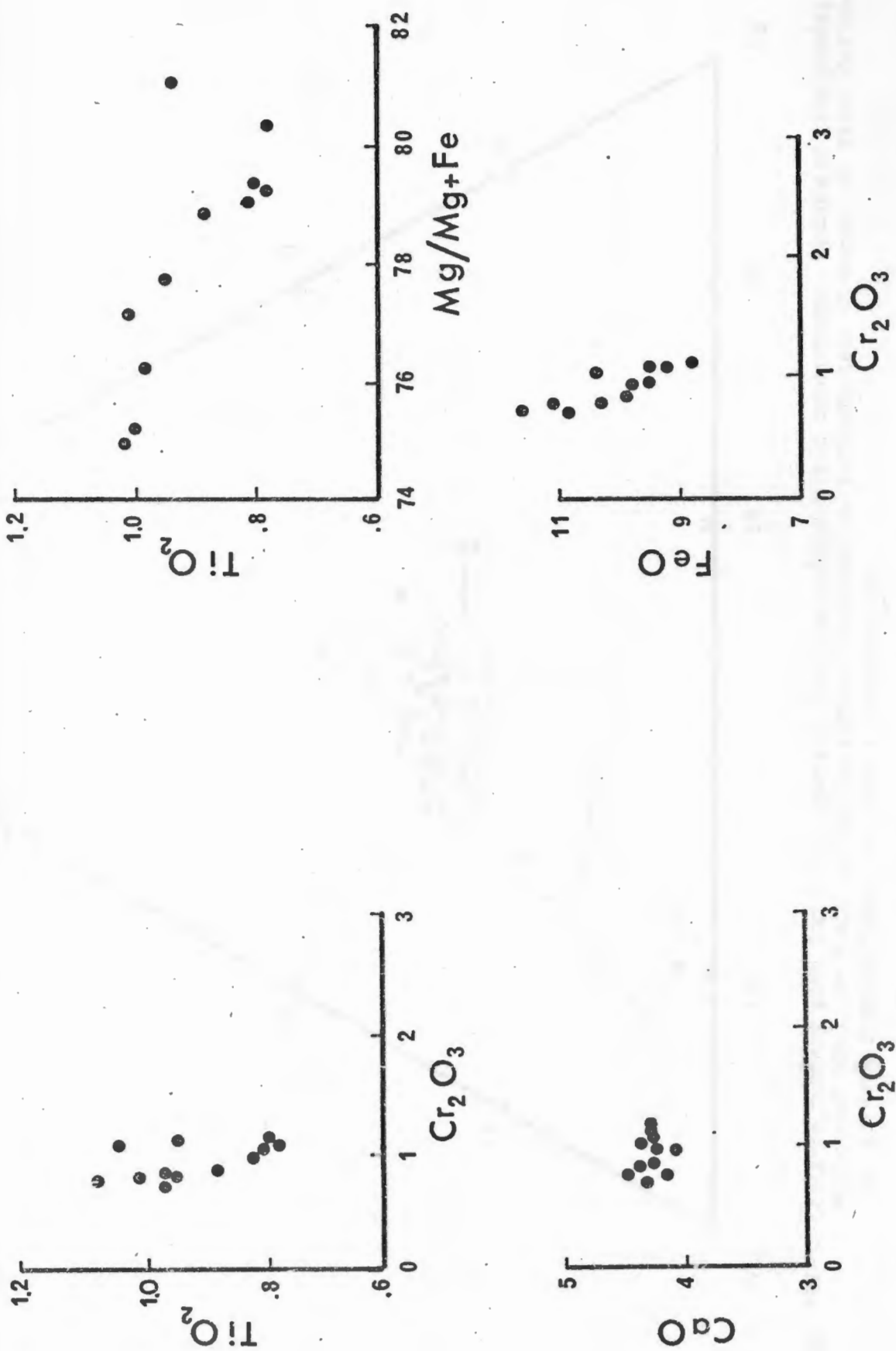


Fig. VI-2. Variation of TiO₂(wt%), CaO(wt%) and FeO(wt%) with respect to Cr₂O₃ contents, together with the variation of TiO₂(wt%) as a function of the Mg/Mg+Fe ratio, for the Koffiefontein garnet megacrysts.

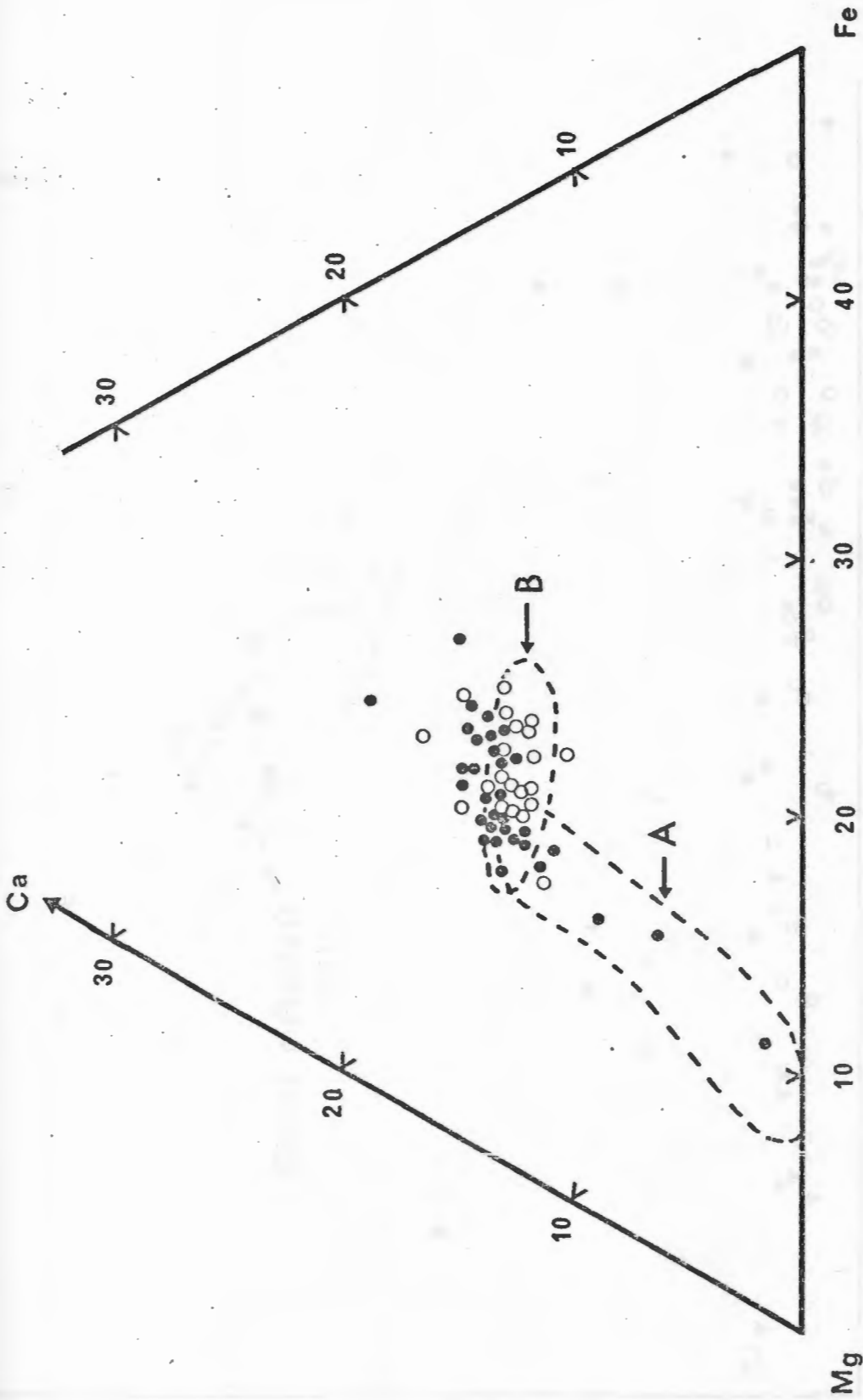


Fig. VII-1. Ca-Mg-Fe ternary plot for purple garnets from the Koffiefontein concentrate. Symbols: ○ this study; ● Lawless (1974). A- field defined by garnet inclusions in Koffiefontein diamonds; B- field defined by garnets from Koffiefontein Type II pyroxenites.

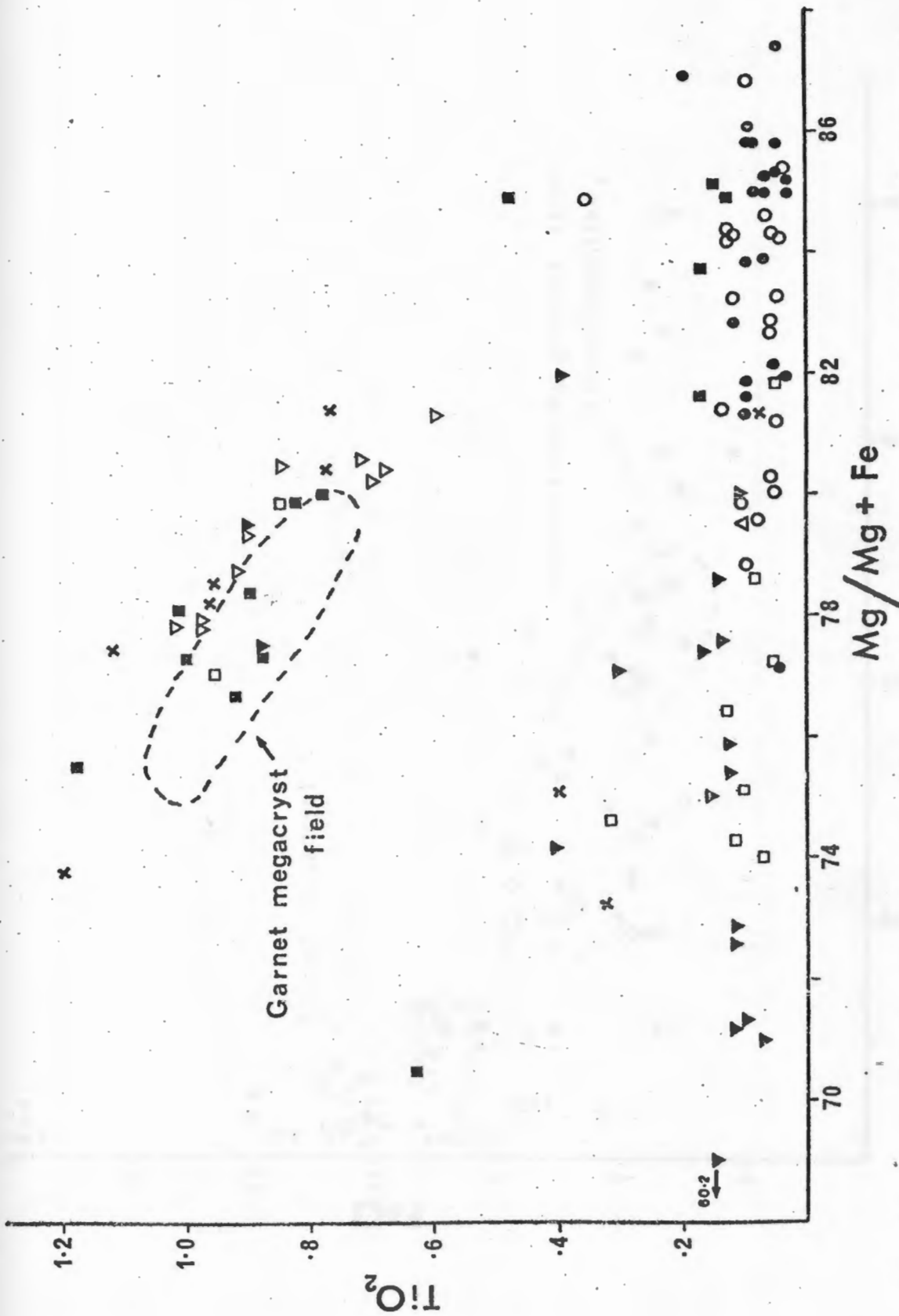


Fig. VII-2. Variation of TiO_2 with respect to $Mg/Mg+Fe$ ratio for garnets from the Koffiefontein concentrate. Symbols: purple garnets \circ this study; \blacktriangle Lawless (1974); orange garnets ∇ this study; \square Lawless (1974-red) red garnets ∇ this study; \blacksquare Lawless (1974-orange); red-brown garnets \times this study.

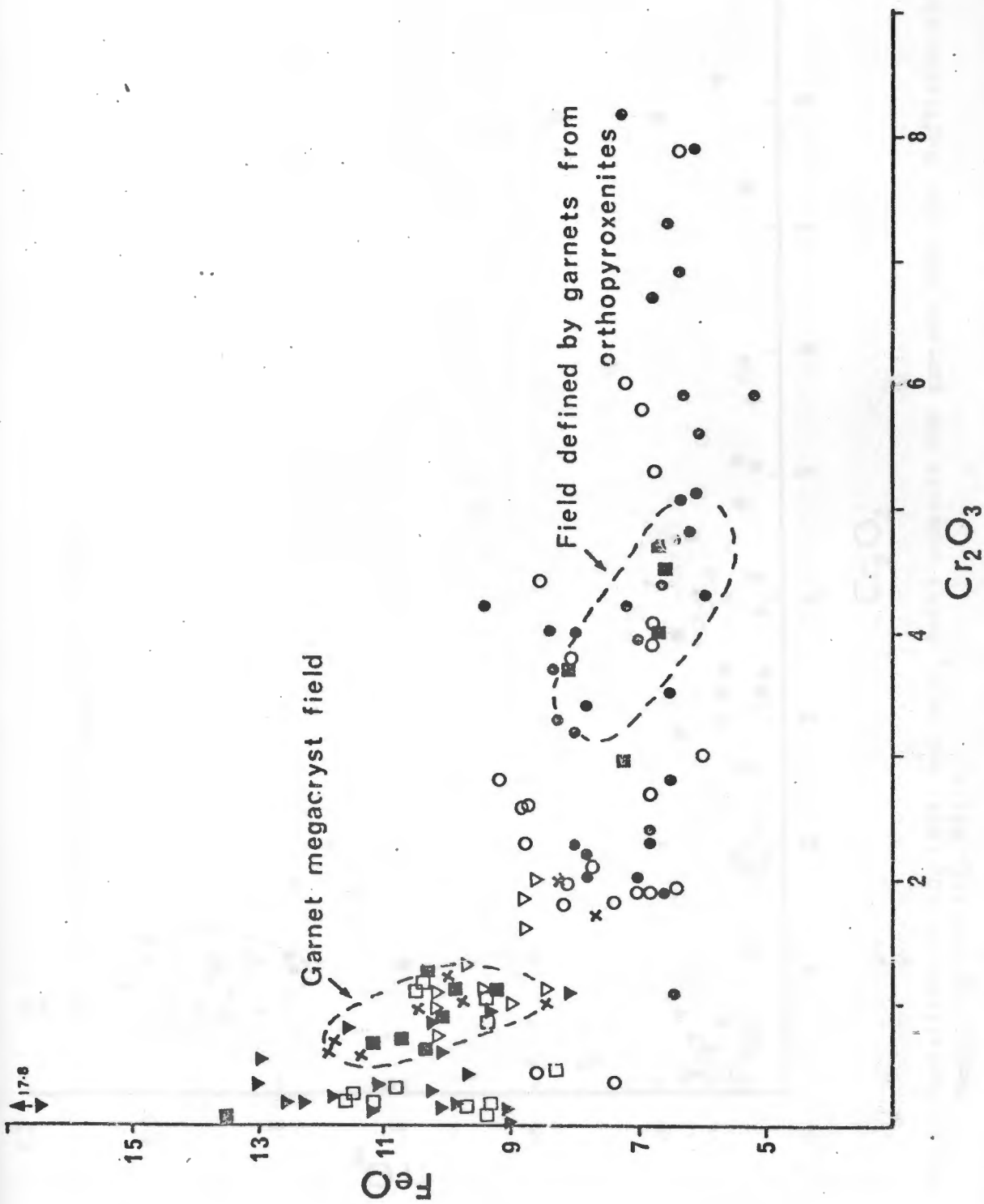


Fig. VII-3. Variation of FeO(wt%) as a function of Cr₂O₃ (wt%) for garnets from the Koffiefontein concentrate. Symbols as for Fig. VII-2.

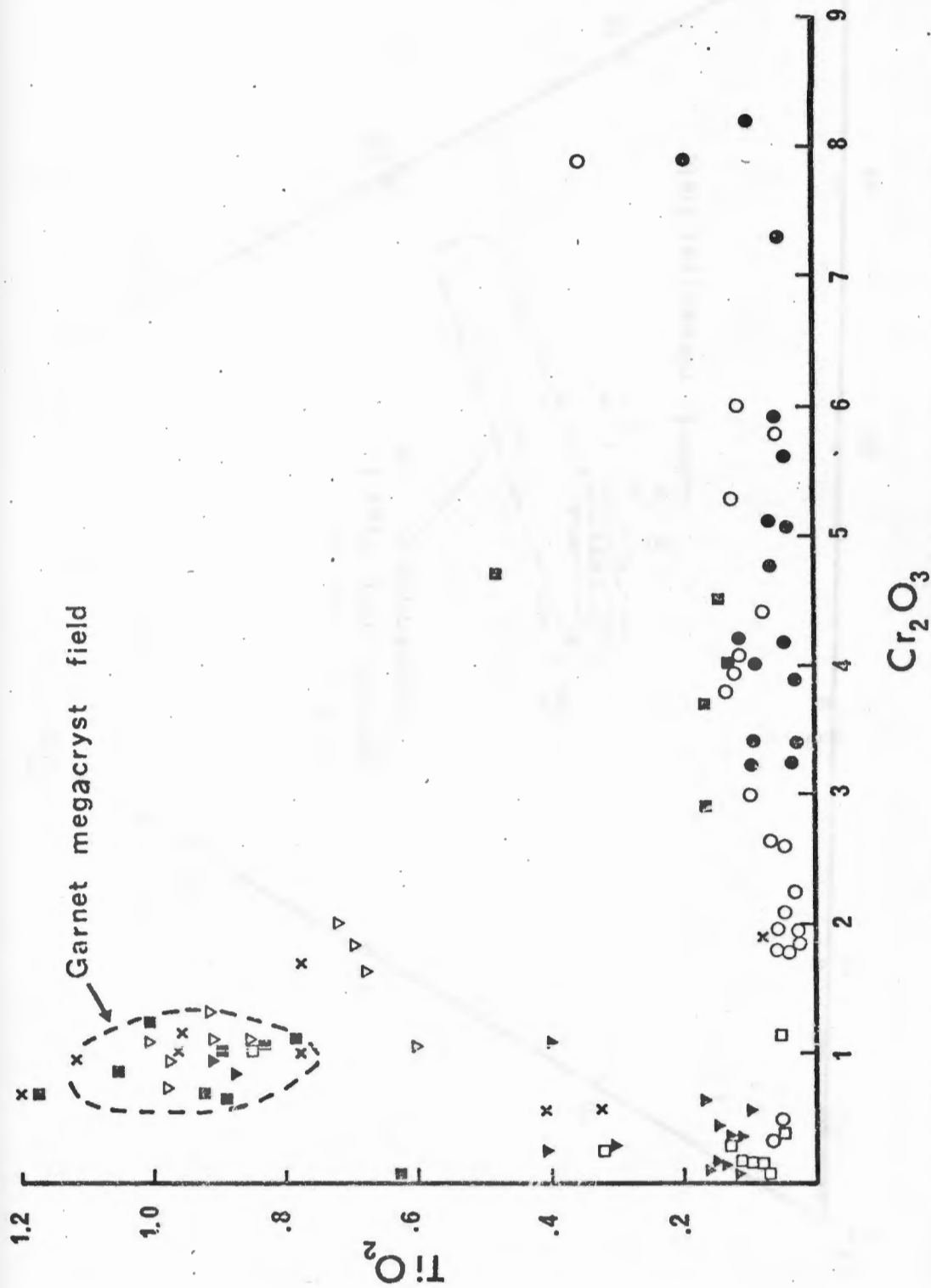


Fig. VII-4. Variation of TiO_2 (wt%) and Cr_2O_3 (wt%) contents for garnets from the Koffiefontein concentrate. Symbols as for Fig. VII-2.

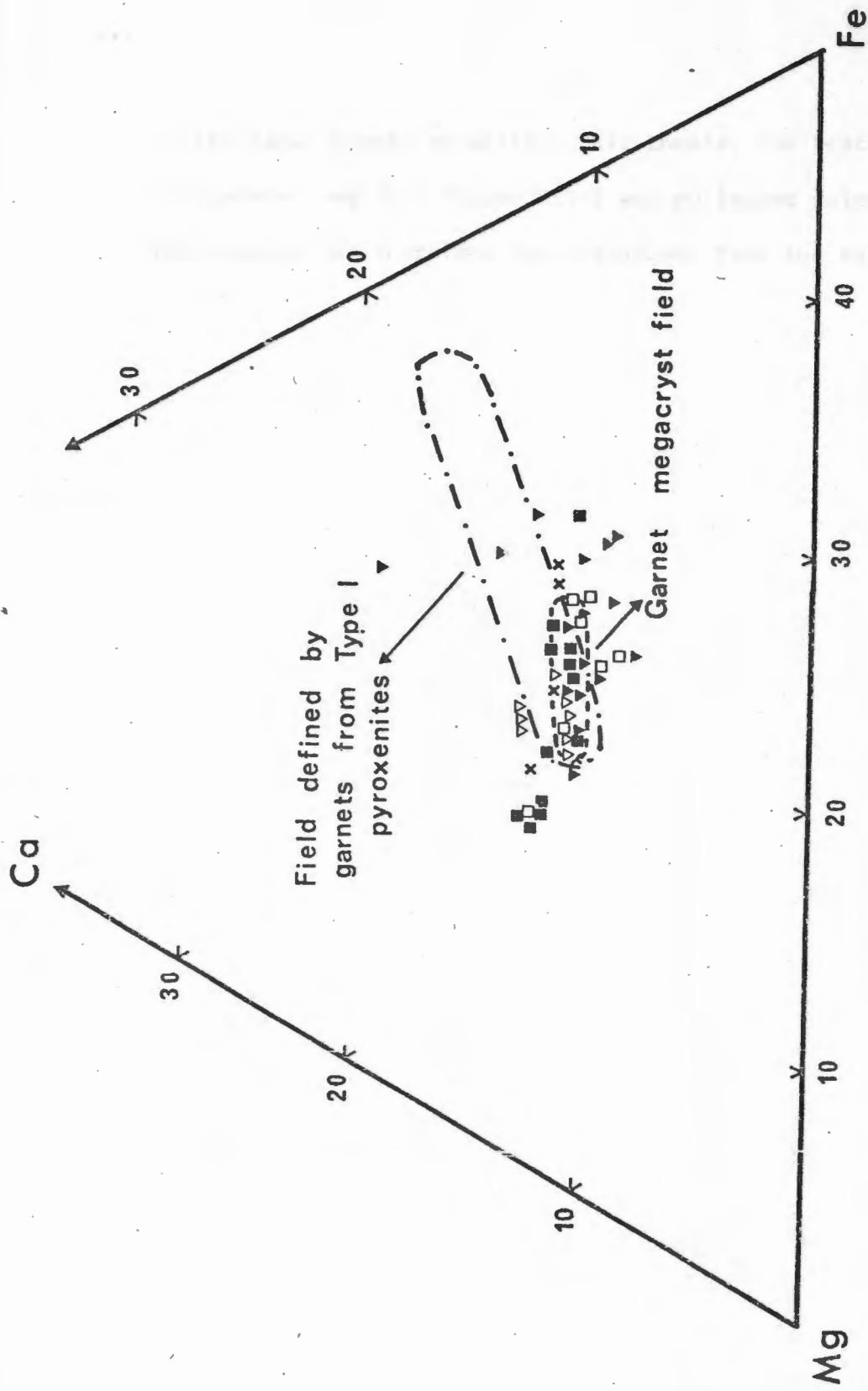


Fig. VII-5. Ca-Mg-Fe ternary plot for orange, red and red-brown garnets from the Koffiefontein concentrate. Symbols as for Fig. VII-2. Fields defined by garnet megacrysts and garnets from Type I pyroxenites from Koffiefontein are also illustrated for comparison.

In the final stages of writing this thesis, the text was amended, so that Figure VII-6 was no longer relevant. The diagram has therefore been withdrawn from the thesis.



Fig. VII-6. Variation of CaO with weight percent content of orthopyroxene from the collection of air-separation products as for Fig. VII-5. Dotted line field represents field of composition of variation of orthopyroxene inclusions in approximately 1000°C - 1200°C lava from Hawaii (1970).

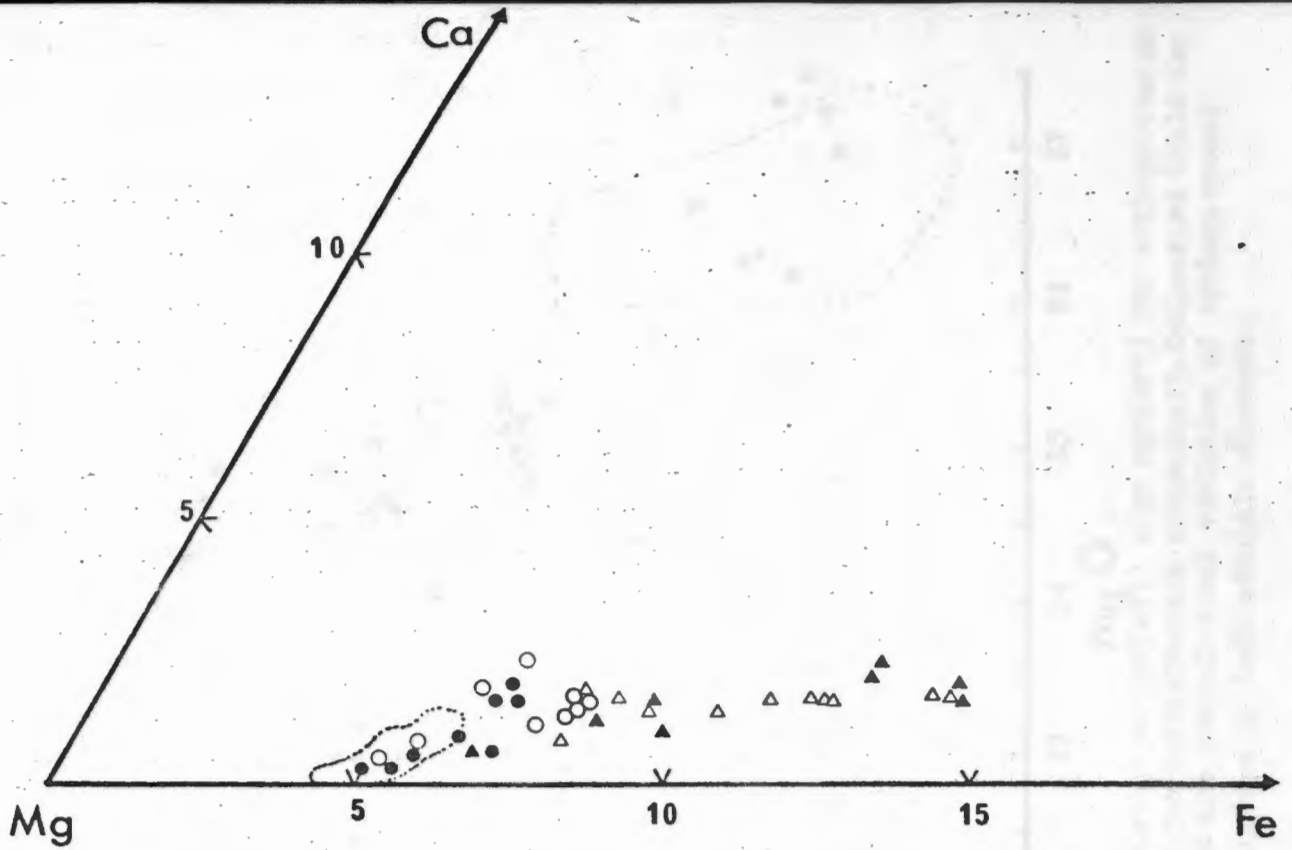


Fig. VII-7. Ca-Mg-Fe ternary plot for orthopyroxenes from the Koffiefontein concentrate. Symbols: \circ green(glassy); \bullet green (with cleavage); \triangle brown(glassy); \blacktriangle brown (with cleavage). Delineated field represents the compositional variation of orthopyroxene inclusions in Koffiefontein diamonds.

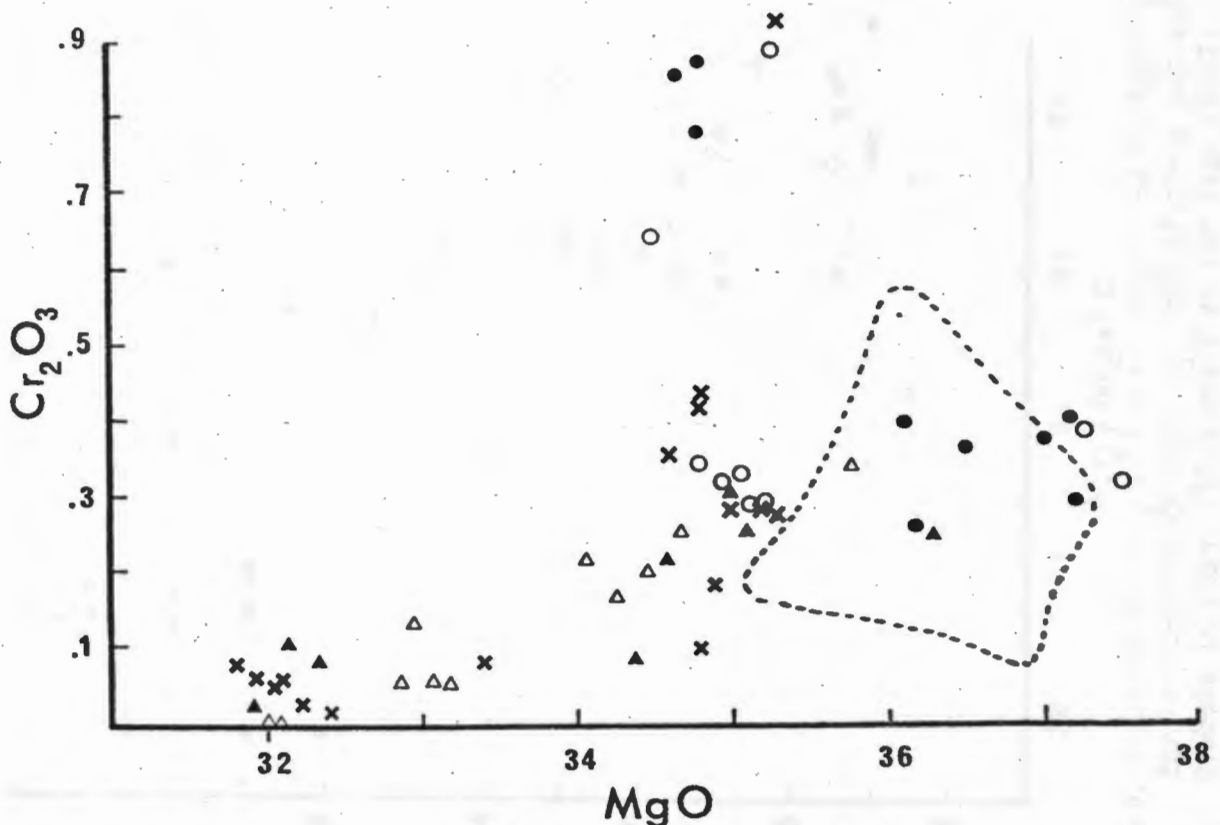


Fig. VII-8. Variation of Cr_2O_3 (wt%) with MgO (wt%) content of orthopyroxenes from the Koffiefontein concentrate. Symbols as for Fig. VII-7. Delineated field represents the compositional variation of orthopyroxene inclusions in Koffiefontein diamonds. X = data from Lawless (1974).

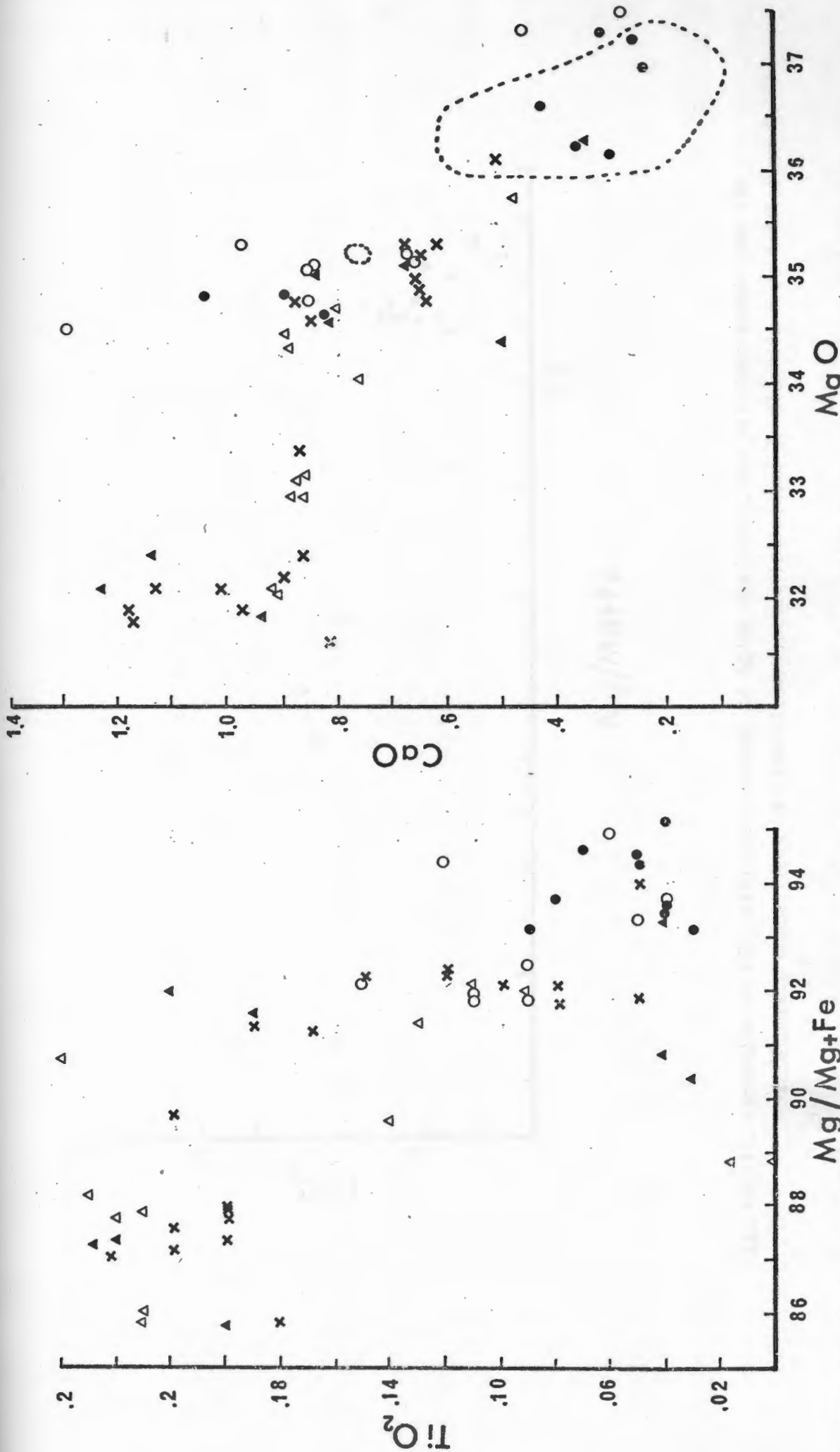


Fig. VII-9. Variation of TiO_2 (wt%) with respect to $Mg/Mg+Fe$ ratio for orthopyroxenes from the Koffiefontein concentrate. Symbols in Figs. VII-9 and 10 as for Fig. VII-7.

Fig. VII-10. Variation of CaO (wt%) with MgO (wt%) for orthopyroxenes from the Koffiefontein concentrate. Delineated field defines the compositional variation of orthopyroxene inclusions in Koffiefontein diamonds.

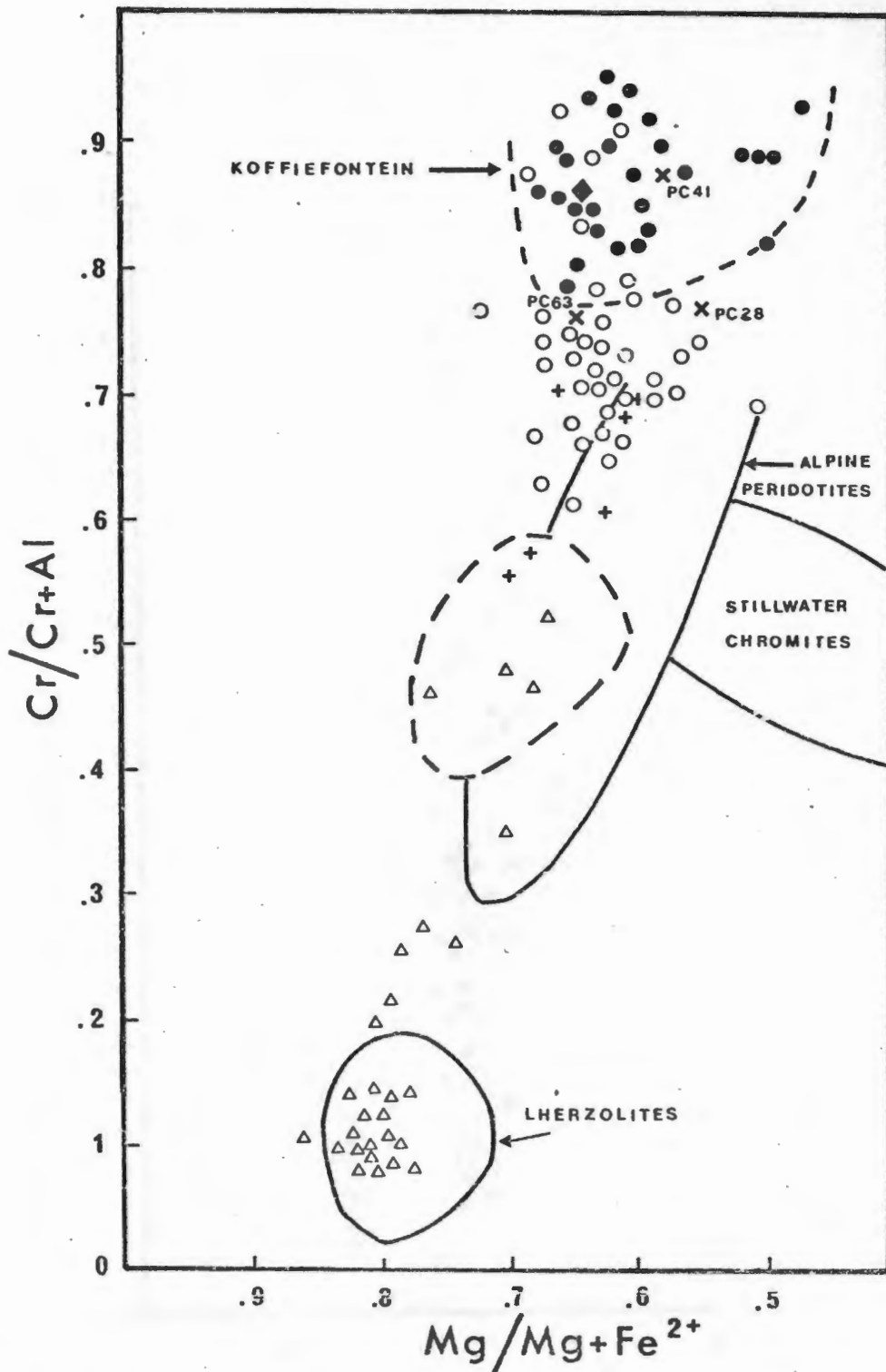


Fig. VII-12 (a). Compositions of chromites and spinels, in terms of the variation of $Cr/Cr+Al$ with respect to the $Mg/Mg+Fe^{2+}$ ratio. Projections after Irvine(1965). Symbols: ● Koffiefontein concentrate; × Koffiefontein xenoliths; ◆ Koffiefontein diamond inclusion; ○ and + euhedral and symplectite chromites, respectively, from kimberlite xenoliths (Basu and MacGregor, 1975); △ interstitial spinels in alkali olivine basalt xenoliths (Basu and MacGregor, 1975) (Fig. after Sigurdson, 1977).

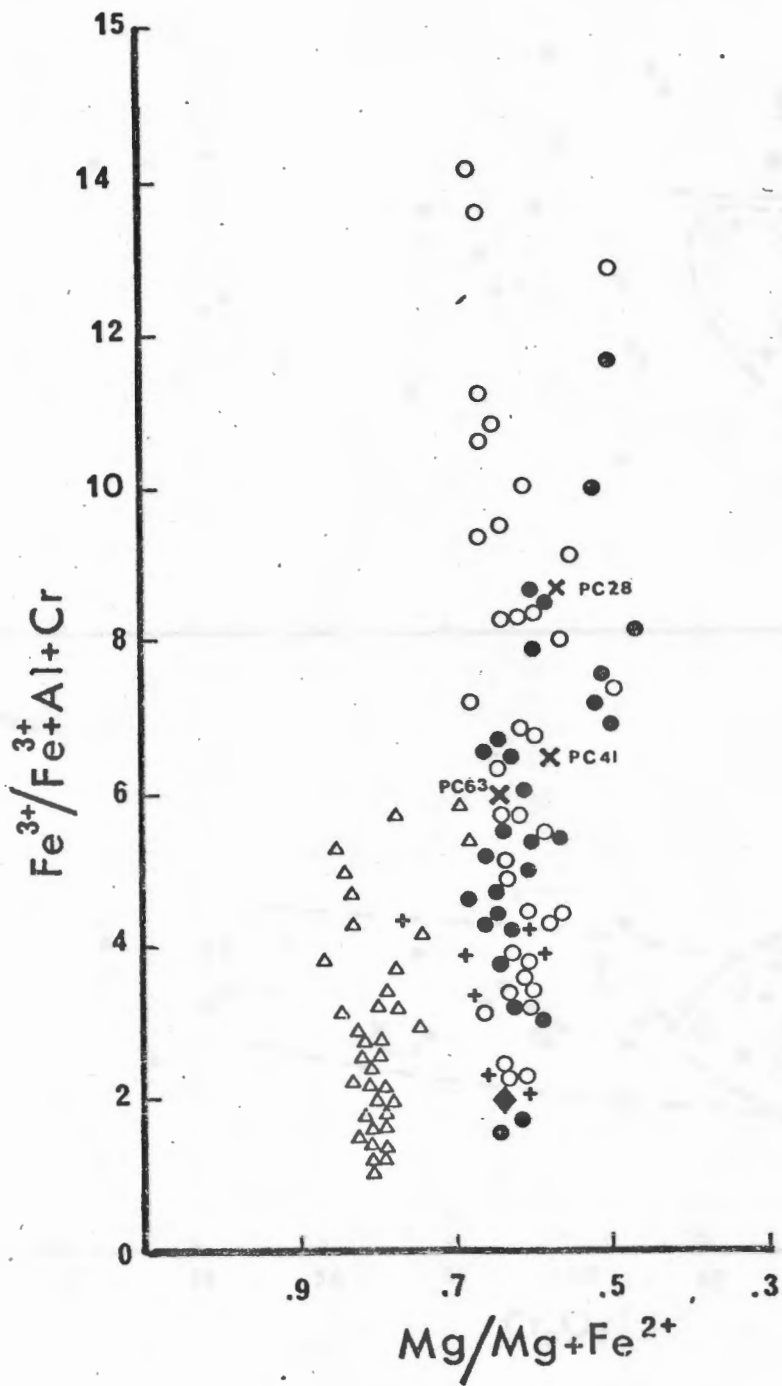


Fig. VII-12 (b). Compositions of chromites and spinels in terms of the variation of $\text{Fe}^{3+}/\text{Fe}^{3+} \text{ Al} + \text{Cr}$ ratio with respect to the $\text{Mg}/\text{Mg} + \text{Fe}^{2+}$ ratio. Projection after Irvine (1965). Symbols as for Fig. VII-12 (a). (after Sigurdson, 1977).

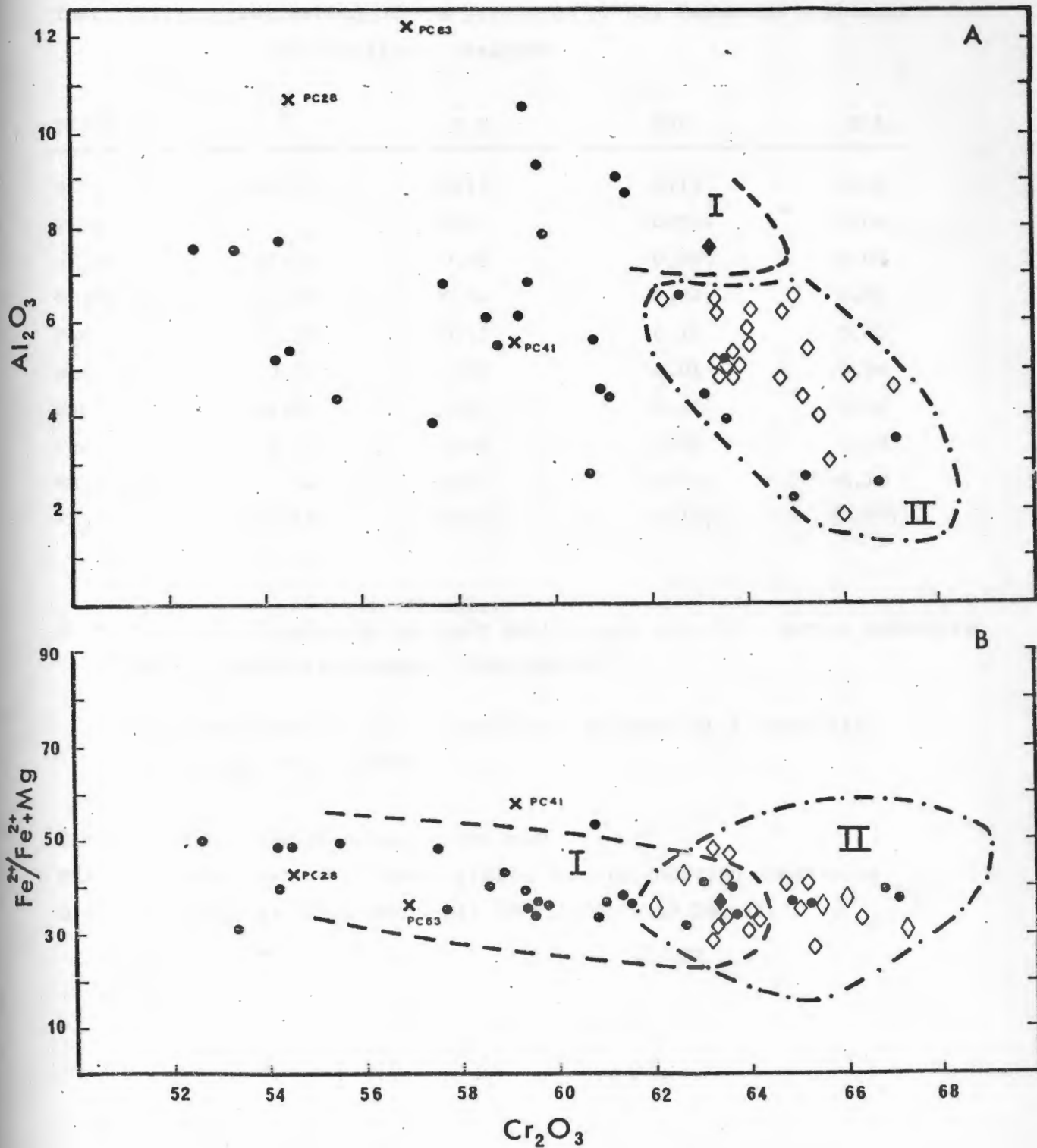


Fig. VII-13. Variation in Al_2O_3 content and $\text{Fe}^{2+}/\text{Fe}^{2+} + \text{Mg}$ ratio with respect to Cr_2O_3 (wt%) in all analysed chromites from Koffiefontein. Symbols: Koffiefontein concentrate; Koffiefontein xenoliths; Koffiefontein diamond inclusion; diamond inclusions, U.S.S.R. (Sobolev, 1977). Fields I and II define the compositional variation observed in chromites from ultramafic rocks and diamond intergrowths/inclusions, respectively (Sobolev, 1977). (after Sobolev, 1977).

TABLE III-1. Estimation of the precision of the Cambridge Microscan
v. Microanalyser analyses.

OXIDE	\bar{x}	S.D.	ERR.	D.L.
SiO ₂	41,45	0,15	0,13	0,06
TiO ₂		0,01	0,031	0,06
Al ₂ O ₃	21,60	0,09	0,08	0,04
Cr ₂ O ₃	0,78	0,02	0,02	0,06
FeO	10,30	0,11	0,10	0,08
MnO	0,26	0,01	0,01	0,06
MgO	19,87	0,17	0,10	0,06
CaO	4,22	0,09	0,06	0,04
Na ₂ O	0,12	0,01	0,02	0,10
*K ₂ O	(1,18)	(0,06)	(0,10)	(0,07)

\bar{x} = Mean of 12 replicate analyses of the same spot of a garnet megacryst
KF 78, from Koffiefontein (this study).

*K₂O estimates are for 10 replicate analyses of a paragonitic
hornblende (Reid, 1977).

S.D. = Standard deviation about the mean

ERR = 2σ error (95% confidence limits) due to counting statistics

D.L. = Theoretical detection limit (99% confidence level).

TABLE III-2. Estimated precision and detection limits, and average absolute error (accuracy) on the calibration curve for the major oxides using XRF techniques. Precision is expressed as an absolute error (2σ) on the given percentage oxide (le Roex, 1980).

OXIDE	PERCENTAGE	PRECISION	ACCURACY	DETEC. LIMIT
SiO ₂	50.0	0.140	0.264	0.036
TiO ₂	1.0	0.008	0.008	0.005
Al ₂ O ₃	15.0	0.080	0.079	0.022
Cr ₂ O ₃	0.5	0.008	0.012	0.007
Fe ₂ O ₃	9.0	0.038	0.064	0.014
MnO	0.15	0.008	0.003	0.008
MgO	8.0	0.148	0.086	0.072
CaO	12.0	0.028	0.030	0.008
Na ₂ O	2.5	0.032	0.067	0.080
K ₂ O	0.20	0.002	0.022	0.002

TABLE IV-1. Chemical modes (wt.%) of Type I pyroxenites.
 Visual estimates of modal proportions (vol.%)
 are given in brackets.

	cpx	opx	exsolved garnet	primary garnet	spinel	phlogopite
PC21	N.C.* (60)	N.C. (11)	N.C. (5)	-	-	-
PC22	30.1 (60)	65.1 (40)	2.8	-	-	-
PC25	62.8 (57)	32.0 (35)	4.7 (8)	-	-	-
PC33	60.7 (60)	27.4 (25)	11.9 (5)	(10)	-	-
PC54	48 (64)	37 (27)	14 (4)	(5)	-	-
PC58	31.4 (69)	24.4 (15)	43.4 (15)	-	-	(1)
PC34	66.8	-	32.6	-	-	-
PC35	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.

- NOTE: (1) In visual estimates, large garnets for which no evidence of exsolution was obvious, were considered 'primary'.
 Reconstructed compositions (Beeson and Jackson, 1970) were not done because of problems discussed in text.
- (2) All garnet in chemical modes is given as exsolved.
- (3) N.C. - not calculated. In the case of PC35, no bulk rock available.

TABLE IV-2 MICROPPURE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE I PYROXENITES

	1	2	3	4	5	6	7	A	9
SiO ₂	55.13	56.22	40.01	54.53	56.54	34.90	54.20	57.59	41.37
TiO ₂	0.05	0.03	0.04	0.03	0.02	0.03	0.16	0.07	0.06
Al ₂ O ₃	1.78	0.44	21.00	0.66	0.39	21.02	2.13	0.69	22.03
Cr ₂ O ₃	3.25	0.15	3.21	0.47	0.13	2.68	1.26	0.16	22.62
FeO	3.13	9.87	14.51	2.87	9.20	15.68	2.21	5.74	10.08
MnO	16.00	0.22	14.78	0.0A	0.20	15.79	0.06	0.11	18.50
MgO	22.00	33.13	14.80	17.42	33.52	14.74	16.07	35.53	18.60
CaO	0.00	0.03	5.84	25.46	0.2A	6.0A	21.44	0.23	5.07
Na ₂ O	ND	ND	ND	0.51	ND	ND	1.73	0.04	0.03
K ₂ O	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.75	100.41	100.10	100.04	100.34	99.15	99.27	100.18	100.37

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	0	6	12	6	6	12	6	6	12
Si	1.091	1.005	2.061	1.984	1.971	2.974	1.978	1.976	2.974
Ti	0.01	0.01	0.02	0.01	0.01	0.02	0.04	0.02	0.03
Al	0.04	0.04	1.840	0.14	0.04	1.847	0.092	0.04	1.867
Cr	0.02	0.04	1.88	0.14	0.04	1.54	0.36	0.04	1.49
Fe ²⁺	0.09	0.28	0.88	0.87	0.27	0.86	0.67	0.16	0.66
Mn	0.04	0.07	0.49	0.02	0.06	0.50	0.02	0.03	0.30
Mg	0.04	1.72	0.62	0.45	1.741	1.634	0.74	1.818	1.993
Ca	0.07	0.12	1.463	0.15	0.01	0.486	0.838	0.008	0.391
Na	0.03	0.02	-	0.36	-	-	0.122	0.003	0.004
K	-	-	-	-	-	-	-	-	-
SUM	0.006	0.024	0.024	0.012	0.019	0.023	0.015	0.007	0.018
Wt	46.66	57	15.53	46.99	52	16.25	47.10	42	13.06
En	42.12	19	50.76	46.53	14	54.78	49.11	30	66.66
Fs	5.22	14.24	29.71	4.49	13.34	28.47	3.79	8.27	20.27
M:	00.21	45.69	64.83	91.54	80.59	65.41	92.84	91.69	76.68
C:	49.23	0.67	-	49.10	0.60	-	48.96	0.46	-

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 22,CPX(4)	4	PC25,GT(3)
2	PC 22,CPX(6)	7	PC33,CPX(5)
3	PC 22,GT(1)	A	PC33,OPX(5)
4	PC25,CPX(3)		PC33,GT(4)
5	PC25,OPX(4)		

* * * ND = NOT DETECTED * *

TABLE IV-2 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE I PYROXENITES

	1	2	3	4	5	6	7	8	9
SiO2	54.07	56.78	40.76	55.16	57.56	40.61	54.53	56.77	40.08
TiO2	.11	.02	.05	1.12	.06	.09	.96	.06	.08
Al2O3	2.40	.00	23.24	1.97	.56	22.20	.75	.39	20.08
Cr2O3	2.66	.06	11.22	3.85	.09	1.71	8.21	.12	12.68
FeO	2.69	6.78	11.74	3.55	8.75	13.69	2.38	8.21	12.81
MnO	.05	.10	.36	.06	.13	.48	.08	.15	17.63
MgO	16.50	35.27	18.36	15.98	33.27	16.98	17.25	33.00	17.61
CaO	21.01	21.20	4.73	21.61	.27	4.96	22.91	.19	5.61
Na2O	1.82	.04		1.75			.74		ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	99.40	100.02	100.49	101.04	101.29	99.93	99.69	98.91	99.40

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OXYGEN	6	6	12	6	6	12	6	6	12
Si	1.971	1.964	2.934	1.986	1.979	2.972	1.985	1.994	2.966
Ti	.003	.001	.003	.003	.002	.005	.002	.002	.004
Al	.103	.024	1.972	.084	.023	1.923	.041	.016	.151
Cr	.010	.002	.069	.024	.002	.090	.003	.003	.157
Fe2+	.082	.002	.707	.107	.252	.838	.072	.241	.793
Mn	.002	.003	.022	.002	.004	.030	.002	.004	.039
Mg	.897	1.818	1.970	.857	1.734	1.754	.936	1.727	1.920
Ca	.921	.007	.365	.834	.010	.389	.894	.007	.445
Na	.120			.122			.052		
K									
SUM	4.020	4.023	4.044	4.019	4.007	4.013	4.008	3.996	4.077
W0	45.62	47	42.00	46.37	46.50	43.05	46.99	47.36	44.09
EN	49.43	84.93	64.76	47.69	80.68	54.84	49.21	87.43	60.81
FS	4.58	9.70	23.24	5.95	12.02	28.11	3.81	12.21	25.11
M:	91.02	90.26	73.59	88.92	97.32	67.67	92.81	87.75	70.78
C:	47.79	.41		49.30	.57		48.85		

** SAMPLE DIRECTORY **

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC55, CPX(2)	6	PC54, GT(3)
2	PC55, OPX(2)	7	PC55, CPX(5)
3	PC55, GT(3)	8	PC55, OPX(2)
4	PC54, CPX(2)	0	PC55, GT(2)
5	PC54, OPX(2)		

** ND = NOT DETECTED **

TABLE IV-2 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE I PYROXENITES

	1	2	3	4	5
STO2	54.61	57.59	41.69	55.40	42.15
TiO2	0.07	.03	ND	.12	.09
AL2O3	3.06	.00	25.40	4.67	24.04
CR2O3	1.25	.12	1.32	4.45	4.43
FFO	1.64	5.03	8.80	2.24	4.84
MNO	.04	.04	.33	.05	.24
MCO	16.56	37.25	20.32	15.24	20.60
CAO	20.86	.16	4.30	19.14	4.12
HA2O	2.40	.04	ND	2.84	.04
K2O	.02	ND	ND	ND	ND
TOTAL	100.55	101.06	100.20	100.44	100.62

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * * *

OXYGEN	6	12	6	12
ST	1.962	2.962	1.977	2.970
TI	.001	.001	.003	.005
AL	.130	1.074	.205	1.999
CR	.036	.003	.013	.024
FF2+	.143	.523	.067	.521
MN	.001	.002	.002	.017
MC	.847	2.152	.813	2.164
CA	.803	.327	.733	.311
HA	.167	.003	.190	.005
K	.001	.001	.001	.001
SiM	4.034	4.021	4.011	4.017
W	46.14	10.91	45.47	10.39
EN	50.90	71.68	50.34	72.22
FS	2.83	17.42	4.14	17.39
M:	94.74	80.45	92.40	80.59
C:	47.52	.51	47.44	.59

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC5A,CPX(2)	4	PC34,CPX(5)
2	PC5A,OPY(3)	5	PC34,GT(4)
3	PC5A,C1(2)		

** ND = NOT DETECTED **

TABLE IV -3. Calculated end member molecules (mole%) for clinopyroxenes from Type I pyroxenites.

	PC21	PC22	PC25	PC33	PC35	PC54	PC55	PC58	PC34
NaTi(AlSi) ₂ O ₆	0.10	0.10	0.10	0.39	0.29	0.30	0.20	0.19	0.29
NaCrSi ₂ O ₆	2.28	2.19	1.38	3.55	1.85	2.37	2.19	3.47	1.27
NaAlSi ₂ O ₆	3.17	3.98	2.08	8.09	9.75	7.98	2.78	12.34	19.21
NaFe ³⁺ Si ₂ O ₆	-	-	-	-	0.68	1.38	-	0.19	-
CaAl(AlSi) ₂ O ₆	0.45	0.15	0.30	0.30	-	-	0.55	-	0.29
Ca ₂ Si ₂ O ₆	43.55	43.55	45.06	41.17	40.01	41.10	44.15	38.72	35.77
Mg ₂ Si ₂ O ₆	45.68	44.96	46.69	43.10	43.71	42.24	46.51	42.77	39.83
(Fe,Mn) ₂ Si ₂ O ₆	4.76	5.07	4.40	3.40	3.70	4.63	3.63	2.31	3.33

Table IV-4. Estimates of temperatures and pressures of equilibration for Type I pyroxenites from Koffiefontein.

	Temperature °C						Pressure kb	
	(1)	(2)	(3)	(4)	(5)	(6)		(7)
	Wood and Banno (1973)	Wells (1977)	Davis and Boyd (1960)	Boyd and Nixon (1973)	Akella and Boyd (1974)	Ellis and Green (1979)	Mysen (1976)	Wood (1974)
						(P=col. (8))		(T = col. (1))
PC21			<900°C		885			
PC22	940	860	<900	~960	905	1121	1223	39,7
PC25	927	836	"	950	865	1095	1304	41,9
PC33	922	794	"	<950	980	1138	1112	35,5
PC35	943	826	~930	"	983	1127	1170	38,3
PC54	900	798	<900	"	992	1161	1095	38,2
PC55	950	853	"	"	884	1117	1211	45,7
PC58	887	746	~940	"	946	1028	1154	32,9
PC34 (eclogite)	-	-	~940	-	(1093)		-	-

TABLE IV-5 RINK ROCK XRF ANALYSES OF TYPE I PYROXENITES

	1	2	3	4	5	6	7	8
ST02	54.71	54.45	54.11	54.01	54.65	54.30	52.80	53.20
TI02	.31	.31	.28	.28	.05	.05	.13	.23
AI2O3	1.80	1.41	1.41	1.35	1.45	1.44	4.20	4.25
CR2O3	6.45	6.36	7.04	7.74	5.66	5.52	1.17	6.74
FFU	1.14	1.14	1.14	1.14	1.14	1.14	4.13	4.14
MGO	24.55	24.20	27.54	27.10	21.01	22.19	21.55	22.56
CAO	11.13	11.55	7.50	7.53	15.07	15.02	13.95	11.84
NA2O	-	.42	.14	.14	.25	.24	.06	.05
K2O	.06	.00	.11	.12	.09	.08	.07	.00
TOTAL	100.57	99.90	99.94	99.94	99.94	99.94	98.68	100.00

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	1	2	3	4	5	6	7	8
OXYGEN	6	6	6	6	6	6	6	6
ST	1.048	1.050	1.032	1.030	1.070	1.058	1.909	1.907
TI	.008	.008	.008	.008	.001	.001	.004	.006
AI	.074	.057	.053	.057	.062	.061	.179	.180
CR	.017	.014	.013	.013	.012	.012	.032	.018
FF2+	.142	.140	.228	.231	.171	.164	.126	.203
MG	.005	.005	.005	.005	.004	.005	.004	.004
MC	1.303	1.244	1.404	1.470	1.181	1.143	1.159	1.205
CA	.025	.027	.027	.028	.036	.035	.067	.058
NA	.037	.034	.034	.034	.011	.011	.003	.002
KT	.002	.000	.003	.003	.003	.002	.002	.000
SUM	4.015	4.024	4.045	4.049	4.015	4.027	4.017	4.018
W0	22.12	22.33	10.47	14.49	30.42	24.93	29.30	23.58
FN	67.87	67.70	74.02	73.88	60.67	61.49	63.76	63.42
FS	10.01	9.97	11.51	11.63	8.92	8.58	6.94	11.00
M:	47.15	47.17	46.55	46.40	47.19	47.15	40.19	45.61
C:	24.58	24.60	16.35	16.40	33.39	32.74	31.49	26.49

* * * SAMPLE IDENTIFICATION * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 21-A	5	PC25A
2	PC 21-M	6	PC25B
3	PC27A	7	PC33A
4	PC27B	8	PC 54-A

TABLE IV-5 (CONTINUED) BULK ROCK XRF ANALYSES OF TYPE I PYROXENITES

	1	2	3	4	5	6
SiO ₂	51.34	51.09	47.36	48.97	50.76	50.53
TiO ₂	0.07	0.06	0.07	0.07	0.13	0.13
Al ₂ O ₃	2.36	2.36	11.25	11.60	10.20	10.20
Cr ₂ O ₃	1.04	1.09	1.11	1.13	4.46	4.47
FeO	7.41	7.20	5.53	5.69	4.70	4.82
MnO	0.17	0.17	0.22	0.22	0.15	0.16
MgO	25.90	25.60	22.95	23.11	17.94	18.15
CaO	10.08	10.08	0.29	0.09	13.54	13.42
Na ₂ O	0.55	0.55	1.10	1.11	1.68	1.69
K ₂ O	0.07	0.07	0.04	0.04	0.05	0.05
NiO	0.14	0.14	0.04	0.04	0.05	0.05
TOTAL	99.97	100.00	100.00	100.01	94.84	94.87

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	6	6	6	6	6	6
Si	1.861	1.871	1.752	1.738	1.819	1.812
Ti	0.002	0.002	0.002	0.002	0.004	0.004
Al	0.100	0.101	0.471	0.485	0.431	0.431
Cr	0.031	0.031	0.031	0.032	0.113	0.113
Fe ₂	0.221	0.221	0.164	0.166	0.141	0.145
Mn	0.005	0.005	0.007	0.007	0.005	0.005
Mg	1.399	1.383	1.214	1.223	0.958	0.970
Ca	0.226	0.224	0.076	0.076	0.520	0.516
Na	0.030	0.030	0.076	0.076	0.117	0.117
K	0.003	0.003	0.004	0.003	0.011	0.012
Ni	0.004	0.004	0.001	0.001	0.001	0.001
SUM	4.042	4.083	4.055	4.041	4.020	4.026
NO	20.43	20.92	19.62	18.14	32.12	31.63
EN	64.34	64.20	71.89	72.06	59.19	59.50
FS	10.42	10.08	9.69	9.80	8.70	8.07
M:	46.33	46.24	43.09	48.03	47.18	47.03
C:	23.36	23.48	20.62	20.11	35.18	34.71

A * S A M P L E D I R E C T O R Y * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC55A	1	PC58A
2	PC55B	5	PC34A
3	PC55A	A	PC34A

TABLE IV-5(a). Calculated pyroxene end member molecules (mole%) from bulk rock analyses of Type I pyroxenites.

	PC21	PC22	PC25	PC33	PC54	PC55	PC58	PC34
$\text{NaTi(AlSi)}_2\text{O}_6$	0.8	0.8	0.1	0.4	0.6	0.2	0.2	0.4
$\text{NaCrSi}_2\text{O}_6$	1.7	1.3	1.2	3.1	1.8	2.8	3.1	1.3
$\text{NaAlSi}_2\text{O}_6$	1.3	2.1	3.5	3.7	3.5	0.9	4.4	11
$\text{MgAl(AlSi)}_2\text{O}_6$	2.8	1.45	1.4	6.7	6.8	4.1	20.7	15.4
$\text{Ca}_2\text{Si}_2\text{O}_6$	21.0	13.9	29.9	26.1	21.3	19.6	15.0	25.3
$(\text{Fe,Mn})\text{Si}_2\text{O}_6$	9.7	11.3	3.9	6.4	10.2	10.4	8.3	7.2
$\text{Mg}_2\text{Si}_2\text{O}_6$	62.8	70.1	60.0	53.5	55.8	61.9	48.3	39.4

TABLE IV- 6. Bulk rock analyses of clinopyroxenites (with exsolved orthopyroxene and garnet from other localities.

	(1)	(2)	(3)	(4)
SiO ₂	50.20	48.41	49.26	49.00
TiO ₂	0.51	00.62	0.62	0.60
Al ₂ O ₃	8.37	10.41	8.63	8.63
Cr ₂ O ₃	0.24	0.43	0.31	0.32
FeO	7.14	7.93	8.01	6.56
MnO	0.16	0.18	0.17	0.15
MgO	19.00	17.78	19.40	19.40
CaO	13.28	12.17	12.44	13.08
Na ₂ O	0.87	1.24	0.88	1.10
K ₂ O	0.02	0.11	0.06	-
	<u>99.79</u>	<u>99.28</u>	<u>99.78</u>	<u>98.84</u>

(1) Type I clinopyroxenite, Salt Lake Crater, Ohau, Hawaii (Beeson and Jackson, 1973)

(2) "Eclogite", Salt Lake Crater, Ohau, Hawaii (Green, 1966)

(3) "Eclogite", Salt Lake Crater, Ohau, Hawaii (Green, 1966)

(4) Garnet-websterite, French Pyrenees (Herzberg, 1978).

TABLE IV -7. Microprobe analyses of high pressure pyroxenes, experimentally crystallised from an olivine-rich alkali basalt (data from Table II of Thompson, 1974)

Pres.(Kb)	17	20	24	28	31
Temp.(°C)	1360	1310	1400	1440	1475
°C below est. liq.	15	45	50	50	50
Pyroxene type	cpx	cpx	cpx	cpx	cpx
Other solids	pig	-	-	gt	gt
SiO ₂	52.2	52.1	50.3	50.3	50.3
TiO ₂	0.50	0.44	0.47	0.96	0.55
Al ₂ O ₃	6.39	6.84	9.54	9.78	10.8
Cr ₂ O ₃	0.53	0.41	0.32	0.23	0.33
FeO	9.29	9.14	8.79	9.25	8.21
MnO	0.20	0.21	0.21	0.19	0.20
MgO	24.3	22.0	18.0	17.1	17.4
CaO	6.01	8.04	10.6	10.7	10.6
Na ₂ O	0.51	0.85	1.43	1.57	1.88
K ₂ O	0.01	0.02	0.03	0.03	0.01
	<u>99.9</u>	<u>100.1</u>	<u>99.7</u>	<u>100.1</u>	<u>100.3</u>

cpx- Ca rich clinopyroxene (including sub-calcic augite)

pig- pigeonite

gt- garnet

Table IV-8. Chemical modes (wt.%) of Type II pyroxenites (visual estimates (vol.%) are given in brackets.)

	orthopyroxene	clinopyroxene	garnet	chromite	phlogopite
PC20A	81.2	7.17	11.64	-	-
PC20B	86.55	11.45	-	-	-
PC24A	92.53 (94)	-	5.32 (5)	-	2.4 (1)
PC24B	N.C. (92)	-	N.C. (8)	-	-
PC27	84.6 (89)	1.95 (1)	11.67 (10)	-	-
PC28	87.6 (88)	8.5 (7)	3.3 (3)	.01 (2)	-
PC71	N.C. (92)	-	N.C. (8)	-	-

NOTE: N.C. - Not calculated. In the case of PC71 bulk rock not available.

TABLE IV-9 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE II PYROXENITES

	1	2	3	4	5	6	7	8
SiO ₂	58.31	61.71	61.67	58.91	41.84	36.92	57.83	41.93
TiO ₂	ND	ND	ND	ND	ND	ND	ND	ND
Al ₂ O ₃	75	70	15.31	70	21.39	11.50	69	20.72
Cr ₂ O ₃	32	31	31	31	4.26	6.51	30	4.90
FeO	3.64	5.70	2.46	3.99	6.40	6.51	4.51	6.00
MnO	0.8	26	0.02	0.8	2.0	21.83	35.07	6.32
CaO	35.83	21.97	25.09	36.95	21.74	21.83	35.77	21.66
Na ₂ O	0.6	4.0	0.2	3.3	4.52	2.50	6.0	4.0
K ₂ O	0.11	ND	0.06	0.02	ND	2.45	0.8	ND
TOTAL	94.55	94.12	93.77	101.37	100.61	83.41	99.88	100.62

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	12	22	6	12	22	6	12
Si	1.947	2.943	5.947	1.942	2.942	5.942	1.981	2.972
Ti	0.001	0.004	0.024	0.001	0.002	0.060	0.001	0.001
Al	0.30	1.733	2.239	0.28	1.784	2.171	0.028	1.731
Cr ₂ +	0.09	0.65	0.90	0.09	0.384	0.77	0.08	0.361
Mn	0.04	0.242	0.294	0.112	0.17	0.35	0.02	0.19
Fe	0.02	0.16	0.02	0.02	0.295	5.166	0.02	0.288
Ca	1.819	2.67	5.354	1.853	3.43	4.25	1.826	2.377
Na	0.017	0.382	0.22	0.12	0.07	0.39	0.05	0.05
K	0.007	0.01	0.039	0.01	0.01	0.452	0.005	0.005
SUM	3.966	8.005	15.746	4.002	8.029	15.250	4.003	8.026
MN	0.07	12.77	15.746	0.60	11.34	15.250	1.11	12.47
FE	5.37	75.79	75.79	5.68	75.95	75.95	6.53	75.60
CA	11.44	11.44	11.44	12.71	12.71	12.71	11.93	11.93
M:	94.58	86.69	86.69	94.29	85.66	85.66	93.39	86.37
C:	92.92	86.69	86.69	86.69	86.69	86.69	86.37	86.37

* * * SAMPLE D I R F C T O R Y * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 24A, OPX(5)	5	PC 24B, GT(2)
2	PC 24A, G1(2)	6	PC 24B, MICA(1)
3	PC 24A, PHLOGOPITE(2)	7	PC 71, OPX(3)
4	PC 24B, OPX(4)	8	PC 71, GARNET(6)

** ND = NOT DETECTED **

TABLE IV-9 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE II PYROXENITES

	1	2	3	4	5	6	7
STO2	54.30	41.74	54.89	58.14	54.63	40.97	.06
TI02	.04	.18	.10	ND	.02	ND	ND
AL2O3	.70	21.27	2.24	.58	3.53	21.14	10.76
CR2O3	.31	4.20	1.68	.17	2.44	3.71	54.53
FE2O3	-	-	-	-	-	-	7.02
MNO	4.79	7.09	2.23	5.08	2.37	8.82	15.24
W0	.11	.35	.11	.11	.10	.44	.83
MGO	35.43	20.34	17.53	35.74	14.91	19.73	11.41
CAO	.57	4.75	14.55	2.4	18.61	4.14	.03
NA2O	.14	ND	1.74	.03	5.66	ND	.03
K2O	ND	ND	.02	ND	ND	ND	.03
TOTAL	100.42	100.03	100.10	100.11	100.28	98.98	99.93

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

	6	12	6	6	6	12	4
OXYGEN	6	12	6	6	6	12	4
ST	1.988	2.980	1.977	1.989	1.972	2.974	.002
TI	.002	.010	.001	.023	.001	1.809	.415
AL	.028	1.790	.095	.005	.150	.213	1.173
CR	.008	.242	.048	.145	.070	.535	.417
FE3+	.137	.423	.067	.003	.072	.027	.023
FE2+	.003	.021	.004	.003	.003	.134	.556
MN	1.801	2.164	.941	1.822	.802	2.122	.001
MG	.021	.363	.754	.009	.720	.322	.001
CA	.000	-	.121	.002	.256	-	.001
NA	-	-	.001	-	-	-	.001
K	-	-	-	-	-	-	.001
SUM	3.997	7.996	4.010	3.998	4.046	8.016	3.000
MO	1.04	CA 12.31	MO 42.40	MO 45	MO 45.17	CA 10.76	CR .77
FN	91.84	MG 73.34	FN 92.20	FN 92.20	FN 50.34	MG 71.34	MG .57
FS	6.98	FE 14.35	FS 3.81	FS 7.35	FS 4.49	FE 17.90	FF .09
M:	92.95	M: 85.64	M: 93.34	M: 92.61	M: 91.81	M: 79.44	
C:	1.14	C: 15.64	C: 44.50	C: .48	C: 47.30		

** SAMPLE DIRECTORY **

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC27, Opx(3)	5	PC28, Cpx(2)
2	PC27, St(2)	6	PC28, St(2)
3	PC27, Cpx(3)	7	PC28, Chromite(3)
4	PC28, Opx(3)		

** ND = NOT DETECTED **

TABLE IV-9 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE II PYROXENITES

	1	2	3	4	5	6	7	8
SiO2	41.41	41.30	58.17	54.27	57.51	54.18	55.78	57.52
TiO2	0.04	0.05	0.04	0.12	0.06	0.17	0.13	0.05
Al2O3	22.03	21.87	0.87	2.63	1.45	4.27	3.69	1.14
Cr2O3	3.15	3.21	0.28	1.83	0.33	1.30	1.53	1.37
FeO	7.93	7.69	4.16	1.83	4.07	1.78	1.02	4.30
MnO	0.35	0.32	0.17	0.05	0.07	0.05	0.04	0.86
MgO	20.35	20.02	36.52	16.37	36.25	14.49	15.13	35.88
CaO	4.70	5.02	0.14	21.27	0.04	21.07	21.33	0.14
Na2O	ND	ND	ND	2.08	ND	2.33	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	99.48	99.50	100.29	99.66	100.02	98.74	101.00	99.50

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	12	12	6	6	6	6	6	6
Si	2.970	2.966	1.978	1.966	1.962	1.971	1.984	1.974
Ti	1.863	1.851	0.02	0.03	0.02	0.05	0.03	0.01
Al	1.170	1.182	0.08	0.12	0.05	0.18	0.15	0.06
Cr	0.458	0.462	0.11	0.02	0.09	0.40	0.43	0.10
Fe2+	0.021	0.019	0.02	0.03	0.02	0.02	0.03	0.02
Mn	0.145	0.143	0.51	0.84	1.842	0.78	0.80	1.835
Mg	0.368	0.366	0.05	0.25	0.02	0.21	0.13	0.02
Ca	-	-	-	0.14	0.03	0.16	0.16	-
Na	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-
SUM	9.008	8.015	4.000	4.022	4.004	3.995	3.994	3.998
CA	12.39	12.42	0.26	07.43	0.46	50.37	49.41	26
MG	72.20	71.60	93.75	50.77	93.93	48.18	48.75	93.45
FE	15.41	15.40	5.99	1.79	5.90	1.46	1.84	6.28
M:	82.41	82.27	93.99	96.59	94.07	97.07	96.35	93.70
C:	-	-	0.27	48.30	0.49	51.11	50.34	0.28

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSTS NO.	DESCRIPTION
1	PC20A, GT 1	5	PC20A, GPX 5
2	PC20A, GT 2	6	PC20A, CPX 6
3	PC20A, GPX 3, NEXT TO GT 2	7	PC20A, CPX 7
4	PC20A, CPX 4	8	PC20A, GPX 8

** ND = NOT DETECTED **

TABLE IV-9 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE II PYROXENITES

	1	2	3	4
STO2	58.11	58.52	58.07	55.35
TiO2	.05	.05	.05	.15
Al2O3	.96	.98	.97	3.48
CR2O3	.43	.42	.40	1.83
FFO	4.22	4.27	4.13	1.13
MNO	.05	.05	.04	.06
MGO	35.96	36.13	36.08	15.98
CAO	.16	.13	.20	21.02
NA2O	.06	.05	.05	2.37
K2O	.03	ND	ND	ND
TOTAL	100.03	100.58	100.00	101.38

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6
ST	1.982	1.984	1.980	1.966
TI	.001	.001	.001	.004
AL	.039	.039	.039	.146
CR	.012	.011	.011	.051
FF2+	.120	.121	.118	.034
MN	.001	.001	.001	.002
MG	1.828	1.828	1.834	.846
CA	.004	.005	.007	.800
NA	.004	.003	.003	.163
K	.001			
SUM	3.994	3.991	3.995	4.013
MO	30	24	37	60
EN	93.54	93.55	93.61	47.63
FS	6.14	6.21	6.01	50.37
M:	93.82	93.78	93.96	96.18
C:	.32	.26	.40	48.61

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION
1	PC20R, OPX 1
2	PC20R, OPA 2
3	PC20R, OPX 3, NEXT TO CPX LAMELLAE
4	PC20R, CPX 4, LAMELLAE

** ND = NOT DETECTED **

TABLE IV - 10. Calculated end member molecules (mole%) for orthopyroxenes from Type II pyroxenites.

	PC20A	PC20B	PC24A	PC24B	PC27	PC28	PC71
$\text{NaTi(AlSi)}_2\text{O}_6$	0.09	0.1	0.1	0.1	0.2	-	0.1
$\text{NaCrSi}_2\text{O}_6$	0.09	0.4	0.6	0.4	0.7	0.2	0.4
$\text{MgCr(AlSi)}_2\text{O}_6$	0.9	0.8	0.3	0.4	0.1	0.3	0.5
$\text{MgAl(AlSi)}_2\text{O}_6$	1.69	1.50	1.32	1.25	1.25	1.00	1.10
$\text{Ca}_2\text{Si}_2\text{O}_6$	0.20	0.3	0.9	0.6	1.05	0.45	1.10
$(\text{Fe,Mn})\text{Si}_2\text{O}_6$	5.9	6.51	5.38	5.68	7.02	7.41	5.96
$\text{Mg}_2\text{Si}_2\text{O}_6$	91.13	90.39	91.43	91.57	89.67	90.63	90.83

TABLE IV-11. Estimates of temperatures and pressures of equilibration for Type II pyroxenites.

	<u>Temperature °C (1 to 7)</u>							<u>Pressure Kb (8 to 10)</u>		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Boyd and Nixon (1973)	Davis and Boyd (1966)	Wood and Banno (1973)	Wells (1977)	Mysen (1976)	Akella and Boyd (1974)	Ellis and Green (1979) P(col.9) P(col.10)	T(col.1)	T(col.3)	T(col.4)
PC20A	~ 900	~ 900	809	558	-	-	-	-	23.4	14.9
PC20B	~ 900	~ 900	929	785	-	-	-	-	-	-
PC24A	~ 1030	-	-	-	-	-	-	40	-	-
PC24B	~ 970	-	-	-	-	-	-	37	-	-
PC27	~ 1070	~ 1050	1118	1015	1267	1119	1322	1299	43	45
PC28	~ 925	~ 940	858	702	991	1112	1222	1191	38	32
PC71	~ 1050	-	-	-	-	-	-	43	-	-

TABLE IV - 12 BULK ROCK XRF ANALYSES OF TYPE II PYROXENITES

	1	2	3	4	5	6	7	8
SiO2	55.20	55.31	55.13	56.84	56.63	56.63	54.90	54.84
TiO2	.04	.04	.05	.04	.05	.04	.17	.17
Al2O3	3.42	3.43	3.73	2.13	1.97	1.95	3.09	3.13
Cr2O3	1.00	1.08	1.11	3.57	3.52	3.52	4.42	4.45
FeO	4.57	4.57	4.51	3.90	4.11	4.10	5.17	5.14
MgO	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10
MnO	32.93	32.56	32.16	35.24	35.34	35.20	33.27	33.34
CaO	2.21	2.22	2.03	35.97	35.90	35.96	1.96	1.98
Na2O	.18	.18	.17	.11	.18	.18	.17	.17
K2O	.18	.18	.17	.07	.10	.12	.20	.23
H2O	.00	.00	.00	.00	.00	.00	.00	.00
TOTAL	100.00	100.00	99.94	99.99	99.93	99.90	99.93	100.02

A * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

OXYGEN	0	6	6	6	6	6	6	6
Si	1.010	1.013	1.009	1.046	1.043	1.045	1.005	1.002
Ti	.002	.002	.001	.002	.001	.002	.004	.004
Al	.140	.086	.050	.086	.050	.079	.126	.123
Cr	.040	.030	.030	.012	.014	.014	.022	.023
Fe ²⁺	.132	.131	.131	.112	.112	.120	.150	.150
Mg	.003	.003	.003	.003	.003	.003	.004	.004
Mn	1.603	1.603	1.600	1.794	1.807	1.801	1.723	1.723
Ca	.082	.082	.090	.036	.035	.035	.073	.074
Na	.036	.036	.037	.003	.012	.012	.011	.011
K	.008	.008	.008	.003	.004	.005	.011	.010
NT	.000	.000	.000	.000	.000	.000	.000	.000
SUM	4.024	4.023	4.021	4.007	4.017	4.016	4.027	4.029
Wt	4.32	4.35	4.79	1.83	1.74	1.80	3.75	3.78
FM	84.71	84.70	84.26	92.43	92.22	92.05	84.53	84.52
FS	6.97	6.91	6.95	5.74	6.02	6.15	7.72	7.70
M:	92.71	92.77	92.70	94.15	93.87	93.74	91.98	91.99
C:	4.64	4.67	5.15	1.94	1.88	1.92	4.06	4.09

A * S A M P L E D I R E C T O R Y * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 20A-A	5	PC 24B-A
2	PC 20A-B	6	PC 24B-B
3	PC 20A-C	7	PC 27-A
4	PC 24A-A	8	PC 27-B

TABLE IV-12(CONTINUED) RIM K ROCK XRF ANALYSES OF TYPE II PYROXENITES

	1	2	3	4
SiO2	56.20	56.15	56.28	55.03
TiO2	0.04	0.06	0.02	0.03
Al2O3	1.61	1.94	2.20	4.16
Cr2O3	4.95	7.74	5.77	4.06
FeO	4.12	5.05	4.20	4.40
MnO	35.43	33.33	34.57	36.66
MgO	2.10	2.10	2.95	1.98
CaO	0.36	0.37	0.98	1.19
K2O	0.10	0.20	0.00	0.00
Na2O	0.10	0.11	0.00	0.00
TOTAL	99.92	100.00	99.24	102.71

* * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	0	0	6
Si	1.940	1.944	1.944	1.852
Ti	0.002	0.001	0.001	0.001
Al	0.064	0.093	0.093	0.165
Cr	0.21	0.18	0.18	0.02
Fe2+	0.143	0.144	0.124	0.124
Mn	0.04	0.04	0.02	0.03
Mg	1.720	1.720	1.720	1.838
Ca	0.04	0.05	0.05	0.07
Na	0.024	0.025	0.005	0.012
K	0.00	0.00	0.00	0.00
NT	0.003	0.003	0.000	0.003
SUM	11.022	11.025	11.003	11.071
Wt %	6.18	6.17	6.0	3.51
FM	48.45	48.42	41.70	40.40
FS	7.57	7.51	6.50	6.00
M:	92.31	92.16	93.40	93.69
C:	4.51	4.51	1.94	3.74

A * S A M P L E D I R E C T O R Y * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC28A	3	PC71(ESTIMATED)
2	PC28B	4	1195(CARSWELL,1973)

TABLE IV - 12 (A). Calculated pyroxene end member molecules (mole%) from bulk rock analyses of Type I pyroxenites.

	<u>FC20A</u>	<u>FC20B</u>	<u>FC24A</u>	<u>FC24B</u>	<u>FC27</u>	<u>FC28</u>
NaTi(AlSi) ₂ O ₆	0.2	0.2	0.2	0.2	0.4	0.4
NaCrSi ₂ O ₆	2.9	2.9	0.8	1.4	1.7	2.1
NaAlSi ₂ O ₆	1.2	1.3	--	0.1	-	1.1
MgCr(AlSi) ₂ O ₆	-	-	0.7	-	0.5	-
MgAl(AlSi) ₂ O ₆	6.1	6.4	3.8	3.8	5.7	2.6
CaSi ₂ O ₆	3.9	4.2	1.8	1.7	3.6	4.0
(Fe,Mn)Si ₂ O ₆	6.6	6.6	5.7	6.0	7.5	7.3
Mg ₂ Si ₂ O ₆	79	78.4	87	86.8	80.6	82.8

TABLE IV-13. Visual estimates of modal proportions (vol.%) of minerals in Type III pyroxenites.

	<u>orthopyroxene</u>		<u>clinopyroxene</u>		<u>garnet</u>	<u>chromite</u>
	primary	exsolved	total	total		
PC29	75	-	20	20	5	-
PC30	70	10	20	30	-	-
PC31	75	-	5	5	20	-
PC39	90	1(?)	1(?)	2	8	-
PC41	87	-	8	8	-	5
PC50	85	-	10	10	5	-

TABLE IV-10 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE III PYROXENITES.

	1	2	3	4	5	6	7	8	9
SiO2	57.68	55.60	41.47	57.81	54.64	51.67	54.55	42.15	41.69
TiO2	.02	.07	.05	.14	.20	.02	.07	.04	.19
Al2O3	.71	2.44	.54	.75	1.70	.83	4.77	22.55	14.90
FeO	.21	1.31	2.21	.27	1.09	.27	2.77	2.80	2.82
Fe2O3	4.76	1.40	6.40	5.07	2.64	4.42	2.42	7.30	2.72
MnO	.09	1.05	.36	.11	.11	.10	13.89	21.40	25.51
MgO	35.21	19.30	14.79	34.33	18.04	35.72	17.02	3.77	ND
CaO	.21	2.55	4.79	.66	1.41	.26	4.36	.07	.64
Na2O	ND	2.02	.07	ND	1.57	ND	ND	ND	8.93
K2O	ND	ND	ND	ND	1.03	ND	ND	ND	ND
TOTAL	99.55	101.24	100.12	99.26	94.63	94.44	99.86	100.53	95.45

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	12	6	6	6	6	6	12	22
Si	1.079	2.940	1.046	1.079	1.079	1.042	1.071	2.975	5.818
Ti	.002	.003	.004	.007	.007	.001	.001	.002	.020
Al	.032	1.095	.031	.074	.031	.034	.200	1.876	2.451
Fe	.014	.125	.007	.031	.031	.007	.073	1.156	.090
Fe2+	.137	.501	.146	.040	.040	.127	.434	.434	.317
Mn	.002	.022	.003	.003	.003	.003	.003	.023	.005
Mg	1.832	2.092	1.764	.075	.075	1.820	.747	2.251	5.306
Ca	.009	.366	.024	.754	.754	.010	.659	.285	1.173
Na	.139	.010	.008	.112	.112	.009	.305	.010	.590
K	-	-	-	.001	.001	-	-	-	-
SUM	4.000	8.000	3.986	4.018	4.018	4.002	4.040	8.012	15.773
Si	30	47.48	40	41.69	41.69	40	44.55	9.60	12
Fe	92.00	14.95	91.18	53.80	53.80	93.05	50.50	75.79	22
Fe2+	6.92	2.56	7.56	4.42	4.42	6.46	4.91	14.61	12
Mn	93.05	80.00	82.35	2.42	2.42	93.51	91.08	83.84	22
Ca	.42	48.73	1.36	43.61	43.61	4.52	46.87	14.61	22

* * * SAMPLE IDENTIFY * *

ANALYSIS NO.	DESCRIPTION	ANALYSTS NO.	DESCRIPTION
1	PC20, CPX(3)	7	PC31, OPX(5)
2	PC20, CPX(3)	8	PC31, CPX(3)
3	PC20, GT(2)	9	PC31, GT(5)
4	PC30, OPX(4)		PC31, MICA(2)
5	PC30, CPX(2)		

** ND = NOT DETECTED **

TABLE IV-14 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE III PYROXENITES

	1	2	3	4	5	6	7	8
STO2	58.08	54.75	41.84	57.33	57.31	54.62	19	45.01
TiO2	.02	1.10	ND	.11	.11	.14	2.31	1.73
Al2O3	.22	3.82	23.24	.51	.49	1.14	5.59	1.73
Cr2O3	.22	2.14	2.14	.46	1.31	2.55	59.07	17.10
FeO	4.37	2.05	7.41	5.42	6.14	2.12	20.14	17.07
MnO	.08	.04	.30	.13	.15	.12	12.91	20.52
MgO	26.83	14.91	21.97	35.07	34.02	17.84	12.33	1.49
CaO	.23	10.95	3.84	.66	.67	14.54	ND	.17
Na2O	.00	5.44	ND	.12	.16	1.45	-	.05
K2O	ND	ND	ND	ND	.02	.05	-	.17
TOTAL	100.60	100.25	100.82	99.82	100.42	99.60	100.55	86.30

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	6	12	6	6	6	6	4	9
OXYGEN	1.072	2.941	1.972	1.972	1.975	1.983	.006	2.894
ST	.001	.002	.003	.003	.003	.000	.058	.003
Ti	.030	1.924	.021	.021	.020	.040	.559	.131
Al	.004	.122	.013	.013	.034	.061	1.562	.005
Cr	.124	.434	.154	.154	.178	.077	.019	.004
Fe2+	.002	.018	.009	.009	.004	.004	.026	.004
Mn	1.863	2.302	1.802	1.747	1.747	.967	.614	1.966
Mg	.008	.289	.024	.024	.025	.702	-	.103
Ca	.004	-	.008	.008	.011	.102	-	.006
Na	-	-	-	-	.001	.002	-	.014
K	-	-	-	-	-	-	-	-
SUM	6.013	8.034	4.008	4.008	4.000	4.010	3.046	6.045

	W0	FN	FS	M:	C:
W0	.42	9.54	4.008	W0 1.27	W0 12.14
FN	3.36	76.05	FN 90.49	FN 89.60	FN 53.57
FS	6.22	14.39	FS 7.88	FS 4.13	FS 4.29
M:	3.74	84.09	M: 92.02	M: 90.75	M: 92.58
C:	.45	-	C: 1.34	C: 1.40	C: 44.03

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION
1	PC30, OPX(5)
2	PC30, Cpx(2)
3	PC30, Cpx(2)
4	PC41, OPX(4)
5	PC41, OPX(4)
6	PC41, Cpx(4)
7	PC41, CHROMITIFS(2)
8	PC41, SERPENTINIF(1)

* * * ND = NOT DETECTED * *

TABLE IV-14 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE III PYROXENITES

	1	2	3
STO2	55.44	53.50	34.60
TIO2	.05	.13	.67
AL2O3	.50	1.22	13.89
CR2O3	5.72	2.41	12.30
FFU	.12	.09	8.10
MNO	35.71	14.28	3.36
CAO	.01	14.57	16.94
NA2O	.13	1.52	8.67
K2O	ND	.04	.03
TOTAL	94.28	94.24	100.57

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	0	6	12
ST	1.745	1.963	2.951
TI	.001	.004	.034
AL	.024	.053	1.220
CR	.014	.058	.725
FF2+	.107	.082	.505
MN	.004	.003	.023
MG	1.853	.049	1.842
CA	.023	.761	.642
NA	.009	.104	.004
K	-	.002	-
SUM	4.040	4.033	4.041
MO	1.11	41.31	22.49
FM	90.73	54.23	61.11
FS	4.16	4.46	10.40
M:	91.75	96.40	78.80
C:	1.21	43.24	-

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC50, OXY(5)	3	PC50, GT(3)
2	PC50, OXY(2)		

* * * ND = NOT DETECTED * *

TABLE IV-15. Estimates of temperatures and pressure of equilibration for Type III pyroxenites.

		Temperature °C (1 to 7)							(8)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)		
	Wood and Banno(1973)	Davis and Boyd(1966)	Boyd and Nixon(1973)	Wells (1977)	Mysen (1976)	Akella and Boyd(1974)	Ellis and Green(1979)	Wood (1974)	
PC29	933	~ 908	~ 900	798	1462	924	1047	36	
PC30	1136	~ 1080	~ 1120	1033	1395	-	-	-	
PC31	894	~ 970	~ 930	752	1218	1272	1242	31	
PC39	868	~ 940	~ 900	721	1289	1169	1286	40	
PC41	1148	~ 1070	~ 1100	1051	1677	-	-	-	
PC50	1119	~ 1090	~ 1080	999	1524	-	-	36	

T(col.1)

TABLE IV-16. Visual estimates of modal proportions (vol.%) of minerals in Type IV pyroxenites.

	<u>orthopyroxene</u>	<u>clinopyroxene</u>	<u>phlogopite</u>	<u>amphibole</u>	<u>% porphyroclasts</u>
PC65	100	-	-	-	-
PC60	97	-	3	1 grain	40
PC43	97	3	-	-	-
PC23	93	5	2	-	30
PC26	89	10	-	1	-
PC66	87	10	3	-	3
PC68	60	40	2 small grains	-	55
PC53	65	35	3 small grains	-	10
PC57	-	70	30	-	-

TABLE IV-17 MICROANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7	8	9
SiO2	42.64	42.43	53.43	55.58	53.68	53.84	55.63	55.89	55.81
TiO2	15.19	14.73	2.21	1.76	1.20	1.20	1.06	1.10	1.12
Al2O3	2.54	2.43	2.95	9.71	2.08	2.10	8.57	8.79	9.04
Cr2O3	ND	ND	12	31.45	16.99	17.02	32.17	31.17	32.11
MnO	26.50	26.15	74.62	ND	24.45	24.79	ND	ND	32.40
MgO	10.19	10.52	ND	ND	ND	ND	ND	ND	ND
CaO	98.65	97.68	100.62	99.32	100.21	100.51	98.08	98.43	98.72
K2O									
TOTAL									

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	22	22	6	6	6	6	6	6	6
Si	5.770	5.809	1.943	1.960	1.958	1.958	1.976	1.980	1.974
Ti	2.027	2.377	.095	.073	.053	.055	.044	.046	.047
Al	.064	.054	.012	.005	.002	.003	.001	.001	.001
Cr	.290	.278	.090	.286	.089	.089	.255	.260	.267
Fe2+	5.352	5.334	.875	1.453	.924	.922	1.703	1.683	1.692
Mn	.050	.089	.060	.016	.071	.066	.016	.019	.015
Mg	1.702	1.834	.044	.044	.025	.025	.016	.019	.015
Ca	15.804	15.856	4.024	4.001	4.025	4.025	4.001	3.997	4.003
K									
SUM									
			MO 49.90 EN 45.44 FS 4.66 M: 90.70 C: 52.34	MO 84.54 EN 14.05 FS 1.41 M: 85.23 C: 51.26	MO 44.02 EN 46.62 FS 4.36 M: 91.45 C: 51.16	MO 48.44 EN 46.60 FS 4.52 M: 91.16 C: 51.15	MO 83.27 EN 86.60 FS 12.90 M: 86.99 C: 51.14	MO 85.75 EN 85.54 FS 13.26 M: 86.60 C: 51.14	MO 85.77 EN 85.54 FS 13.54 M: 86.36 C: 51.14

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSTS NO.	DESCRIPTION
1	PC 23, PHENOPTIC 2	6	PC23, CPX6, EDGE, NEXT TO OPX 8
2	PC 23, PHENOPTIC 3	7	PC23, OPXA, EDGE
3	PC 23, PHENOPTIC TO OPX 4, 5	8	PC23, OPXA, CENTRE
4	PC 23, OPTIC. HORNG. GRAIN	9	PC23, OPX10 (RECRYST. GRAIN)
5	PC 23, CPX6, CLITK (WITH FXSOL.)		

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7	8	9	10
STP	56.01	56.37	56.82	55.93	55.52	55.85	55.62	52.40	53.43	52.59
TI	.06	.07	.06	.02	.06	.05	.11	.21	.13	.24
AL	2.50	2.48	2.51	2.42	2.47	2.45	2.53	3.27	3.22	3.79
CR	7.82	7.30	7.31	6.30	7.28	7.30	7.32	3.65	5.58	3.66
FFU	1.09	1.11	1.11	0.97	1.12	1.07	1.09	3.07	5.09	3.80
MNU	32.89	33.14	33.24	34.46	32.91	33.41	31.81	14.85	22.85	15.01
CAI	ND	.26	.18	ND	ND	ND	2.16	23.07	12.13	23.06
NA2O	ND	ND	.02	ND	ND	ND	ND	1.20	ND	1.20
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	99.89	100.57	101.18	100.52	99.30	100.18	99.90	99.98	98.68	100.45

A * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6	6	6
ST	1.944	1.949	1.949	1.927	1.940	1.936	1.939	1.920	1.933	1.918
TI	.002	.002	.002	.001	.002	.001	.003	.006	.004	.007
AL	.106	.101	.101	.098	.102	.100	.104	.163	.137	.163
CR	.009	.008	.008	.008	.008	.008	.009	.019	.017	.019
FE2+	.226	.227	.227	.201	.222	.222	.210	.115	.168	.116
MN	.003	.003	.003	.002	.004	.003	.003	.002	.003	.002
MG	1.704	1.698	1.698	1.770	1.714	1.726	1.652	.811	1.232	.816
CA	.010	.007	.007	.012	.012	.012	.081	.906	.470	.901
NA	-	.001	.001	-	-	.001	.004	.085	.048	.085
K	-	-	-	-	-	-	-	-	-	-
SUM	3.998	3.996	3.996	4.020	4.004	4.010	4.004	4.026	4.011	4.027
W	87.98	87.50	87.50	89.25	87.98	88.59	85.15	49.45	25.14	49.17
EN	11.49	11.04	11.75	10.13	11.40	11.35	10.79	44.27	65.87	44.51
FS	-	-	-	-	-	-	-	6.27	8.99	6.32
M:	86.45	88.31	88.21	89.81	88.53	88.59	88.74	87.59	87.99	87.56
C:	.61	.56	.59	.68	.69	.68	4.65	52.76	27.62	52.48

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC26, OXYIC(OPTIC: HOMOG.)	6	PC26, DITIIO, B
2	PC26, OXYIC(OPTIC: HOMOG.)	7	PC26, DITIIO, C
3	PC26, OXYIC(OPTIC: HOMOG.)	8	PC 26, CPX 4 TRAVERSE, A
4	PC 26, OXYIC(OPTIC: HOMOG.)	9	PC 26, CPX 4 TRAVERSE, B
5	PC26, OXY 3 TRAVERSE, A	10	PC 26, CPX 4 TRAVERSE, C

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	11	12	13	14	15	16
SiO2	52.59	52.15	55.67	51.91	43.54	43.82
TiO2	.13	.20	.06	.19	1.09	1.06
Al2O3	2.20	3.40	2.49	3.82	13.67	13.87
Cr2O3	.57	.70	.30	.62	1.22	1.10
FeO	0.11	3.68	7.69	3.63	6.13	5.63
MnO	.04	.07	.09	.06	.04	.04
MgO	23.21	15.22	34.00	15.42	17.53	17.43
CaO	12.99	23.20	.00	23.05	12.32	12.40
Na2O	.54	1.24	.00	1.22	2.86	2.60
K2O	ND	ND	ND	ND	1.10	1.14
TOTAL	94.21	100.50	100.41	100.11	94.59	94.47

A A ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	23	23
Si	1.004	1.003	1.021	1.002	6.102	6.195
Ti	.004	.005	.001	.005	.116	.112
Al	.146	.172	.101	.165	2.263	2.311
Cr	.016	.020	.002	.020	.137	.133
Fe2+	.185	.112	.222	.111	.726	.689
Mn	.005	.002	.003	.002	.005	.005
Mg	1.252	.829	1.742	.845	3.701	3.573
Ca	.092	.007	.012	.005	1.870	1.879
Na	.032	.091	.012	.091	1.765	1.757
K	-	-	-	-	.215	.206
SUM	4.034	4.041	4.024	4.046	14.004	15.041

	MO	EM	FS	W	C
MO	25.59	14.01	17.93	48.61	88.37
EM	64.31	64.61	7.93	45.41	51.70
FS	4.59	6.02	11.16	5.92	
W	47.13	48.05	49.74	88.37	
C	26.20	52.20	1.03	51.70	

A A A SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11	PC 26, CPX 4 TRAVERSE F, D	14	PC 26, CPX 7
12	PC 26, CPX 5	15	PC 26, AMPHIBOLE A
13	PC 26, Opx 6	16	PC 26, AMPHIBOLE 9

* * ND = NOT DETECTED * *

TABLE IV-17 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7	8	9	10
STO2	55.35	55.51	55.31	54.19	52.50	55.44	55.50	54.76	54.43	55.11
TiO2	.02	.03	.06	.15	.29	.02	.06	.10	.05	.02
AL2O3	2.08	2.49	2.70	1.58	3.55	2.47	2.81	2.79	2.73	2.76
CR2O3	4.07	4.12	4.13	2.28	2.24	4.16	4.17	6.17	8.14	9.23
FeO	9.07	9.17	8.91	4.54	2.94	9.30	9.13	6.90	8.80	9.23
MnO	31.02	32.36	32.11	25.05	15.04	31.44	31.12	28.11	31.14	31.13
MgO	.20	.18	.32	10.40	15.84	31.40	31.94	28.70	31.43	31.45
CAU	ND	ND	ND	0.06	23.20	0.02	0.63	2.18	0.53	0.02
NA2O	ND	ND	ND	0.04	23.76	0.02	ND	0.11	ND	ND
K2O	ND	ND	ND	0.04	ND	ND	ND	ND	ND	ND
TOTAL	99.50	100.40	99.82	97.04	99.19	100.15	100.38	97.83	98.82	99.43

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * * *

	6	6	6	6	6	6	6	6	6	6
OXYGEN	1.941	1.931	1.933	1.969	1.928	1.934	1.933	1.961	1.940	1.938
ST	.001	.001	.002	.004	.008	.001	.002	.003	.001	.001
AL	.111	.111	.111	.068	.145	.118	.115	.114	.114	.114
CR	.003	.003	.004	.002	.007	.007	.005	.005	.004	.004
FE2+	.263	.257	.260	.130	.090	.272	.266	.267	.261	.271
MN	.004	.004	.003	.002	.002	.004	.004	.003	.004	.004
Mg	1.468	1.477	1.487	1.392	.857	1.439	1.458	1.532	1.454	1.448
CA	.008	.007	.007	.003	.013	.026	.024	.024	.020	.021
NA	-	-	-	.002	.054	.001	-	.008	.001	.001
K	-	-	-	-	-	-	-	-	-	-
SUM	4.002	4.008	4.009	3.992	4.015	4.003	4.006	3.979	4.001	4.003
W0	39	34	38	20.92	48.02	1.55	1.21	4.44	1.04	1.09
EN	85.91	85.99	86.51	71.80	46.36	44.63	85.14	81.39	85.47	84.93
FS	13.70	13.67	13.31	7.10	4.83	14.02	13.66	14.16	13.49	13.99
M:	86.25	86.28	86.64	90.91	90.57	85.78	86.18	85.18	86.37	85.86
C:	.45	.40	.44	22.54	51.29	1.57	1.40	5.18	1.20	1.26

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC43, OPX1, TRAVERSE	6	PC43, OPX2, CENTRE
2	PC43, OPX1, TRAVERSE	7	PC43, OPX2, EDGE
3	PC43, OPX1, TRAVERSE	8	PC43, OPX1, TRAVERSE
4	PC43, OPX1, TRAVERSE	9	PC43, OPX4, TRAVERSE
5	PC43, OPX1, TRAVERSE, CRY LAMPHIA	10	PC43, OPX4, TRAVERSE

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPOROUS ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	11	12	13	14	15	16	17	18	19	20
STOP	54.94	54.62	54.97	54.59	55.00	54.94	55.02	54.86	55.06	54.23
TT	.04	.05	.18	.05	.04	.03	.04	.04	.04	.04
AL2O3	2.76	2.99	2.70	2.75	2.72	2.72	2.77	2.61	2.65	2.63
CR2O3	9.14	8.13	9.11	8.15	9.12	9.14	9.17	8.13	9.14	8.14
FFU	9.33	8.93	9.33	8.73	9.43	9.21	9.41	8.68	9.20	8.81
MNO	31.52	30.12	31.14	30.40	31.29	31.13	31.13	30.97	31.64	30.81
CAO	1.55	1.55	1.50	2.11	1.40	1.67	.62	1.40	ND	2.98
NA2O	.02	.04	.02	.05	.02	.02	.02	.05	ND	.07
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	99.41	98.82	99.48	98.96	99.19	99.56	99.48	98.87	99.22	99.65

A. ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OXYGEN	6	6	6	6	6	6	6	6	6	6
ST	1.934	1.937	1.934	1.934	1.939	1.932	1.936	1.941	1.939	1.914
TT	.001	.001	.005	.001	.001	.001	.001	.001	.001	.001
AL	.115	.112	.114	.114	.115	.113	.113	.109	.110	.109
CR	.004	.004	.003	.004	.004	.004	.004	.004	.004	.004
FF2+	.274	.265	.274	.258	.274	.271	.277	.257	.271	.260
MN	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
MG	1.621	1.633	1.604	1.604	1.644	1.669	1.645	1.633	1.661	1.621
CA	.021	.059	.019	.080	.015	.025	.023	.053	.013	.113
NA	.001	.003	.001	.003	.001	.001	.001	.003	.001	.005
K	-	-	-	-	-	-	-	-	-	-
SUM	4.007	4.006	4.005	4.007	4.001	4.010	4.005	4.004	4.003	4.031
MO	1.06	3.03	.47	4.12	.78	1.29	1.16	2.73	.66	5.65
EN	14.05	13.52	14.13	13.31	14.35	13.44	14.24	13.22	13.94	11.30
FS	14.05	13.52	14.13	13.31	14.35	13.44	14.24	13.22	13.94	11.30
M:	85.79	85.96	85.76	86.12	85.53	85.79	85.59	86.41	85.97	86.17
C:	1.24	3.51	1.13	4.75	.91	1.50	1.36	3.15	.77	6.50

A. SAMPLE IDENTIFY **

ANALYSIS NO.	DESCRIPTION
11	PC43, OPX4, TRAVERSE
12	PC43, OPX4, TRAVERSE
13	PC43, OPX4, TRAVERSE
14	PC43, OPX4, TRAVERSE
15	PC43, OPX4, TRAVERSE

DESCRIPTION

ANALYSIS NO.	DESCRIPTION
16	PC43, OPX4, TRAVERSE
17	PC43, OPX4, TRAVERSE
18	PC43, OPX4, TRAVERSE
19	PC43, OPX4, TRAVERSE
20	PC43, OPX4, TRAVERSE

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	21	22	23	24	25	26	27	28	29	30
STU2	54.81	54.36	55.39	56.32	56.44	56.13	56.22	56.33	55.71	55.48
TiO2	.04	.04	.19	.14	.04	.07	.09	.08	.11	.10
AL2O3	2.52	2.64	2.43	2.70	2.70	2.78	2.74	2.71	2.67	2.67
CR2O3	9.12	9.13	8.63	9.13	9.10	9.12	9.25	9.17	8.88	8.24
FEU	32.08	33.39	32.12	32.92	31.99	31.96	31.99	31.95	31.83	29.44
MNO	ND	ND	.06	ND	ND	ND	ND	ND	ND	ND
CAU	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NA2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	94.18	100.82	100.50	100.88	100.99	100.53	100.92	100.87	100.03	99.74

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * * *

OXYGEN	6	6	6	6	6	6	6	6	6	6
ST	1.932	1.904	1.936	1.947	1.949	1.946	1.944	1.948	1.944	1.950
TI	.001	.001	.005	.004	.002	.002	.002	.002	.003	.003
AL	.105	.109	.100	.110	.110	.114	.112	.110	.110	.111
CR	.004	.004	.005	.004	.005	.005	.004	.004	.004	.004
FE2+	.260	.268	.252	.262	.263	.265	.268	.268	.259	.242
MN	.004	.004	.004	.004	.004	.004	.004	.004	.004	.003
MG	1.685	1.634	1.624	1.640	1.646	1.652	1.647	1.647	1.641	1.544
CA	.012	.015	.079	.013	.019	.007	.013	.014	.031	.030
NA	-	-	.004	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-	-	-
SUM	4.013	4.050	4.009	3.943	3.943	3.944	3.996	3.990	3.997	3.992
W0	EN 15.69	EN 15.71	EN 14.04	EN 15.69	EN 15.39	EN 15.87	EN 15.48	EN 15.51	EN 14.97	EN 14.97
FS	13.67	13.28	12.90	13.04	13.03	13.77	13.87	13.77	13.42	13.65
M:	86.24	85.92	86.56	86.26	86.23	86.13	86.04	86.13	86.36	86.43
C:	.77	6.50	4.86	.80	1.13	.43	.76	.83	1.86	7.75

* * * S A M P L E I D E N T I F I C A T I O N * * *

ANALYSIS NO.	DESCRIPTION
21	PC43, OPX4, CFMIF, LIGHT RANU
22	PC43, OPX4, DAKK, RANU
23	PC43, OPX4, EDGF, NEXT TO CPX
24	PC43, OPX3, TRAVERSE
25	PC43, OPX3, TRAVERSE

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	31	32	33	34	35	36	37	38	39	40
STO2	56.04	56.07	55.65	55.35	53.04	53.07	53.30	52.85	52.77	54.48
TiO2	.04	.04	.09	.01	.22	.19	.15	.21	.22	.07
AL2O3	2.76	2.70	2.84	3.01	3.58	3.51	3.60	3.64	3.63	3.15
CR2O3	9.13	9.13	8.04	9.12	9.05	9.21	9.22	9.25	9.25	10.33
FFU	4.09	4.22	4.05	4.22	3.78	4.11	4.11	4.08	3.60	4.13
MNU	1.74	1.15	1.13	1.12	.09	.04	.11	.08	15.43	27.56
MGO	31.74	32.01	30.41	31.34	15.66	10.41	19.96	15.76	15.43	27.56
CAO	.43	.42	2.97	.17	23.52	22.16	16.53	23.38	23.80	4.68
NA2O	ND	ND	.07	ND	ND	.01	ND	ND	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.42	100.65	101.11	99.40	100.64	100.46	99.80	100.81	100.55	101.00

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6	6	6
ST	1.947	1.941	1.934	1.941	1.926	1.926	1.927	1.918	1.920	1.922
Ti	.002	.001	.014	.002	.006	.005	.004	.006	.006	.002
Al	.113	.114	.116	.120	.153	.154	.153	.156	.156	.131
Cr	.264	.267	.271	.265	.291	.296	.296	.298	.297	.266
FF2+	.004	.004	.004	.004	.002	.002	.003	.002	.002	.004
MN	1.652	1.652	1.575	1.638	.847	.847	1.075	.852	.837	.849
Mg	.016	.016	.005	.006	.015	.012	.031	.000	.028	.047
CA	-	-	-	-	.051	.043	.037	.050	.054	-
NA	-	-	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-	-	-
SUM	3.991	4.000	4.006	3.993	4.017	4.011	4.008	4.020	4.020	4.031
NO	85.42	84.30	81.15	85.53	45.74	45.48	33.01	48.52	49.51	8.64
EN	13.72	13.80	13.25	14.14	45.14	47.36	57.31	45.31	44.64	75.48
FS	-	-	-	-	6.11	6.86	9.09	6.37	5.85	15.88
M:	86.17	86.09	85.96	85.82	88.07	87.08	86.31	87.67	88.42	92.62
C:	86.96	86.93	86.46	86.59	51.92	44.26	36.96	51.61	52.58	10.28

* * * SAMPLE IDENTIFY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
31	PC43, CPX3, TRAVERSE	36	PC43, CPX5, TRAVERSE
32	PC43, CPX3, TRAVERSE	37	PC43, CPX5, TRAVERSE
33	PC43, CPX3, TRAVERSE	38	PC43, CPX5, TRAVERSE
34	PC43, CPX3, TRAY TO LIP	39	PC43, CPX5, TRAVERSE
35	PC43, CPX5, TRAVERSE, ADJ. TO OPX	40	PC43, CPX5, TRAVERSE

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	41	42	43	44	45	46	47	48	49	50
STO2	52.30	54.05	52.46	53.01	55.12	55.20	55.19	52.24	52.79	52.64
TIU2	5.66	5.07	3.72	5.45	2.05	2.12	2.70	4.31	3.71	3.80
AL2O3	3.22	5.43	3.25	5.27	8.14	8.14	8.13	3.22	3.24	3.25
CR2O3	3.85	4.25	3.97	5.06	8.72	8.72	8.64	3.08	3.08	3.37
FFO	15.63	14.94	15.76	15.06	31.94	31.80	31.65	15.09	15.83	15.74
MNO	23.27	23.73	23.75	24.05	ND	ND	ND	23.32	23.45	23.37
CAO	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NA2O	100.05	100.72	100.54	100.79	99.13	99.33	99.31	99.97	99.96	99.92
K2O										
TOTAL										

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OXYGEN	6	6	6	6	6	6	6	6	6	6
ST	1.914	1.913	1.911	1.922	1.939	1.938	1.939	1.909	1.923	1.922
TI	.006	.002	.004	.008	.001	.003	.002	.009	.009	.007
AL	.158	.147	.160	.147	.110	.113	.112	.173	.159	.155
CR	.005	.007	.007	.007	.004	.004	.004	.006	.007	.007
FF2+	.118	.121	.121	.121	.252	.252	.254	.102	.092	.103
MNO	.002	.002	.002	.002	.004	.004	.004	.002	.002	.002
MG	.852	.856	.856	.846	1.675	1.604	1.628	.849	.859	.857
CA	.910	.911	.911	.934	.014	.014	.028	.913	.915	.912
NA	.051	.053	.053	.053	.001	.001	.001	.060	.035	.047
K										
SUM	4.023	4.027	4.027	4.020	4.003	4.001	4.002	4.023	4.003	4.014
WD	48.42	48.28	48.28	49.71	40.27	40.27	40.46	48.97	49.03	48.73
EN	45.31	45.33	45.33	45.02	40.22	40.22	40.46	45.54	46.03	45.77
FS	6.24	6.39	6.39	5.28	13.51	13.28	13.09	5.49	4.94	5.50
M:	87.84	87.64	87.64	89.51	86.45	86.91	86.72	89.24	90.30	89.27
C:	51.64	51.58	51.58	52.48	51.51	51.91	51.67	51.82	51.58	51.57

** SAMPLE D I R F C T O R Y **

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
41	PC43, CPX5, TRAVERSE	46	PC43, OPX9, EDGE
42	PC43, CPX5, TRAVERSE	47	PC43, OPX9, CENTRE
43	PC43, CENTRE	48	PC43, SMALL CPX10
44	PC43, CPX6, SMALL INTERST. CPX6	49	PC43, SMALL CPX11, EDGE
45	PC43, CPX6, EDGE	50	PC43, SMALL CPX11, CENTRE

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7	8	9	10
STO2	54.01	53.87	50.84	50.40	53.46	53.66	54.10	41.61	42.49	43.1A
TiO2	.04	.04	.50	.31	.02	.04	.12	.59	ND	ND
AL2O3	3.06	3.97	4.96	4.77	3.61	3.42	.39	11.61	ND	1.2A
CR2O3	.30	.55	.67	3.72	.41	.40	1.31	3.2A	ND	17.82
FEU	4.04	4.7A	3.55	3.97	4.81	4.14	2.24	.02	16.2A	22.5A
FMU	.13	.11	.07	.07	.12	.14	.07	.60	.15	.0A
MCO	31.01	31.84	34.83	15.41	31.71	31.60	17.64	26.60	26.9A	1.34
CAO	1.20	1.46	23.20	22.41	.40	.02	22.93	13	.1A	.37
NA2O	.02	ND	.5A	ND	ND	ND	.03	10.67	.1A	.37
K2O	ND	ND	ND	ND	ND	ND	09.06	94.87	.1A	.37
TOTAL	99.76	99.44	99.04	98.62	99.06	99.25	99.06	100.00	87.64	87.99

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	22	9	9
SI	1.015	1.894	1.870	1.873	1.905	1.843	1.984	5.931	2.71A	2.773
Ti	.001	.001	.00A	.009	.001	.001	.004	.063	.058	.097
Al	.151	.165	.216	.207	.150	.163	.017	1.951	.058	.002
Cr	.011	.010	.020	.021	.011	.011	.038	.024	.058	.002
Fe ²⁺	.235	.258	.110	.122	.260	.254	.069	.391	.069	.004
Mn	.00A	.003	.002	.002	.004	.004	.064	.002	.00A	.004
Mg	1.620	1.600	.817	.853	1.60A	1.60A	.901	5.650	2.483	2.161
Ca	.045	.017	.022	.022	.015	.020	.013	.036	.022	.109
Na	.001	-	.040	.043	-	.001	.001	1.931	.015	.042
K	-	-	-	-	-	-	-	-	-	.030
SUM	4.004	4.01A	4.015	4.025	4.015	4.020	3.993	16.002	6.271	6.213
AN	2.35	ND	09.8A	09.7A	ND	ND	46.59			
FM	14.40	95.43	FM 14.1A	FM 15.70	FM 15.8A	FM 15.3A	49.85			
FS	13.2A	FS 13.2A	FS 5.93	FS 6.52	FS 13.3A	FS 13.17	5.55			
M:	80.42	86.00	88.16	87.51	86.51	89.93	93.35			
C:	2.71	1.03	53.03	51.11	1.72	1.72	48.31			

A * * S A M P L E I D E N T I F I C A T I O N * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC53, Opx1, CENTRE	6	PC53, Opx5, CENTRE
2	PC57, Opx1, EDGF, ANJ.	7	PC57, CPX (3)
3	PC 53, CPX 3	8	PC57, PHLOGOPITIF (4)
4	PC 53, CPX 4	9	PC57, SERPENTINITIF
5	PC53, Opx5, EDGF	10	PC57, SERPENTINITIF

* * * ND = NOT DETECTED * *

TABLE IV-17(Continued) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7
STO2	54.07	40.59	50.06	54.86	55.38	54.53	40.34
TIOP	ND	1.08	ND	ND	ND	ND	1.26
AL2O3	5.34	13.28	3.14	2.42	3.13	2.78	13.67
CR2O3	ND	ND	ND	ND	ND	ND	ND
FeO	7.41	1.59	7.17	7.40	7.01	7.36	1.41
MNO	ND	ND	ND	ND	ND	ND	ND
MGO	30.12	26.55	35.04	34.74	30.47	34.22	26.27
CaO	ND	ND	ND	ND	ND	ND	ND
Na2O	ND	ND	ND	ND	ND	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.21	94.01	102.80	100.90	101.51	99.50	96.67

A * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

OXYGEN	6	22	6	6	6	6	20
ST	1.862	5.768	1.897	1.893	1.898	1.903	5.162
TI	ND	0.115	ND	ND	ND	ND	0.121
AL	0.138	2.216	0.125	0.119	0.124	0.114	2.062
CR	ND	ND	ND	ND	ND	ND	ND
Fe2+	0.116	0.058	0.203	0.111	0.111	0.110	0.041
MN	ND	ND	ND	ND	ND	ND	ND
Mg	1.770	5.619	1.767	1.786	1.760	1.742	5.010
Ca	0.016	0.091	0.018	0.013	0.025	0.005	0.099
Na	ND	ND	ND	ND	ND	ND	ND
K	ND	1.873	ND	ND	ND	ND	2.001
SUM	9.048	15.968	4.035	4.043	4.034	4.035	14.716
	MO 28.41	MO 28.41	MO 28.41	MO 28.41	MO 28.41	MO 28.41	MO 28.41
	FS 10.77	FS 10.77	FS 10.20	FS 10.35	FS 10.11	FS 10.59	FS 10.59
	MO: FS	MO: FS	MO: FS	MO: FS	MO: FS	MO: FS	MO: FS
	89.16: 10.77	89.16: 10.77	89.70: 10.20	89.58: 10.35	89.76: 10.11	89.58: 10.59	89.58: 10.59

A * * SAMPLE D T P F C T O P Y * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 60, OPX 1	5	PC 60, OPX 6
2	PC 60, OPX 2	6	PC 60, OPX 7
3	PC 60, OPX 3	7	PC 60, PHLOGOPITE 8
4	PC 60, OPX 4		

** ND = NOT DETECTED **

TABLE IV-17 (CONTINUED) MICROPIPETTE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7	A	9
SiO ₂	57.01	55.74	57.58	56.54	54.52	51.28	54.67	54.46	52.28
TiO ₂	ND	ND	ND	ND	ND	ND	ND	ND	ND
Al ₂ O ₃	1.10	1.10	1.19	1.10	3.00	3.52	2.87	2.87	3.19
Fe ₂ O ₃	0.04	0.04	0.04	0.04	0.35	0.55	0.34	0.34	0.52
FeO	0.05	0.05	0.04	0.05	0.41	0.67	0.33	0.33	0.57
MgO	35.02	34.83	34.83	34.47	34.11	16.65	33.93	33.76	17.22
CaO	0.56	0.51	0.48	0.52	0.66	24.02	0.50	0.49	23.59
Na ₂ O	0.02	0.03	0.03	ND	ND	0.49	ND	ND	0.54
K ₂ O	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.29	98.97	100.62	96.92	100.77	99.50	100.54	100.56	100.49

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6	6
Si	1.002	1.048	1.072	1.065	1.090	1.009	1.098	1.096	1.002
Al	0.05	0.09	0.08	0.05	0.23	0.13	0.17	0.18	0.137
Cr	0.01	0.01	0.02	0.01	0.10	0.06	0.09	0.09	0.015
Fe ²⁺	0.01	0.01	0.01	0.01	0.26	0.08	0.30	0.26	0.090
Mn	0.01	0.01	0.01	0.01	0.04	0.02	0.04	0.05	0.002
Mg	1.797	1.819	1.798	1.792	1.762	0.913	1.756	1.752	0.934
Ca	0.021	0.019	0.018	0.019	0.025	0.047	0.019	0.018	0.020
Na	0.01	0.02	0.02	0.01	0.02	0.035	0.01	0.01	0.038
SUM	4.015	4.028	4.004	4.012	4.040	4.045	4.039	4.040	4.041
MO	49.69	49.49	49.49	49.72	48.54	48.62	49.3	49.1	47.31
EN	9.28	9.47	9.25	9.72	11.25	10.88	11.49	11.76	10.04
FS	0.62	0.44	0.67	0.60	0.61	0.50	0.41	0.43	0.65
M:	1.14	1.00	0.98	1.07	1.37	0.91	1.05	1.03	1.18
C:									

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 65, CPX 1	6	PC 66, CPX 2
2	PC 65, CPX 2	7	PC 66, CPX 3, ADJACENT TO CPX 7
3	PC 65, CPX 3	A	PC 66, CPX 5, ADJACENT TO CPX 7
4	PC 65, CPX 4	9	PC 66, CPX 7
5	PC 66, CPX 1		

* * * MO = NOT SELECTED * *

TABLE IV-17 (CONTINUED) MICROANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5
STU2	54.40	52.49	52.51	55.83	54.45
TTU2	2.03	2.22	2.21	2.03	2.06
AL2O3	2.13	2.85	2.85	2.14	2.13
CR2O3	10.82	4.21	5.29	3.33	3.30
FFO	32.17	16.07	18.10	10.75	10.75
MNU	22.28	19.91	19.91	32.55	32.29
CAU	ND	ND	ND	ND	ND
NA2O	ND	ND	ND	ND	ND
TOTAL	100.00	100.58	100.54	102.59	100.77

* * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6
ST	1.912	1.917	1.914	1.924	1.911
TT	.001	.006	.006	.001	.002
AL	.089	.124	.122	.089	.088
CF	.018	.018	.016	.009	.008
FE2+	.318	.129	.161	.309	.315
MN	.005	.002	.003	.004	.005
MG	1.693	.901	.985	1.671	1.689
CA	.011	.875	.777	.014	.015
NA	-	.057	-	-	-
K	-	-	-	-	-
SUM	4.040	4.035	4.034	4.027	4.040
MO	85.74	85.94	86.40	83.69	85.74
FM	15.72	17.31	15.20	13.82	15.02
FS	-	0.75	0.38	15.49	15.62
M:	84.20	87.51	85.93	84.40	84.26
C:	.82	49.27	44.12	.81	.90

* * * SAMPLE CORRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 68, OPX 1	4	PC 68, OPX 4
2	PC 68, OPX 2, EDGE	5	PC 68, OPX 5
3	PC 68, OPX 3, CENTER		

* * ND = NOT DETERMINED * *

Table IV-18. Microprobe analyses of amphiboles from coarse peridotites.

	1	2	3	4	5
SiO ₂	44.69	45.22	45.40	44.75	45.50
TiO ₂	0.19	0.11	0.42	0.18	<0.01
Al ₂ O ₃	12.26	13.14	11.71	10.87	11.10
Cr ₂ O ₃	2.18	1.98	1.53	2.40	1.67
FeO	3.32	3.41	3.34	3.00	3.18
MnO	0.06	0.06	0.07	0.06	0.06
MgO	19.79	19.61	18.96	19.88	20.00
CaO	10.37	11.10	9.85	11.00	10.6
Na ₂ O	3.29	2.48	4.31	3.64	3.79
K ₂ O	1.41	1.17	1.20	1.34	0.60

1- 07073, garnet lherzolite (Hebron), Robey (unp.data)

2- 07133, garnet lherzolite (Hebron), Robey(unp. data)

3- 07183, garnet lherzolite (Hebron), Robey(unp. data)

4- 07043, lherzolite (Hebron), Robey (unp. data)

5- lherzolite (Wesselton), Boyd (1971).

TABLE IV-19 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM OLIVINE-BEARING PYROXENITE (TYPE V)

	1	2	3	4	5	6	7	A	9	10
STO2	40.34	40.6A	40.7A	40.80	40.90	40.79	40.9A	40.61	39.72	39.76
TI02	0.10	0.09	0.17	0.09	0.0A	0.0A	0.09	0.0A	ND	ND
AL2O3	21.04	21.40	21.34	21.44	21.12	21.39	21.67	21.16	ND	ND
CR2O3	3.33	3.07	3.12	3.13	3.54	3.25	2.96	3.24	0.05	ND
FFO	12.92	12.21	13.02	13.26	12.46	13.27	13.14	13.01	13.66	13.49
MNO	15.34	15.97	15.51	15.62	15.31	15.59	15.81	15.52	45.77	45.93
CAO	6.21	6.10	6.23	6.14	6.30	6.1A	6.02	6.06	ND	ND
NA2O	ND	ND	ND	-	-	ND	ND	ND	ND	ND
K2O	ND	ND	ND	-	-	ND	ND	ND	ND	ND
TOTAL	99.91	99.62	100.84	101.04	100.35	101.20	101.30	100.39	99.39	99.36

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	12	12	12	12	12	12	12	12	4	4
ST	2.973	2.991	2.975	2.972	2.993	2.969	2.972	2.977	2.997	2.998
TI	0.004	0.009	0.009	0.005	0.004	0.004	0.005	0.004	0.004	0.004
AL	1.828	1.854	1.835	1.841	1.822	1.835	1.853	1.82A	1.82A	1.82A
CR	0.194	0.17A	0.180	0.180	0.205	0.187	0.170	0.18A	0.001	0.001
FF3+	0.794	0.751	0.794	0.80A	0.763	0.80A	0.797	0.79A	0.287	0.283
FF2+	0.030	0.042	0.040	0.03A	0.040	0.039	0.037	0.043	0.003	0.003
MN	1.685	1.685	1.686	1.689	1.670	1.691	1.709	1.696	1.713	1.717
CA	0.490	0.481	0.487	0.479	0.494	0.482	0.46A	0.476	0.001	0.001
NA	-	-	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-	-	-
SUM	8.012	7.989	8.009	8.013	7.990	8.017	8.013	8.012	3.002	3.002
CA	16.51	16.4A	16.41	16.10	16.8A	16.17	15.73	16.03	FO 85.65	FO 85.85
MG	56.71	57.7A	56.82	56.76	57.0A	56.72	57.47	57.11	FA 14.35	FA 14.15
FF	26.7A	25.74	26.77	27.14	26.0A	27.10	26.80	26.86		
M:	67.92	69.1A	67.9A	67.65	68.65	67.67	68.19	68.01		

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC47, GI 1	6	PC47, GI 4
2	PC47, GI 2	7	PC47, GI 5, INSIDE OPX
3	PC47, SAME	8	PC47, GI 6
4	PC47, SAME	9	PC47, OLIV: 7, CENTRE
5	PC47, GI 3	10	PC47, OLIV: 7, EDGE

* * * ND = NOT DETECTED * *

TABLE IV-19 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM OLIVINE-BEARING PYROXENITE (TYPE V)

	11	12	13	14	15	16	17	18	19	20
SiO2	39.92	39.91	56.86	57.13	56.68	54.47	56.48	55.66	.027	.36
TiO2	ND	.03	.03	.02	.03	.04	.02	.06	1.27	1.18
Al2O3	ND	ND	.51	.51	.52	1.04	.99	.99	11.91	11.00
Cr2O3	.02	.03	.14	.15	.15	.83	.24	.74	50.91	49.35
Fe2O3	13.62	13.63	6.23	8.26	8.28	2.28	7.87	2.44	6.13	6.37
FeO	13.12	13.12	16	12	14	.09	15	2.08	22.45	22.02
MnO	46.06	45.94	34.85	34.81	34.62	17.54	34.62	17.43	7.80	7.92
MgO	ND	.03	.02	ND	ND	23.61	ND	23.61	ND	ND
CaO	ND	ND	ND	ND	ND	.87	ND	ND	ND	ND
Na2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	99.81	99.72	101.06	101.25	100.65	100.77	100.15	101.78	100.58	98.94

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OXYGEN	4	4	6	6	6	6	6	6	4	4
Si	.997	.998	1.960	1.960	1.962	1.968	1.962	1.986	.001	.012
Ti	ND	.001	.001	.001	.001	.001	.001	.002	.032	.030
Al	ND	.021	.021	.021	.021	.044	.021	.042	.440	.438
Cr	ND	.001	.004	.004	.004	.024	.007	.021	1.342	1.317
Fe3+	.285	.285	.237	.237	.240	.09	.229	.073	1.154	1.162
Fe2+	.003	.003	.005	.003	.004	.003	.004	.002	.020	.019
Mg	1.715	1.712	1.790	1.784	1.786	.942	1.792	.927	3.87	4.01
Ca	ND	.001	.008	.008	.008	.915	.009	.903	.001	.001
Na	ND	ND	ND	ND	ND	.061	ND	ND	ND	ND
K	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SUM	3.003	3.001	4.028	4.024	4.026	4.028	4.025	4.008	3.000	3.000
FA 14.23	FA 14.27	FA 14.27	FN 97.95	FN 97.88	FN 97.81	FN 97.92	FN 98.31	FN 98.45	CR 75	CR 75
FA 14.23	FA 14.27	FS 11.65	FS 11.70	FS 11.79	FS 11.79	FS 11.58	FS 11.27	FS 11.83	MG 38	MG 38
		M: 88.30	M: 88.25	M: 88.17	M: 88.19	M: 88.19	M: 88.69	M: 92.72	FE 30	FE 30
		C: .45	C: .47	C: .45	C: .44.27	C: .44.27	C: .48	C: 49.34		

** SAMPLE DIRECTORY **

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11	PC47, OLIV: 8	16	PC47, CPX 13
12	PC47, OLIV: 9, NEXT TO GT 1	17	PC47, CPX NEXT TO GT 2, OPX 11
13	PC47, OPX 10	18	PC47, LARGE CHROMITIF GRAIN
14	PC47, OPX 11, NEXT TO CPX AND GT 2	19	PC47, CHROMITIF LAMELLA IN OPX 14
15	PC47, OPX 12	20	

** ND = NOT DETECTED **

TABLE IV-20. Visual estimates of modal proportions (vol.%) of minerals in peridotites.

	<u>olivine</u>	<u>orthopyroxene</u>	<u>clinopyroxene</u>	<u>garnet</u>	<u>chromite</u>	<u>phlogopite</u>
PC44	60	30	8	2	-	-
PC61	40	60	-	-	-	10
PC63	92	5	-	-	3	-
PC64	55	45	-	-	-	-

TABLE IV-21 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS IN PRIDOTITES

	1	2	3	4	5	6	7	8
STO2	40.67	57.80	54.38	40.74	41.74	58.25	39.43	39.61
TI02	-	ND	ND	ND	ND	ND	ND	ND
AL2O3	-	ND	ND	ND	ND	ND	ND	ND
CR2O3	-.02	.22	2.56	2.45	ND	.27	13.39	14.14
FFO	7.64	4.93	1.80	8.60	6.44	4.01	2.31	2.33
MNU	.07	1.50	1.05	4.66	.06	.04	ND	25.07
MGO	50.53	36.79	16.66	19.36	51.86	36.44	27.06	25.67
CAU	-	.19	21.25	4.83	ND	.18	ND	ND
NAPO	-	.07	2.00	ND	ND	.08	.79	.77
K2O	-	ND	ND	ND	ND	ND	8.48	9.02
N2O	-.44	.00	.00	-	.47	.12	.24	.26
TOTAL	99.37	100.77	100.24	98.84	100.63	100.19	92.67	92.91

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * * *

OXYGEN	4	6	6	12	4	6	22	22
ST	.005	1.967	1.962	2.054	1.002	1.983	5.696	5.716
TI	-	.026	.109	.022	-	.050	2.278	2.405
AL	-	.006	.045	1.140	-	.007	.108	.122
CP	.000	.140	.045	.522	.120	.114	.279	.281
FF2+	.156	.003	.002	.028	.001	.002	.002	.002
MN	.001	.003	.002	.028	1.855	1.849	5.825	5.521
MG	1.843	1.866	.822	2.092	-	.005	.221	.215
CA	-	.007	.140	.375	-	.005	1.563	1.661
NA	-	.005	-	-	-	.003	.028	.030
K	.000	.000	.000	.000	.009	.003	.028	.030
NI	-	.000	.000	.000	-	.003	.028	.030
SUM	3.005	4.020	4.028	8.014	2.998	4.001	16.002	15.957
FO	92.18	EN	45.61	CA	93.49	EN	53	
FA	7.42	FS	50.82	MG	6.51	FS	93.87	
		M:	2.57	FF	17.45	M:	94.18	
		C:	95.19	M:	80.05	C:	35	
			47.84					

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC44, OLIVINE(4)	5	PC61, OLIVINE(3)
2	PC44, OPX(2)	6	PC61, OPX(3)
3	PC44, CPY(2)	7	PC 61, PHLOGOPIE
4	PC44, GT(1)	8	PC 61, PHLOGOPIE

** ND = NOT DETECTED **

TABLE IV-24 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS IN PRIMITIVE

	1	2	3	4	5	6
STU2	58.16	41.62	41.59	.02	40.6A	55.57
TIU2	ND	ND	ND	.03	ND	ND
AL2O3	.81	ND	ND	12.29	ND	2.43
CR2O3	.31	.02	.0A	56.85	.03	.83
FE2O3	-	-	-	4.97	-	-
FFO	4.06	6.47	6.47	13.35	6.6A	4.19
MNO	.00	.07	.0A	13.73	51.31	.09
MGO	36.90	52.59	52.73	15.33	ND	36.43
CAO	.22	ND	.02	-	ND	.74
NA2O	.11	-	-	-	ND	ND
K2O	ND	-	-	-	ND	ND
TUO	.00	.00	.00	.00	.39	.00
TOTAL	100.77	100.80	100.99	101.59	99.22	100.51

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OXYGEN	6	4	4	4	4	6
ST	1.971	.99A	.994	.001	.993	1.004
TI	.032	-	-	.45A	-	.09A
AL	.00A	-	-	1.421	.001	.022
CR	-	.000	.002	.11A	-	-
FF3+	.115	.129	.129	.353	.136	.120
FF2+	.003	.001	.002	.020	.002	.003
MN	1.86A	1.87A	1.87A	.62A	1.86A	1.860
MG	.00A	-	.001	.001	-	.027
CA	.007	-	-	-	-	-
NA	.000	.000	.000	.000	.00A	.000
K	.000	-	-	-	-	-
NI	.000	-	-	.000	.00A	.000
SUM	4.013	3.004	3.005	3.000	3.007	4.03A
W	.40	FN 93.5A	FN 93.5A	CP	FN 93.19	W 1.35
EN	5.7A	FA 6.4A	FA 6.4A	MG	FA 6.81	FN 92.67
FS	-	-	-	FF	-	FS 5.9A
M:	94.20	-	-	-	-	M: 93.94
C:	.43	-	-	-	-	C: 1.44

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC63, OPX(2)	4	PC63, CHROMITIF(2)
2	PC63, OLIVINE(12)	5	PC64, OLIVINE(3)
3	PC63, OLIVINE ENCLOSED BY CHROMITE	6	PC64, OPX(3)

** ND = NOT DETECTED **

(+) TABLE V-1. (A) Relative diamond inclusions abundances based on observations and analytical determinations, from the Koffiefontein Mine.

<u>No. of inclusions</u>	<u>Sulphides</u>	<u>Peridotitic inclusions</u>	<u>Eclogitic inclusions</u>	<u>Graphite</u>	<u>Clouds</u>	<u>Ec/EctPer %</u>
938	397	277	22	66	176	7

(B) Relative proportions of peridotitic silicate minerals in Koffiefontein diamonds.

<u>observed abundances</u>			<u>calculated proportions</u>		
<u>gt</u>	<u>cpx</u>	<u>colourless ratio (opx+ol) (++)</u>	<u>gt</u>	<u>cpx</u>	<u>ol</u>
47	5	222	17.2	1.8	44.2
		10:12			

Note: Chromite is a rare peridotitic inclusion recorded in Koffiefontein diamonds, but is not included in the above figures. Chromite is 1% of the peridotitic suite at southern African localities.

(+) This table was extracted from Gurney et al (1979) and Hawthorne et al (in prep.).

(++) Determined from 22 analyses.

TABLE V-2A GARNET DIAMOND INCLUSIONS (PERIDOTITE SUITE) FROM KOFFEYFONTEIN (GROUP A)

	1	2	3	4	5	6	7	8
STO2	42.40	42.60	41.80	42.30	43.50	42.50	42.50	42.30
TI02	ND	.03	ND	.04	ND	ND	21.03	.04
AL2O3	20.50	21.60	20.30	19.80	21.70	20.70	21.90	19.50
CR2O3	5.57	4.06	5.97	6.56	3.60	5.07	3.46	6.50
FFO	4.94	5.06	5.66	5.82	3.78	4.97	5.26	5.20
MNO	.26	.23	.26	.28	.19	.25	.21	.25
MGO	25.10	23.60	24.26	23.60	26.50	23.50	23.50	23.90
CAU	.50	2.87	2.91	2.52	2.56	2.20	2.46	1.84
NA2O	ND	ND	ND	ND	ND	ND	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	99.37	99.86	99.33	100.72	100.12	99.10	99.32	99.53

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	12	12	12	12	12	12	12	12
OXYGEN	12	12	12	12	12	12	12	12
SI	2.092	2.994	2.970	2.941	3.010	3.001	2.998	3.004
TI	ND	.002	ND	.002	ND	ND	.002	ND
AL	1.705	1.645	1.700	1.645	1.770	1.731	1.821	1.632
CR	.293	.267	.336	.337	.213	.265	.193	.365
FF2+	.014	.014	.014	.017	.011	.015	.013	.015
MGO	2.640	2.472	2.504	2.479	2.733	2.494	2.471	2.529
CA	.045	.201	.060	.190	.042	.107	.186	.140
NA	ND	ND	ND	ND	ND	ND	ND	ND
K	ND	ND	ND	ND	ND	ND	ND	ND
SUM	8.000	7.997	8.013	8.011	7.990	7.990	7.993	7.996
CA	1.50	5.17	2.32	6.34	1.30	5.05	6.27	4.70
MG	34.70	33.22	36.93	36.62	41.30	34.37	33.27	34.93
FF	9.20	10.01	11.25	11.00	7.31	9.97	10.46	10.37
M	90.05	89.26	89.48	86.21	92.13	89.43	88.84	89.12

* * * SAMPLE IDENTIFY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	GT K1	5	GT K12
3	GT K4	6	GT K15
4	GT K10	7	GT K17
	GT K11	8	GT K18

* * * ND = NOT DETECTED * *

TABLE V-28 GARNET DIAMOND INCLUSIONS (PERIDOTTITE SUITE) FROM KOFFIFONTAIN (GROUP B)

	1	2	3	4	5	6
STO2	42.00	42.10	41.70	42.00	41.60	41.20
TI02	ND	.03	.05	ND	.03	.05
AL2O3	20.40	20.30	21.10	20.70	20.50	17.50
CR2O3	5.14	4.52	3.44	4.54	4.83	4.74
FFO	5.65	5.72	6.44	5.34	6.27	5.44
MNO	25	19	25	21	20	31
MGO	22.00	22.50	20.50	21.70	20.60	20.60
CAO	3.45	3.74	5.23	4.60	5.19	5.09
K2O	ND	.05	ND	.10	-	-
TOTAL	99.73	99.14	99.64	99.24	99.11	99.13

* * * ATOMIC PROPORTIONS BASED ON SELECTED MU. OF OXYGENS * *

	12	12	12	12	12	12
OXYGEN	2.046	3.007	2.947	2.990	2.994	2.994
ST	1.743	1.709	1.741	1.742	1.739	1.739
TI	.290	.347	.217	.257	.263	.263
AL	.356	.411	.417	.320	.377	.331
CR	.015	.011	.015	.013	.018	.012
FF2+	2.331	2.305	2.148	2.300	2.210	2.254
MN	.293	.286	.401	.352	.400	.347
MG	-	.007	-	.014	-	-
CA	7.947	8.013	8.012	8.007	8.003	8.001
NA	CA 9.41	CA 9.47	CA 13.35	CA 11.41	CA 13.40	CA 13.30
K	MG 74.74	MG 79.23	MG 72.79	MG 77.44	MG 73.47	MG 75.00
	FF 11.55	FF 11.50	FF 13.47	FF 10.74	FF 12.03	FF 11.10
	MS 27.40	MS 27.51	MS 30.00	MS 27.43	MS 25.41	MS 27.20

ANALYSIS MU.	DESCRIPTION	ANALYSIS MU.	DESCRIPTION
1	GI K2	4	GI K9
2	GI K3	5	GI K44
3	GI K5	6	GI K46

* * * MU = NOT INFLECTED * *

TABLE V-3 OLIVINE DIAMOND INCLUSIONS FROM KOFFIFONTAIN

	1	2	3	4	5	6	7	8	9	10
STO2	41.10	41.40	41.50	40.90	41.40	41.40	40.90	39.80	40.00	41.40
TIU2	ND	ND	-	ND	-	-	-	ND	ND	ND
AL2O3	.04	.03	.07	.06	.05	.04	.05	.10	.04	.05
CR2O3	.04	.05	.19	.60	.70	.42	.10	7.76	ND	7.15
FFU	5.40	6.53	7.19	7.60	4.10	6.42	7.10	7.08	7.95	7.16
MNO	52.20	51.90	51.19	50.20	52.80	52.14	51.16	50.00	48.09	51.30
MGU	.07	.02	.11	.13	ND	ND	.07	.16	ND	.04
CAU	ND	-	.07	-	ND	ND	.06	-	ND	.06
NA2O	99.50	100.00	99.92	99.42	99.62	100.46	99.70	97.97	96.90	100.17
K2O	-	-	-	-	-	-	-	-	-	-
TOTAL	-	-	-	-	-	-	-	-	-	-

** ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS. * A

	4	4	4	4	4	4	4	4	4	4
OXYGEN	1.000	1.000	1.000	.999	1.000	.995	.994	.988	1.003	1.000
ST	.002	.001	.001	.002	.001	.001	.002	.002	.001	.001
TI	.001	.001	.001	.002	.001	.001	.001	.002	.001	.001
AL	.009	.009	.009	.004	.009	.009	.004	.002	.001	.001
CR2+	.002	.002	.002	.004	.002	.002	.004	.002	.002	.002
MN	1.809	1.866	1.842	1.837	1.901	1.876	1.858	1.850	1.820	1.847
MG	.002	.001	.003	.003	.001	.001	.003	.004	.003	.003
CA	-	-	-	-	-	-	-	-	-	-
NA	3.007	3.000	3.000	3.001	3.000	3.005	3.006	3.010	2.996	3.000
K	-	-	-	-	-	-	-	-	-	-
SUM	FC 94.57 FA 5.43	FC 93.41 FA 6.59	FC 92.68 FA 7.32	FC 92.21 FA 7.79	FC 95.24 FA 4.76	FC 93.57 FA 6.43	FC 92.79 FA 7.21	FC 91.49 FA 8.01	FC 91.61 FA 8.39	FC 92.75 FA 7.25

** SAMPLE DIRECTORY **

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	01 K10	4	01 K24
2	01 K11	7	01 K25
3	01 K1A	8	01 K26
4	01 K20	9	01 K27
5	01 K22	10	01 K31

** NU = NOT DETECTED **

TABLE V-3 DIAMOND INCLUSIONS FROM KOFFIFONTEIN

	11	12	13	14	15
STO2	41.40	41.10	41.40	41.10	40.90
TIU2	ND	ND	.03	ND	ND
AL2O3	.04	.04	.15	.05	.04
CR2O3	5.74	5.93	4.14	7.42	6.20
MMU	US	US	US	US	US
MGO	52.20	51.80	51.80	50.70	50.40
CFD	ND	.03	.08	.12	.08
MA2O	.06	-	-	ND	ND
TOTAL	94.52	94.00	100.42	99.90	99.65

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	4	4	4	4	4
OXYGEN	1.000	.990	1.002	.990	.994
ST	-	-	.001	-	-
TI	.001	.001	.003	.001	.001
AL	.121	.165	.002	.159	.107
CR	1.277	1.224	1.824	1.836	1.833
FE	.003	.001	.002	.003	.002
SUM	3.001	3.000	2.997	3.001	3.002
FA	94.17	93.46	91.70	92.03	91.63
FA	5.83	6.04	8.30	7.97	8.37

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11	OL K52	14	OL K258A
12	OL K48	15	OL K258A
13	OL K258A		

* * * ND = NOT DETECTED * *

TABLE V-4 CLINOPIROXENE DIAMOND INCLUSIONS (PERIDOTTIC SUITE) FROM KOFFIEFONTEIN

	1	2	3	4	5
STOP	55.00	54.70	55.10	54.30	54.80
TTU2	.07	.03	ND	ND	.03
AL2O3	2.14	1.55	1.47	.64	.72
CP2O3	3.64	2.89	2.69	2.44	2.34
FFO	1.75	2.40	2.09	1.91	2.24
FMU	.08	14.50	14.50	17.50	11
MGU	14.60	20.10	19.20	20.30	19.90
CAU	10.30	12.35	11.22	11.30	17.30
NA2O	2.35	.70	1.31	1.69	1.69
K2O	.04	.50	04.04	1.57	1.69
TOTAL	94.99	94.50	94.04	94.12	94.27

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OXYGEN	6	6	6	6	6
ST	1.983	1.985	2.003	1.992	1.994
TT	.002	.001	.029	.029	.001
AL	.091	.064	.071	.071	.031
CP	1.04	.024	.082	.050	.057
FF2+	.053	.073	.083	.002	.069
FMU	.002	.003	.091	.957	.003
MG	.892	1.000	.744	.794	1.037
CA	.707	.781	.084	.023	.699
NA	.164	.032	.073	.073	.021
K	.002	.037	.014	.073	.074
SUM	4.001	4.003	4.007	4.006	4.003
MO	42.80	42.13	41.07	44.01	34.70
EN	54.00	53.94	54.44	52.74	57.46
FS	3.19	3.43	4.49	3.23	3.86
M:	94.41	93.21	92.54	94.23	93.72
C:	44.22	43.66	43.00	45.47	40.24

** SAMPLE DIRECTORY **

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	CPX K13	1	CPX K1A
2	CPX K14	5	CPX K1A-A2
3	CPX K15		

** NO = NOT DEPLETED **

TABLE V-5 URIMOPYROXENE DIAMOND INCLUSIONS FROM KOFFIEFONTEIN

	1	2	3	4	5	6	7	8	9	10
STO2	57.90	58.00	59.30	59.80	58.10	58.80	59.00	57.60	57.30	57.30
TUO2	ND	ND	.60	.56	.90	.30	.73	.76	ND	ND
AL2O3	.59	.74	.28	.31	.18	.10	.41	.57	.39	.55
CR2O3	.21	.26	3.83	3.90	5.03	3.58	4.14	2.79	3.91	3.56
FFO	4.22	4.00	3.12	3.00	5.10	3.05	4.10	2.05	3.08	3.07
MNO	.11	36.70	37.27	36.20	35.20	36.80	36.10	36.10	36.40	36.70
MCO	.61	ND	ND	.48	.76	.13	.48	.21	.58	.44
CAU	.56	.06	ND	ND	.15	ND	.16	.04	.04	.09
NA2O	ND	ND	ND	.03	.10	ND	.09	.04	.04	.04
K2O	ND	ND	ND	.03	.10	ND	.09	.04	.04	.04
TOTAL	94.41	100.51	101.02	101.38	100.52	99.78	101.21	98.08	99.51	98.87

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	6	6	6	6	6	6	6	6	6	6
OXYGEN	1.972	1.987	2.007	2.007	2.003	2.001	2.040	1.991	1.968	1.975
ST	.020	.024	.022	.022	.056	.012	.029	.031	.030	.022
TI	.007	.007	.008	.008	.004	.003	.011	.016	.011	.004
AL	.114	.107	.169	.169	.144	.102	.117	.081	.112	.103
CR2+	.003	.003	.003	.003	.003	.001	.003	.001	.002	.002
FN	1.850	1.858	1.811	1.811	1.791	1.867	1.815	1.859	1.863	1.885
MC	.021	.010	.017	.017	.028	.005	.017	.021	.021	.016
CA	.004	.001	.001	.001	.004	.005	.010	.008	.004	.006
K	-	-	-	-	-	-	-	-	.002	-
SUM	4.012	3.998	3.979	3.979	4.003	3.992	3.997	3.986	4.014	4.014
NO	1.03	ND	ND	ND	1.42	ND	ND	ND	1.07	ND
FS	5.71	5.44	5.46	5.46	7.53	5.16	5.99	4.14	5.31	5.12
M:	93.86	94.50	94.50	94.50	92.58	94.02	93.95	95.84	94.31	94.84
C:	1.14	1.52	1.51	1.51	1.53	1.25	1.95	1.42	1.13	1.13

A * S A F I F O T R E C T O R Y * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	OPX K2	6	OPX K29
2	OPX K0	7	OPX K29
3	OPX K21	8	OPX K36
4	OPX K23	9	OPX K46
5	OPX K27	10	OPX K47

A * ND = NOT DETECTED * *

TABLE V-5 URTHOPYRENE DIAMOND INCLUSIONS FROM KOFFIFONTAIN

	11	12
SiO2	57.70	57.10
TiO2		.03
Al2O3	.53	1.16
Cr2O3		3.33
FeO	3.84	.11
MnO	.04	36.60
MgO	37.00	.12
CaO	.27	
Na2O	ND	
K2O	ND	
TOTAL	99.45	99.11

* * * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

OXYGEN	6	6
Si	1.977	1.961
Ti		.001
Al	.021	.047
Cr		.010
Fe2+	.111	.096
Mn	.002	.003
Mg	1.890	1.888
Ca	.010	.004
Na		
K		
SUM	4.012	4.010
MO	.49	.22
ES	94.00	94.97
FS	5.50	4.81
M:	94.47	95.18
C:	5.53	4.83

A * * S A M P L E D I R E C T O R Y * * *

ANALYSIS NO.	DESCRIPTION
11	OPX K262-A
12	OPX K262-B

* * * ND = NOT DETECTED * *

TABLE V-6 CHROMITE DIAMOND INCLUSION FROM KOFFIFONTIEIN

STO2	.13
TI02	.11
Al2O3	7.72
CR2O3	63.30
FFO	13.61
MNO	13.05
MCO	12.80
CAO	-
NA2O	-
K2O	-
TOTAL	99.44

** ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS **

OXYGEN	4
ST	.004
TI	.003
AL	.290
CR	1.647
FF3+	.040
FF2+	.350
MN	.020
MC	.628
CA	-
NA	-
K	-
SUM	3.000
CR	.85
MC	.69
FF	.02

*** SAMPLE DIRECTORY ***

ANALYSIS NO. 1

DESCRIPTION

CMR N22-8A

ANALYSTS NO. -----

DESCRIPTION -----

TABLE V-7 GARNET DIAMOND INCLUSIONS (FLOCTIC SUITE) FROM KUFFTEFUNIFIN

	1	2	3	4	5	6	7	8	9	10
STOP	40.50	40.40	40.10	38.50	38.70	39.20	40.70	38.00	39.40	38.40
TIU2	54	53	65	10	07	07	38	13	62	60
AI2O3	22.00	22.10	22.00	22.00	22.40	22.40	22.40	21.00	21.10	21.10
CP2O3	14.50	13.80	23	70	40	40	20	.04	.20	.11
FFU	14.50	13.30	14.40	22.70	24.00	21.30	16.25	22.40	22.40	22.30
FeO	15.10	15.20	31	63	61	38	15.40	7.36	11.90	10.90
MgO	5.43	6.21	8.29	7.68	4.13	5.45	4.05	8.00	3.26	4.35
CaO	.07	.16	.14	.11	.08	.20	.18	.07	.17	.03
K2O	.02	.16	.14	.04	.08	.20	.18	.07	.17	.03
TOTAL	99.02	99.42	99.62	98.85	99.63	99.60	99.76	98.52	99.45	98.04

	12	12	12	12	12	12	12	12	12	12
OXYGEN	2.040	2.098	2.074	2.077	2.066	2.076	2.096	2.070	2.019	2.078
SI	1.030	1.029	1.036	1.006	1.004	1.004	1.021	1.008	1.035	1.035
TI	.041	.040	.023	.016	.024	.004	.043	1.002	1.044	1.027
AI	.041	.040	.013	.016	.013	.004	.012	1.002	1.044	1.027
CFE2+	.017	.017	.019	.041	.041	.041	.016	.028	1.044	1.027
MN	1.658	1.459	1.459	.640	1.339	.443	1.649	.857	1.345	1.225
MG	.460	.459	.459	.640	1.339	.443	1.649	.857	1.345	1.225
CA	.010	.023	.020	.017	.012	.029	.026	.670	.265	.391
NA								.011		.023
K										
SUM	8.600	8.002	8.051	8.020	8.024	8.053	8.019	8.052	8.009	8.052
CA	15.28	10.46	21.60	21.01	11.39	14.40	10.63	22.15	8.81	11.92
MG	55.05	56.02	49.02	28.53	30.90	40.00	56.20	28.35	44.75	40.39
FF	29.67	27.51	29.34	49.86	51.67	45.15	35.18	49.50	46.43	47.69
M:	48.98	67.07	62.58	36.40	41.00	47.00	62.88	36.42	49.08	45.86

*** SAMPLE DIRECTORY ***

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	GT K7	6	GT K19A1
2	GT K7	7	GT K37
3	GT K1A	8	GT K37D
4	GT K1A	9	GT K41A
5	GT K10A2	10	GT K42

*** NOT DELETED ***

TABLE V-7 GARNET DIAMOND INCLUSIONS (FLOGITIC SUITE) FROM KOFFIEFONJIN

	11	12	13	14	15	16	17	18
SiO2	40.50	41.10	39.40	39.50	40.50	41.00	39.90	40.60
TiO2	22.70	22.80	21.80	22.50	22.50	23.10	22.76	21.10
Al2O3	16.50	15.10	21.30	19.80	17.10	15.50	22.06	13.74
Cr2O3	16.50	15.10	21.30	19.80	17.10	15.50	22.06	13.74
FeO	15.40	15.20	15.50	15.20	14.40	15.20	15.50	13.50
MnO	15.40	15.20	15.50	15.20	14.40	15.20	15.50	13.50
MgO	3.50	2.80	3.50	3.70	4.00	4.50	11.00	16.20
CaO	3.50	2.80	3.50	3.70	4.00	4.50	11.00	16.20
Na2O	3.50	2.80	3.50	3.70	4.00	4.50	11.00	16.20
K2O	3.50	2.80	3.50	3.70	4.00	4.50	11.00	16.20
TOTAL	99.70	99.53	99.51	99.71	100.70	100.19	100.29	100.19

A A ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	11	12	12	12	12	12	12	12
Si	2.070	3.008	2.044	2.045	2.073	2.091	2.075	2.079
Ti	0.013	0.021	0.020	0.055	0.033	0.012	0.043	0.028
Al	1.069	1.067	1.044	1.046	1.030	1.087	1.060	1.025
Cr	0.009	0.005	0.011	0.04	0.049	0.04	0.04	0.043
Fe2+	1.015	0.924	1.349	1.251	1.050	0.80	0.66	0.51
Fe3+	0.023	0.018	0.025	0.019	0.027	0.014	0.020	0.021
Mn	1.743	1.810	1.325	1.137	1.619	1.646	1.144	1.771
Mg	0.201	0.223	0.324	0.43	0.319	0.357	1.879	1.554
Ca	0.11	0.13	0.21	0.28	0.10	0.21	0.23	0.24
K	0.11	0.13	0.21	0.28	0.10	0.21	0.23	0.24
SUM	8.025	7.992	8.019	8.010	8.009	8.013	8.013	8.072
CA	4.012	4.006	4.009	4.005	4.004	4.006	4.006	4.036
MG	1.003	1.002	1.003	1.002	1.002	1.003	1.002	1.002
FE	33.02	31.21	44.00	42.09	35.14	31.25	32.33	26.26
M:	63.20	60.20	49.68	47.62	60.67	64.50	54.22	68.14

A A S A M P L E I D E N T I F I C A T I O N * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11	GT K43	15	GI K52
12	GT K49	16	GI K53
13	GT K50	17	GI K54
14	GT K51	18	GI K56

* * NO = NOT DEFECTED * *

TABLE V-X CLINOPIRXENE DIAMOND INCLUSIONS (ECLG TIC SUITE) FROM KOFFEONTEIN

	1	2	3	4	5	6	7	8	9
SI02	55.50	54.60	56.30	55.00	54.60	55.50	53.60	54.50	54.80
TiO2	15.41	14.41	13.34	14.42	13.59	13.35	13.35	12.29	13.13
Al2O3	3.18	2.26	7.95	7.57	4.76	4.16	4.15	7.23	2.71
Cr2O3	4.05	7.13	2.21	1.17	4.20	1.11	4.05	7.15	5.25
FeO	7.90	5.05	5.45	6.36	4.52	14.00	12.90	7.00	5.03
MgO	11.13	11.08	10.08	11.10	11.14	14.17	11.18	11.10	10.09
MnO	15.20	14.10	13.50	13.00	12.50	14.00	13.80	12.30	15.90
CaO	30.00	12.20	12.20	12.10	12.50	10.00	12.20	12.30	18.90
Na2O	2.12	3.74	4.17	4.16	2.92	2.56	2.62	4.61	1.64
K2O	0.07	1.19	1.16	1.20	2.23	0.03	0.05	1.14	0.04
TOTAL	100.30	99.70	100.68	99.10	99.65	99.48	99.90	99.22	99.54

** ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS **

OXYGEN	1	2	3	4	5	6	7	8	9
SI	1.000	1.078	1.089	1.086	1.084	1.077	1.087	1.078	1.095
Ti	.000	.011	.010	.011	.011	.010	.010	.008	.004
Al	.135	.267	.331	.323	.208	.182	.181	.309	.116
Cr	.003	.004	.006	.005	.008	.003	.001	.004	.007
Fe2+	.122	.250	.161	.142	.253	.434	.400	.212	.153
Mg	.004	.004	.002	.003	.004	.005	.006	.003	.003
Mn	.814	.761	.700	.700	.840	.818	.707	.698	.863
Ca	.772	.474	.488	.468	.487	.347	.524	.478	.737
Na	.149	.266	.286	.291	.205	.184	.188	.324	.119
K	.003	.009	.007	.009	.011	.001	.002	.006	.002
SUM	4.004	4.013	3.940	3.989	4.007	4.013	4.007	4.023	4.000
Wt %	45.14	32.12	30.18	34.43	30.82	34.00	32.14	34.45	42.06
Fe	47.72	51.64	51.69	51.45	53.14	44.59	43.35	50.25	49.21
FS	7.10	15.24	11.93	14.12	19.01	26.32	24.51	15.50	8.74
M:	24.59	76.04	81.30	78.46	79.85	65.42	63.88	76.66	84.92
C:	48.01	38.55	41.04	40.00	36.70	32.70	42.58	40.67	46.08

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	CPA K4	6	CPX K41
2	CPA K10	7	CPX K42
3	CPA K17	8	CPX K43
4	CPA K37	9	CPX K36
5	CPA K39		

TABLE V-4 >000> DIAMOND INCLUSIONS FROM KOPF EFFLUENT

	1	2	3	4
STU2	.00	.00	.13	.03
TI 203	NU	.07	.07	-
CP 203	.40	.60	.60	-
FEU	21.60	20.50	20.50	18.90
NU	77.15	.16	.17	76.00
CAU	-	.05	.03	-
GPU	.20	.25	.20	-
TOTAL	94.93	94.50	98.41	94.93

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	4	4	4	4
ST	.002	.003	.004	-
TI	-	.002	.002	-
AI	.012	.012	.014	-
FE2+	.537	.517	.510	-
MN	.000	.004	.004	-
CR	3.428	3.445	3.445	-
CA	.015	.002	.001	-
NA	.017	.015	.012	-
K	-	.002	-	-
SUM	4.000	3.998	3.998	.000
FO 86.40	FO 86.40	FO 87.10		
FA 13.56	FA 13.56	FA 12.90		

A * A SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS I.D.	DESCRIPTION
1	UDU K30	3	UDU K30
2	UDU K33	4	PER K262-A

A * NO = NOT DETECTED * *

Table V-10.

Estimates of minimum temperatures and pressures of equilibration of eclogite garnet-clinopyroxene inclusion pairs in diamonds from Koffiefontein.

cpx-gt pairs	T °C		P Kb	
	(1)	(2)	(3)	(4)
K8	1041	1446	43	54
K16	913	1258	39	48
K41	1571	1545	57	56
K42	1420	1529	53	56
K43	1485	1459	55	54
K56	1264	1598	49	58
K37	1398	1451	52	54
K37 _D	886	1225	38	48

(1) - Temperature estimates based on combined equations of Raheim and Green (1974) and Bundy et al. (1961).

(2) - Temperature estimates based on combined equations of Ellis and Green (1979 and Bundy et al. (1961).

(3), (4) - Pressure estimates based on $P = 7,1 + 0,027 T^{\circ}K$ (Bundy et al., 1961), using temperatures from columns (1) and (2) respectively.

TABLE VI-1 ANALYSES OF GARNET MEGACRYSTS FROM KOFFIEFONTEIN

	1	2	3	4	5	6	7	8	9	10
SiO2	41.89	41.70	42.04	42.21	41.73	41.64	41.72	41.68	42.31	41.96
TiO2	1.78	1.41	1.45	1.78	1.05	1.08	1.95	1.00	1.75	1.81
Al2O3	21.70	21.97	21.76	21.78	21.78	21.53	21.79	21.58	21.90	21.93
Cr2O3	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FeO	9.68	9.29	9.10	9.21	11.62	11.57	10.85	11.02	9.20	9.06
MnO	20.59	20.07	20.43	20.49	19.47	19.39	19.31	19.54	20.88	21.25
MgO	4.11	4.00	4.12	4.11	4.58	4.44	4.26	4.42	4.45	4.13
CaO	0.05	0.11	0.02	0.02	0.02	0.02	0.13	0.12	0.12	0.13
K2O	0.05	0.11	0.02	0.02	0.02	0.02	NO	NO	NO	NO
TOTAL	100.18	99.17	100.84	100.83	101.39	100.80	100.42	100.39	100.97	100.47

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	12	12	12	12	12	12	12	12	12	12
Si	2.091	2.003	2.063	2.046	2.073	2.082	2.087	2.089	2.092	2.080
Ti	0.042	0.048	0.048	0.048	0.056	0.058	0.051	0.054	0.040	0.043
Al	1.826	1.830	1.837	1.827	1.827	1.819	1.839	1.824	1.826	1.836
Cr	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
Fe2+	0.577	0.530	0.581	0.540	0.492	0.492	0.490	0.491	0.464	0.542
Mn	0.111	0.111	0.111	0.111	0.115	0.115	0.115	0.118	0.116	0.115
Mg	2.191	2.154	2.120	2.167	2.067	2.070	2.103	2.088	2.201	2.227
Ca	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Na	0.030	0.032	0.017	0.015	0.019	0.019	0.019	0.019	0.017	0.017
K	0.005	0.010	0.002	0.002	0.002	0.002	0.019	0.017	0.016	0.016
SUM	8.043	8.026	8.037	8.030	8.045	8.039	8.032	8.033	8.033	8.038
CA	10.20	10.42	10.05	10.65	11.24	10.99	10.61	11.00	10.94	10.26
MG	71.08	71.11	70.56	70.23	69.49	69.99	68.29	67.61	71.40	72.18
FE	18.71	18.47	18.79	19.12	22.27	22.33	21.10	21.40	17.66	17.56
M:	79.16	79.38	78.97	78.60	74.91	74.91	76.40	75.96	80.18	80.43

* * * S A M P L E D I R E C T O R Y * *

ANALYSIS NO.	DESCRIPTION
1	GT KF49(CENTRF)
2	GT KF49(EDG)
3	GT KF70(CENTRF)
4	GT KF70(EDG)
5	GT KF71(CENTRF)

** NO = NOT DETECTED **

TABLE VI-1 ANALYSES OF GARNET MEGACRYSTS FROM KOFFIFONTAIN

	11	12	13	14	15	16	17	18	19	20
STO2	41.48	41.60	41.75	41.60	42.03	41.82	41.55	41.56	41.94	41.85
TI02	1.07	1.06	1.04	1.06	1.03	1.07	1.04	1.06	1.04	1.04
Al2O3	21.23	21.40	21.60	21.40	21.60	21.71	21.57	21.57	21.39	21.98
CR2O3	1.07	1.03	1.03	1.03	1.09	1.05	1.07	1.07	1.14	1.14
FFO	10.37	10.38	11.27	11.17	9.62	9.43	10.38	10.38	8.80	9.82
MNO	19.65	19.65	19.51	19.42	20.28	20.34	20.23	19.80	21.07	20.72
CAO	4.51	4.47	4.40	4.38	4.30	4.23	4.26	4.22	4.30	4.27
NA2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	99.87	99.50	100.50	100.16	100.12	99.71	99.91	99.74	100.00	100.75

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	11	12	12	12	12	12	12	12	12	12
OXYGEN	12	12	12	12	12	12	12	12	12	12
ST	2.084	2.093	2.091	2.092	3.002	2.097	2.082	2.090	2.092	2.094
Al	1.054	1.054	1.051	1.057	1.043	1.041	1.051	1.052	1.050	1.043
CR	1.012	1.004	1.027	1.014	1.022	1.034	1.034	1.029	1.064	1.054
FF2+	0.61	0.50	0.45	0.46	0.57	0.50	0.44	0.44	0.525	0.584
MNO	0.16	0.15	0.17	0.16	0.15	0.15	0.16	0.16	0.10	0.13
CA	2.108	2.113	2.043	2.042	2.150	2.172	2.103	2.135	2.240	2.194
NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SUM	8.029	8.027	8.033	8.028	8.021	8.025	8.037	8.029	8.042	8.044
CA	11.22	11.49	10.96	10.93	10.75	10.91	10.34	10.55	10.62	10.48
MG	60.43	60.58	67.50	67.42	70.49	70.94	69.92	69.20	72.41	70.72
FF	20.28	20.33	21.40	21.65	18.76	18.46	19.74	20.25	16.97	18.81
M	77.13	77.13	75.92	75.70	78.48	74.35	77.98	77.56	81.01	78.99

A * * S A M P L E D I R E C T O R Y * * *

ANALYSIS NO.	DESCRIPTION
11	GI KF70(CENTRE)
12	GI KF70(EDGE)
13	GI KF70(CENTRE)
14	GI KF70(EDGE)
15	GI KF70(CENTRE)

* * ND = NOT DETERMINED

TABLE VI-2 ANALYSES OF ORTHOPYROXENE MEGACRYSTS FROM KOFFIEFONJIN

	1	2	3	4	5	6	7
STO2	57.20	55.93	40.45	57.80	56.76	57.09	57.44
TTUO3	.71	.71	1.84	.17	.14	.13	.13
AL2O3	.15	.15	12.29	.45	.25	.51	.50
FFO	7.78	7.80	5.22	5.23	5.50	5.73	5.76
MNGU	13	12	23.01	5.07	5.09	5.08	10
MNGU	34.69	34.27	23.01	35.42	35.14	34.98	35.13
CAU	.40	.47	MD	.53	.24	.25	.27
NAPO	.23	.23	MD	.19	.20	.24	.20
NPO	MD	MD	9.73	MD	MD	MD	.03
TOTAL	100.00	94.79	94.13	100.49	99.15	99.86	100.41

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	6	6	20	6	6	6	6
OXYGEN	1.971	1.952	5.303	1.979	1.971	1.972	1.973
ST	.003	.003	1.141	.004	.004	.003	.003
TT	.029	.029	1.053	.018	.021	.021	.020
AL	.004	.004	.030	.006	.007	.008	.009
FF21	.224	.224	5.12	.161	.160	.164	.166
MN	.004	.004	.002	.002	.003	.002	.003
MNG	1.750	1.750	4.652	1.807	1.819	1.801	1.790
CA	.018	.018	.031	.019	.020	.021	.020
NA	.015	.015	.031	.012	.013	.017	.013
K	-	-	1.627	-	-	-	.001
SUM	4.018	4.036	14.353	4.010	4.018	4.019	4.016
MD	91	MD	98	MD	MD	MD	MD
FN	87.04	87.91	90.91	90.91	91.00	90.31	90.23
FS	11.22	11.23	8.11	8.11	7.99	8.30	8.35
M:	84.65	84.67	91.81	91.81	91.93	91.58	91.53
C:	1.02	1.02	1.06	1.06	1.09	1.52	1.55

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 42(CENTRE)	5	PC 70(EDGE)
2	PC 42(CENTRE)	6	PC 72(CENTRE)
3	PC 42(CENTRE)	7	PC 72(EDGE)
4	PC 70(CENTRE)		

** MD = NOT DETECTED **

TABLE VI-3 ANALYSES OF CLINDIPYROXENE MEGACRYSTS FROM KUFFTEFUNEIN

	1	2	3	4
STO2	53.74	54.13	39.10	54.49
TI02	2.21	2.22	1.01	.24
AL2O3	2.34	2.55	ND	1.63
CFU	5.42	3.4	7.43	5.33
MNO	.11	1.0	.04	5.52
MCO	21.74	21.50	35.65	19.11
CAU	13.00	12.97	15.15	19.82
NA2O	1.93	1.91	.04	15.69
K2O	.04	1.03	1.0	.87
TOTAL	99.25	99.25	83.09	99.65

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OXYGEN	6	9	6
ST	1.045	2.516	1.970
TI	.004	.004	.004
AL	.110	.077	.070
CF2+	.140	.000	.009
MN	.003	.000	.108
MG	1.173	.003	.003
CA	1.500	3.419	1.073
NA	.135	.010	.611
K	.002	.005	.064
SUM	4.054	6.046	4.026
NO	27.57	NO	32.99
FU	43.72	FM	57.46
FS	4.91	FS	9.06
MS	87.74	MS	86.48
C:	30.05	C:	30.27

*** SAMPLE DIRECTORY ***

ANALYSIS NO.	DESCRIPTION
1	PC 56(CEHMF)
2	PC 56(FOHF)
3	PC 56(ALT)
4	PC 56(ALT) 3,5-FURFENITIF ????

** NO = NOT DETECTED **

TABLE VII-1. Relative abundance of individual minerals from the Koffiefontein concentrate.

Size fraction (mm)	Garnet	Ortho- pyroxene	Clino- pyroxene	Opagues (chromites + ilmenites) [†]	"Accessory minerals"	Total ^{††}
2	365	152	3	2	(533)	522
2 - 1.4	212	74	3	14	(103)	303
1.4- 1.0	194	85	5	25	(109)	309
1.0- 0.71	230	98	4	49	(254)	381
0.71-0.50	58	62	6	20	(148)	146
Total ^{††}	1059	471	21	110	(1147)	1661
%Total	63.8	28.4	1.3	6.6		

+ Chromite : imenite 28:6

†† Fragments classified as " accessory minerals", not taken into account.

TABLE VII-2 ANALYSES OF PURPLE GARNETS FROM THE KOFFIEFONTEIN CONCENTRATE.

	1	2	3	4	5	6	7	8	9	10
STO2	42.53	41.70	36.56	36.93	37.83	42.17	41.44	41.62	42.26	42.04
TIO2	24.47	24.05	21.81	21.84	21.95	25.23	22.13	22.42	23.10	22.92
Al2O3	7.39	4.45	11.34	11.17	11.17	1.64	1.81	2.57	1.88	1.84
FeO	7.39	4.45	11.34	11.17	11.17	1.64	1.81	2.57	1.88	1.84
MNO	21.21	20.13	4.36	5.37	5.84	6.35	9.18	8.45	6.27	8.34
MGO	4.05	4.05	4.05	5.52	1.87	20.39	19.12	19.59	20.77	19.99
CAO	4.05	4.05	4.05	5.52	1.87	4.05	4.91	5.04	5.17	5.00
NA2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.87	99.75	100.06	100.07	101.23	100.93	100.20	100.61	100.45	100.46

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	12	12	12	12	12	12	12	12	12	12
OXYGEN	12	12	12	12	12	12	12	12	12	12
ST	2.912	2.961	2.931	2.940	2.956	2.973	2.971	2.965	2.979	2.982
TI	2.015	2.019	2.003	2.009	2.022	2.039	2.035	2.043	2.020	2.015
AL	0.20	0.15	0.07	0.06	0.11	0.10	0.159	0.145	0.105	0.103
CP	0.13	0.13	0.04	0.04	0.12	0.14	0.150	0.123	0.106	0.103
FF2+	0.13	0.13	0.04	0.04	0.12	0.14	0.150	0.123	0.106	0.103
MN	2.202	2.173	0.521	0.537	0.640	0.742	0.777	0.785	0.842	0.820
MG	0.04	0.04	0.07	0.07	0.05	0.04	0.04	0.04	0.04	0.04
CA	0.04	0.04	0.07	0.07	0.05	0.04	0.04	0.04	0.04	0.04
NA	0.04	0.04	0.07	0.07	0.05	0.04	0.04	0.04	0.04	0.04
K	0.04	0.04	0.07	0.07	0.05	0.04	0.04	0.04	0.04	0.04
SUM	8.010	8.015	8.037	8.039	8.029	8.009	8.011	8.018	8.006	8.008
CA	11.70	10.29	2.60	1.49	5.55	11.70	12.70	12.88	13.10	12.75
MG	73.43	72.57	17.35	21.41	22.90	71.98	68.77	69.53	73.21	70.88
FF	10.48	17.14	80.05	77.10	71.58	10.32	18.53	17.49	13.69	16.38
M:	83.01	80.40	17.81	21.73	24.25	81.51	78.78	79.92	84.25	81.23

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	GT KF41	6	GT KF48
2	GT KF43	7	GT KF49
3	GT KF44	8	GT KF50
4	GT KF45	9	GT KF51
5	GT KF47	10	GT KF52

* * * ND = NOT DETECTED * *

TABLE VII-2 ANALYSES OF HIMPFL GARNETS FROM THE KOFFIFONTAIN CONCENTRATE.

	11	12	13	14	15	16	17	18	19	20
STU2	42.16	42.24	41.93	42.15	42.20	41.83	41.95	41.69	42.50	42.20
TI02	25.00	25.03	25.06	25.12	25.07	25.13	25.12	25.30	22.20	23.11
AL2O3	1.70	1.94	2.28	2.08	2.65	3.41	4.02	5.30	2.96	1.40
CR2O3	6.29	6.27	8.39	7.74	6.61	6.90	6.34	6.81	5.98	7.39
FeO	20.70	21.00	20.05	20.70	20.49	20.55	20.76	20.39	22.02	20.50
MgO	5.12	5.26	4.81	4.70	5.11	4.90	4.91	5.48	4.53	4.99
CaO	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.19	100.21	100.86	100.99	100.74	100.46	100.58	100.59	100.71	100.54

* * * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	12	12	12	12	12	12	12	12	12	12
STU	2.982	2.970	2.984	2.964	2.973	2.971	2.981	2.975	2.983	2.982
TI	1.002	1.003	1.003	1.003	1.004	1.007	1.006	1.007	1.005	1.003
AL	1.00	1.07	1.018	1.016	1.079	1.292	1.787	1.711	1.840	1.925
CR	4.13	5.18	4.56	4.10	4.01	4.10	4.26	4.06	4.64	4.34
Fe2+	0.17	0.23	0.20	0.20	0.16	0.22	0.24	0.24	0.31	0.17
Mg	2.181	2.117	2.180	2.150	2.204	2.217	2.199	2.168	2.303	2.159
Ca	3.88	3.50	3.50	3.50	3.86	3.73	3.74	4.19	3.41	3.78
Na	0.03	-	-	-	-	0.07	0.06	0.07	0.12	0.05
K	-	-	-	-	-	-	-	-	-	-
SUM	8.004	8.010	8.015	8.015	8.011	8.020	8.009	8.017	8.017	8.006
CA	13.01	11.72	11.45	12.43	12.40	12.43	12.50	14.00	11.37	12.72
MG	73.17	70.91	72.42	73.02	73.02	73.91	73.72	72.43	76.90	72.66
FF	13.86	17.37	15.23	15.23	13.42	13.06	13.75	13.57	11.72	14.62
M:	84.07	80.33	82.72	80.60	84.28	84.00	84.28	84.22	86.78	83.25

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11	GT VFS3	16	GT KFS9
12	GT KFS4	17	GT KFS9
13	GT KFS5	18	GT KFS9
14	GT KFS6	19	GT KFS9
15	GT VFS7	20	GT KFS9

* * ND = NOT DETECTED * *

TABLE VII-2 ANALYSES OF PURPLE GARNETS FROM THE KOFFIFONTAIN CONCENTRATE.

	21	22	23	24	25	26
SiO2	41.84	41.54	41.78	41.41	41.32	41.32
TiO2	21.05	21.08	19.12	19.06	19.27	19.27
Al2O3	2.57	3.80	6.03	5.82	7.94	7.94
FeO	8.42	8.07	7.29	7.01	6.41	6.41
MnO	19.78	18.51	20.35	18.41	20.24	20.24
CaO	4.59	5.63	4.83	6.24	5.66	5.66
Na2O	ND	.10	.10	ND	.05	.05
K2O	ND	.02	.02	ND	ND	ND
TOTAL	100.68	100.73	100.88	99.21	100.70	100.70

* * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	12	12	12	12	12	12
Si	2.074	2.069	2.077	2.082	3.010	2.910
Ti	.003	.004	.004	.006	.003	.019
Al	1.087	1.810	1.702	1.671	1.654	1.548
Fe	.529	.484	.514	.340	.335	.451
Mn	.027	.031	.033	.030	.025	.024
Mg	2.045	2.199	2.007	2.104	2.051	2.171
Ca	.350	.432	.369	.369	.484	.432
Na	.004	.013	.014	.014	.003	.007
K	ND	ND	.002	.002	ND	ND
SiH	8.011	8.017	8.012	8.014	7.994	8.014
CA	11.77	12.74	14.64	12.44	19.40	14.57
MG	70.57	70.98	67.96	72.40	69.21	72.55
FF	17.66	16.28	17.40	14.66	14.38	12.88
M:	74.90	81.35	74.82	83.26	82.79	84.92

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
21	GT KF63	24	GI KF66
22	GT KF64	25	GI KF67
23	GT KF65	26	GI KF68

* * ND = NOT DETECTED * *

TABLE VII-3 ANALYSES OF URANIF GARNETS FROM THE KOFFIFONTIEN CONCENTRATE.

	1	2	3	4	5	6	7	8	9	10
STUP	41.47	41.23	41.10	41.28	41.82	42.02	41.41	41.64	41.36	40.29
TiO ₂	23.92	23.76	23.45	23.73	23.15	23.11	23.41	23.35	23.76	23.15
Al ₂ O ₃	11.60	12.21	10.14	11.58	9.71	9.11	13.38	10.26	9.87	17.85
FeO	17.55	17.35	14.71	14.80	20.00	20.35	18.21	19.39	19.34	15.12
MnO	5.37	4.72	3.51	3.00	4.00	4.12	3.37	4.08	7.34	3.01
CaO	ND	ND	ND	0.05	0.11	0.12	0.08	ND	0.05	ND
K ₂ O	ND	ND	ND	0.05	ND	ND	ND	ND	ND	ND
TOTAL	100.42	100.26	98.43	99.66	100.12	99.74	100.45	99.78	99.96	100.12

* * * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

OXYGEN	12	12	12	12	12	12	12	12	12	12
Si	2.973	2.971	2.959	2.962	2.974	2.969	2.977	2.981	2.975	2.969
Al	2.004	2.012	2.024	2.007	2.008	2.004	2.006	2.017	2.007	2.008
Fe ²⁺	0.05	0.12	0.09	0.22	0.24	0.06	0.22	0.17	0.14	2.003
Mn	0.44	0.49	0.41	0.65	0.57	0.50	0.78	0.64	0.54	1.100
Ca	1.875	1.863	1.815	1.847	1.816	1.817	1.821	1.829	1.817	1.824
Ca	0.413	0.364	0.271	0.231	0.305	0.314	0.260	0.313	0.266	1.238
K	0.07	0.11	0.11	0.15	0.06	0.11	0.11	0.11	0.07	0.11
SUM	8.012	8.017	8.023	8.027	8.014	8.019	8.020	8.015	8.009	8.023
CA	13.83	12.20	9.04	7.71	10.15	10.43	8.66	10.45	19.00	7.93
MC	62.84	62.38	70.58	70.07	70.01	71.65	65.06	69.05	61.06	55.38
FF	23.31	23.42	20.38	22.22	19.24	17.92	26.28	20.50	19.94	36.69
M:	72.98	71.05	71.60	75.93	74.59	79.49	71.22	77.10	75.38	60.15

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	GT K13	6	GT K14
2	GT K14	7	GT K11
3	GT K15	8	GT K12
4	GT K16	9	GT K13
5	GT K17	10	GT K13

** ND = NOT DEFINED **

TABLE VII-3 ANALYSES OF ORANGE GARNETS FROM THE KOFFIFONTAIN CONCENTRATE.

	11	12	13	14	15	16	17	18
STUP	40.94	41.26	41.38	41.76	41.92	41.52	41.09	41.47
TIUP	23.70	23.10	23.11	23.36	23.79	21.91	21.70	23.04
CH2O3	12.30	12.97	11.83	10.14	11.21	9.30	10.33	1.11
FFO	14.25	14.08	19.05	19.35	14.80	20.22	19.93	8.10
MGO	3.94	3.53	3.56	4.03	3.97	4.34	4.11	20.82
CAU	ND	ND	ND	ND	ND	ND	ND	4.18
K2O	99.40	100.22	99.77	100.02	100.10	99.44	99.22	99.48
TOTAL								

** ATOMIC PROPORTIONS BASED ON SELECTED MU. OF OXYGENS **

OXYGEN	12	12	12	12	12	12	12	12
ST	2.954	2.974	2.978	2.982	2.979	2.974	2.972	2.959
TI	2.007	1.905	1.922	1.909	2.007	1.833	1.850	1.931
AI	0.006	0.030	0.015	0.038	0.006	0.056	0.048	0.063
FF2+	7.42	7.42	7.12	6.06	6.71	5.05	6.25	4.83
MN	0.21	0.23	0.15	0.21	0.23	0.13	0.13	0.16
MG	1.305	1.273	2.043	2.073	2.005	2.192	2.148	2.214
CA	0.006	0.008	0.017	0.007	0.007	0.028	0.015	0.010
NA								0.002
K								
SUM	8.027	8.020	8.021	8.011	8.011	8.047	8.039	8.025
CA	10.12	9.10	8.60	10.32	10.21	10.82	10.30	10.59
MG	65.21	64.81	67.78	69.40	67.27	70.40	69.49	73.39
FF	24.06	26.09	23.62	20.27	22.51	18.28	20.21	16.02
M	72.56	71.30	74.16	77.30	74.93	74.50	77.47	82.08

DESCRIPTION

ANALYSTS NO.

DESCRIPTION

ANALYSIS NO.

GI KF18
GI KF19
GI KF20
GI KF21

15
16
17
18

GI KF14
GI KF15
GI KF16
GI KF17

** ND = NOT DETECTED **

TABLE VII-4 ANALYSES OF KFD GARNETS FROM THE KOFFIEFONTEIN CONCENTRATF.

	1	2	3	4	5	6	7	8	9	10
STUP	41.87	41.85	41.07	41.07	41.04	41.60	41.66	40.89	41.28	40.99
YTOP	21.34	21.60	21.42	21.49	21.65	21.69	21.78	21.53	21.85	21.03
AL2O3	1.10	1.07	1.28	1.08	1.13	1.85	1.62	1.72	1.07	1.35
CFE2+	9.49	8.52	9.70	10.16	10.13	8.81	8.77	8.59	9.04	10.12
MNO	20.79	20.18	20.22	20.24	20.21	19.29	20.29	19.27	20.20	19.22
MCO	4.37	4.26	4.37	4.47	4.20	5.00	5.03	5.00	4.22	4.40
CAU	4.10	4.11	4.14	4.09	4.20	4.09	4.09	4.05	4.08	4.07
NA2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K2O	100.05	99.04	99.58	99.49	99.24	100.21	100.09	99.05	99.31	99.37

* * * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

OXYGEN	12	12	12	12	12	12	12	12	12	12
ST	2.944	3.006	2.964	2.966	2.969	2.985	2.978	2.957	2.968	2.965
Y	1.749	1.832	1.820	1.829	1.845	1.826	1.837	1.835	1.836	1.820
AL	0.069	0.071	0.074	0.056	0.042	0.094	0.092	0.114	0.061	0.064
CFE2+	5.49	5.12	5.86	6.14	6.13	5.24	5.24	5.20	5.44	6.13
MNO	0.13	0.12	0.13	0.15	0.14	0.18	0.18	0.17	0.12	0.13
MCO	2.200	2.225	2.169	2.153	2.156	2.124	2.148	2.155	2.240	2.155
CA	3.35	3.28	3.38	3.46	3.30	3.83	3.85	3.87	3.25	3.41
NA	0.019	0.015	0.020	0.013	0.024	0.012	0.012	0.007	0.011	0.010
K	-	-	-	-	-	-	-	-	-	-
SUM	8.034	8.024	8.046	8.045	8.050	8.019	8.029	8.033	8.044	8.042
CA	10.79	10.79	10.93	11.11	10.65	12.01	12.60	12.66	10.46	10.96
MG	70.51	72.61	70.13	64.17	64.58	70.05	70.25	70.57	72.05	69.24
FE	18.50	16.70	18.94	19.72	19.77	17.34	17.15	16.97	17.49	14.81
M:	79.49	81.30	78.74	77.82	77.68	80.16	80.38	80.57	80.47	77.76

* * * S A M P L E D I R E C T O R Y * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	GT KFP2	7	GI KF27
2	GT KFP3	8	GI KF28
3	GT KFP4	9	GI KF29
4	GT KFP5	10	GI KF30
5	GT KFP6		GI KF31

** ND = NOT DETECTED **

TABLE VII-5 ANALYSES OF REDDISH-BROWN GARNETS FROM THE KUFFIEFUNIFIN CONCENTRATE

	1	2	3	4	5	6	7	8	9
SiO2	41.55	41.10	41.78	41.64	41.56	41.90	41.68	41.53	40.99
TiO2	21.41	22.33	21.12	21.78	21.47	21.78	22.53	21.13	21.01
Al2O3	11.59	11.59	11.57	11.70	11.24	11.65	11.75	11.17	11.70
FeO	11.43	11.43	10.96	10.73	10.75	10.50	10.36	10.28	11.85
MnO	19.28	18.35	19.28	19.29	19.26	19.22	20.25	20.15	18.95
MgO	4.30	4.48	4.11	4.52	4.09	4.09	4.09	4.11	4.33
CaO	0.02	0.09	0.13	0.08	0.09	0.09	0.09	0.11	0.13
K2O	ND	ND	0.02	ND	ND	ND	ND	ND	ND
TOTAL	99.71	99.52	100.99	99.11	99.16	99.20	99.23	99.79	99.24

* * * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

OXYGEN	12	12	12	12	12	12	12	12	12
Si	3.001	2.960	2.976	2.990	3.004	3.004	2.988	2.988	2.989
Al	1.850	1.811	1.811	1.810	1.825	1.825	1.803	1.792	1.806
Fe2+	0.334	0.333	0.325	0.325	0.313	0.313	0.307	0.307	0.303
Mg	2.046	1.977	1.977	1.975	1.975	1.975	1.963	1.963	1.967
Ca	0.332	0.348	0.346	0.349	0.322	0.322	0.312	0.312	0.318
K	0.002	0.013	0.012	0.013	0.011	0.011	0.004	0.015	0.018
SUM	8.037	8.030	8.042	8.030	8.018	8.004	8.004	8.038	8.032
CA	10.70	11.43	11.13	11.31	10.51	10.51	10.49	10.80	11.09
MG	67.09	64.66	68.74	69.61	72.64	72.64	72.77	69.70	65.54
FE	22.21	23.71	20.12	19.08	16.55	16.55	16.74	19.50	23.37
M:	75.13	73.23	77.36	76.49	81.40	81.40	81.50	78.14	73.72

A * * S A M P L E D I R E C T O R Y * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	GI KF32	6	GI KF37
2	GI KF33	7	GI KF38
3	GI KF34	8	GI KF39
4	GI KF35	9	GI KF40
5	GI KF36		

** ND = NOT DETERMINED **

TABLE VII-6A ANALYSES OF GREEN ORTHOPYOXENES (GLASSY) FROM THE MOFFICHTON CONCENTRATE

	1	2	3	4	5	6	7	8	9
SiO ₂	57.97	58.08	55.95	57.43	56.77	57.55	57.64	56.77	56.74
TiO ₂	.12	.04	.04	.09	.01	.15	.11	.09	.11
Al ₂ O ₃	.50	.53	2.83	.70	2.01	.71	.77	.75	.76
Cr ₂ O ₃	.38	.32	.89	.20	.60	.20	.34	.33	.32
FeO	3.98	3.61	4.83	5.12	4.40	5.35	5.49	5.33	5.49
MnO	.11	.09	.10	.12	.12	.19	.12	.12	.12
MgO	37.34	37.52	35.32	35.20	34.51	35.19	34.79	35.12	35.09
CaO	.42	.28	.97	.66	.51	.67	.83	.64	.85
Na ₂ O	.12	.09	.02	.10	.12	.15	.10	.13	.15
K ₂ O	.00	.00	.00	.00	.00	.00	.00	.00	.00
TOTAL	100.79	100.59	100.36	99.78	100.02	100.21	100.50	99.67	99.64

* * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6	6
Si	1.967	1.969	1.915	1.974	1.949	1.975	1.978	1.964	1.963
Ti	.003	.002	.001	.002	.001	.004	.003	.002	.003
Al	.012	.021	.114	.030	.081	.029	.031	.031	.031
Cr	.010	.009	.024	.008	.017	.008	.009	.009	.009
Fe ²⁺	.103	.102	.121	.147	.128	.154	.158	.159	.159
Mn	.003	.003	.003	.003	.003	.004	.003	.004	.004
Mg	1.849	1.844	1.801	1.807	1.766	1.800	1.779	1.810	1.809
Ca	.017	.010	.036	.024	.047	.025	.031	.031	.032
Na	.008	.006	.001	.007	.012	.010	.011	.009	.010
K	.000	.000	.000	.000	.000	.000	.000	.000	.000
SUM	4.023	4.018	4.016	4.006	4.006	4.008	4.006	4.019	4.019
MO	93.57	94.40	92.00	91.55	90.99	90.78	90.44	90.48	90.48
EN	5.00	5.10	6.18	7.42	6.57	7.78	8.01	7.97	7.94
FS									
M:	94.36	94.53	93.70	92.49	93.27	92.13	91.86	91.91	91.93
C:	4.44	4.53	1.90	1.33	2.69	1.55	1.69	1.69	1.71

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION
1	OPX KF3
2	OPX KF4
3	OPX KF5
4	OPX KF6
5	OPX KF7
7	OPX KF9
8	OPX KF10
9	OPX KF11

* * MO = .01 DEFLECTED * *

TABLE VII-6R ANALYSES OF GREEN ORTHOPYROXENES (WITH CLEAVAGE) FROM THE KOFFIEFONTJIN CONCENTRATE

	1	2	3	4	5	6	7	8	9
SiO2	56.39	56.23	56.24	57.67	57.49	56.14	57.60	57.37	57.67
TiO2	.00	.07	.04	.80	.52	.07	.05	.37	.04
Al2O3	3.25	3.85	3.53	.37	.52	.26	.75	.37	.69
Cr2O3	4.40	4.56	4.30	3.81	4.36	3.29	4.00	4.26	4.40
FeO	4.11	4.13	4.11	3.09	4.11	3.77	3.82	4.75	3.43
MnO	34.82	34.85	34.78	36.99	36.53	37.12	36.13	36.11	37.08
CaO	1.07	.06	.04	.23	.42	.15	.30	.37	.26
MgO	.07	.06	.04	.07	.12	.15	.16	.10	.10
Na2O	.00	.04	.04	.00	.00	.00	.00	.00	.00
K2O	.00	.04	.04	.00	.00	.00	.00	.00	.00
TOTAL	100.90	100.46	100.61	100.09	100.01	100.57	99.53	99.64	99.86

* * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6	6
Si	1.918	1.923	1.917	1.966	1.969	1.977	1.978	1.974	1.968
Ti	.001	.001	.001	.001	.002	.002	.001	.002	.001
Al	.130	.124	.134	.032	.021	.010	.030	.015	.028
Cr	.021	.023	.023	.010	.010	.008	.011	.007	.011
Fe	.125	.130	.123	.109	.125	.107	.110	.137	.098
Mn	.003	.004	.003	.003	.003	.003	.003	.003	.002
Mg	1.766	1.766	1.767	1.880	1.864	1.887	1.849	1.857	1.891
Ca	.038	.030	.033	.005	.016	.012	.011	.014	.010
Na	.005	.003	.003	.005	.008	.010	.011	.007	.007
K	.000	.003	.000	.000	.000	.000	.000	.000	.000
SUM	4.008	4.007	4.004	4.014	4.018	4.017	4.005	4.016	4.015
Wt	1.97	1.56	1.60	1.42	1.79	1.58	1.56	1.68	1.48
EN	91.54	91.67	91.93	94.14	92.99	94.07	93.87	92.51	94.63
FS	8.46	8.77	8.38	5.44	6.23	5.34	5.57	6.81	4.90
M:	93.38	93.12	93.51	94.54	93.72	94.82	94.40	93.14	95.08
C:	2.10	1.67	1.81	4.45	6.27	5.61	5.59	6.73	4.50

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	OPX KF23	6	OPX KF28
2	OPX KF24	7	OPX KF30
3	OPX KF25	8	OPX KF31
4	OPX KF26	9	OPX KF32
5	OPX KF27		

* * MD = NOT DETERMINED * *

TABLE VII-6C ANALYSES OF ROWN ORTHOPYROXENES (GLASSY) FROM THE KOFFIFONTAIN CONCENTRATE

	1	2	3	4	5	6	7	8	9	10
SiO2	57.00	57.22	56.60	57.34	56.85	56.79	56.24	56.51	56.86	55.77
TiO2	.75	.13	.14	.11	.26	.24	ND	.23	.25	.23
Al2O3	.30	.67	.22	.54	.75	.46	.83	.96	.84	.91
Cr2O3	5.34	5.77	7.04	5.41	6.28	.05	.14	ND	.05	ND
FeO	34.47	34.13	34.13	35.12	34.10	6.15	7.38	9.41	7.94	9.20
MnO	.89	.88	.76	.48	.40	.88	.86	32.09	33.13	32.08
CaO	.14	ND	.11	.12	.16	.24	.82	.30	.24	.26
Na2O	.02	ND	ND	.12	ND	ND	.12	ND	ND	.02
K2O	.25	99.58	99.85	100.26	100.17	100.28	99.29	100.59	100.55	99.53
TOTAL										

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

	6	6	6	6	6	6	6	6	6	6
OXYGEN	6	6	6	6	6	6	6	6	6	6
Si	1.972	1.968	1.967	1.968	1.967	1.973	1.972	1.969	1.972	1.964
Ti	.031	.033	.031	.023	.035	.004	.034	.039	.034	.038
Al	.004	.005	.006	.009	.007	.001	.004	.001	.001	.001
Cr	.155	.167	.155	.155	.181	.237	.216	.274	.230	.271
Fe2+	.004	.004	.004	.003	.004	.004	.004	.004	.005	.004
Mn	1.781	1.780	1.786	1.829	1.785	1.785	1.722	1.697	1.713	1.684
Ca	.033	.028	.030	.018	.033	.016	.032	.034	.032	.034
Na	.009	.007	.011	.008	.011	.016	.042	.020	.016	.018
K	.001	.001	.001	.001	.001	.001	.005	.001	.001	.001
SUM	4.064	4.016	4.018	4.017	4.018	4.011	4.033	4.015	4.011	4.020
MO	1.68	1.42	1.48	1.88	1.66	1.66	1.64	1.74	1.68	1.73
EN	91.43	88.58	88.44	91.36	89.44	89.36	87.38	84.38	86.70	84.65
FS	7.89	7.76	7.08	7.76	7.08	11.38	10.98	13.88	11.66	13.62
M:	91.47	89.61	90.78	92.17	89.78	87.81	88.84	85.87	88.15	86.14
C:	1.82	1.58	1.63	1.96	1.63	1.89	1.84	2.02	1.85	2.00

** SAMPLE DIRECTORY **

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	UPX KF12	6	NPX KF17
2	UPX KF13	7	NPX KF18
3	UPX KF14	8	NPX KF19
4	UPX KF15	9	NPX KF20
5	UPX KF16	10	NPX KF21

** ND = NOT DETECTED **

TABLE VII-6C ANALYSES OF BROWN ORTHOPYROXENES (GLASSY) FROM THE KOFFIEONTJIN CONCENTRATE

11

SiO2	56.01
TiO2	.21
Al2O3	.45
Cr2O3	.05
FeO	8.17
MnO	.12
MgO	35.14
CaO	.56
Na2O	.20
K2O	ND
TOTAL	99.69

** ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS **

OXYGEN	6
Si	1.900
Ti	.006
Al	.045
Cr	.001
Fe2+	.230
Mn	.004
Mg	1.751
Ca	.032
Na	.010
K	.
SUM	4.022

WD	1.61
ES	16.44
FS	11.94
M:	47.86
C:	1.83

*** SAMPLE DIRECTORY ***

ANALYSIS NO.	DESCRIPTION
11	UPX NF22
ANALYSIS NO.	DESCRIPTION

** ND = NOT DETECTED **

TABLE VII-6D ANALYSES OF BROWN ORTHOPYROXENES (WITH CLEAVAGE) FROM THE KOFFIEFONTEIN CONCENTRATE

	1	2	3	4	5	6	7	8
SiO2	58.13	57.73	57.37	56.96	57.38	56.36	56.11	55.92
TiO2	.04	.19	.04	.22	.03	.20	.25	.24
Al2O3	.63	.79	.22	.74	.56	.82	1.03	1.08
Cr2O3	.33	.25	.22	.31	.08	.02	.11	.11
FeO	4.55	5.77	6.13	5.43	6.48	4.41	8.32	8.13
MnO	.15	5.11	6.13	5.41	6.14	4.14	8.32	8.13
MgO	36.25	35.11	34.58	35.02	34.42	31.87	32.38	32.18
CaO	.36	.15	.16	.15	.50	.22	1.14	1.28
Na2O	.10	.15	.16	.15	.18	.22	.30	.28
K2O	ND	.02	ND	ND	ND	ND	ND	ND
TOTAL	100.49	100.72	100.29	99.78	99.78	100.06	99.75	99.49

* * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6
Si	1.970	1.974	1.975	1.967	1.985	1.974	1.965	1.964
Ti	.001	.005	.001	.006	.001	.005	.007	.006
Al	.025	.030	.036	.030	.023	.036	.043	.045
Cr	.000	.007	.006	.008	.001	.001	.002	.003
Fe2+	.000	.164	.179	.157	.187	.276	.244	.244
Mn	.003	.003	.004	.003	.004	.004	.004	.004
Mg	1.840	1.774	1.774	1.802	1.775	1.653	1.684	1.684
Ca	.013	.024	.030	.031	.019	.035	.043	.046
Na	.007	.011	.011	.010	.012	.015	.020	.019
K	-	-	-	-	-	-	-	-
Si/M	4.006	4.008	4.011	4.014	4.008	4.010	4.017	4.016
Wt %	92.80	91.52	91.52	91.56	90.90	91.79	91.16	91.34
FS	9.54	9.45	9.03	7.88	9.47	8.24	8.49	8.50
M:	93.42	91.62	90.83	92.00	90.44	85.77	87.38	87.34
C:	.71	1.31	1.68	1.70	1.03	2.08	2.47	2.67

* * * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	UPA KF33	5	OPX KF37
2	UPX KF34	6	OPX KF38
3	UPA KF35	7	OPX KF51
4	UPA KF36	8	OPX KF52

* * ND = NOT DETECTED * *

TABLE VII-7 ANALYSES OF CLIMOPYROXENES FROM KOFFIFONTAIN CONCENTRATE

	1	2	3	4	5	6	7	8	9	10
SiO2	54.89	55.04	54.64	54.89	54.74	54.76	54.85	55.03	54.57	54.11
TiO2	1.14	1.03	1.23	1.15	1.04	1.06	1.04	1.05	1.19	1.36
Al2O3	2.50	2.30	1.01	1.42	3.32	1.55	3.28	2.17	3.59	1.72
FeO	1.45	1.07	1.50	1.37	1.50	1.55	1.58	1.56	1.63	2.20
MnO	1.65	1.33	2.65	2.87	1.05	2.08	1.54	1.04	1.11	2.09
MgO	1.04	0.94	1.10	1.11	1.05	0.88	1.04	1.07	1.11	1.31
CaO	15.93	16.56	17.85	18.29	15.56	18.31	15.80	16.04	15.02	19.35
Na2O	20.93	22.09	20.48	19.54	20.96	20.51	20.82	21.08	19.08	21.01
K2O	2.10	1.70	1.48	1.41	2.10	1.51	2.31	2.13	3.23	2.03
TOTAL	100.02	100.26	100.27	100.12	99.33	99.47	99.83	100.67	100.18	98.78

* * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6	6	6
Si	1.982	1.980	1.942	1.940	1.983	1.987	1.979	1.973	1.973	1.983
Ti	.004	.001	.006	.004	.001	.002	.001	.001	.005	.008
Al	.101	.043	.045	.063	.142	.045	.136	.125	.117	.072
Fe	.030	.030	.045	.038	.032	.044	.034	.033	.043	.079
Fe2+	.054	.041	.080	.087	.044	.062	.048	.047	.049	.067
Mn	.001	.001	.003	.003	.002	.001	.001	.001	.003	.003
Mg	.857	.838	.961	.983	.840	.890	.850	.859	.809	.891
Ca	.810	.852	.793	.755	.913	.797	.805	.832	.739	.760
Na	.153	.110	.104	.090	.147	.073	.102	.148	.226	.143
K	-	-	.002	.002	-	.005	-	.001	-	.001
SUM	4.015	4.013	4.020	4.015	4.004	4.006	4.016	4.021	4.026	4.006
MO	47.04	47.45	43.23	41.38	47.93	43.14	47.29	47.87	46.26	44.23
FM	40.74	44.90	52.40	53.87	44.49	53.57	49.91	49.44	50.65	51.85
FS	3.24	2.25	4.37	4.74	2.59	3.28	2.80	2.60	3.08	3.92
M:	93.84	95.00	92.31	91.91	95.03	94.22	94.69	94.83	94.26	92.96
C:	48.58	48.96	45.20	43.44	49.24	44.61	48.65	49.19	47.73	46.03

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION
1	CPX KF30
2	CPX KF40
3	CPX KF41
4	CPX KF42
5	CPX KF43
6	CPX KF44
7	CPX KF45
8	CPX KF46
9	CPX KF47
10	CPX KF48

* * MD = NOT DETERMINED * *

TABLE VII-7 ANALYSES OF CINOPYROXINES FROM KOFFIFONTAIN CONCENTRATE

	11	12	13	14	15	16	17	18	19	20
SiO2	55.05	54.44	55.11	55.01	54.83	55.04	54.68	54.83	54.99	54.66
TI02	2.21	1.16	2.25	2.34	1.82	.82	2.10	.91	.94	2.11
AL2O3	2.37	2.81	2.56	1.67	1.90	1.47	1.45	2.20	2.77	2.87
CaF2	2.10	2.17	2.35	1.34	2.48	2.08	1.05	2.46	2.09	1.61
MNO	16.24	17.09	17.08	16.05	17.28	16.02	16.25	16.58	14.79	15.84
CAU	18.28	18.70	18.71	18.45	18.90	21.17	20.17	19.83	18.07	18.06
NA2O	2.57	3.40	2.05	1.77	1.74	1.46	1.83	1.72	3.12	2.56
K2O	0.03	ND	0.07	0.93	0.03	0.02	ND	ND	ND	ND
TOTAL	99.90	99.84	99.27	99.73	99.57	99.02	98.50	98.73	98.94	98.12

* * ATOMIC PROPORTIONS BASED ON SELF-CALCULATED NO. OF OXYGENS * *

OXYGEN	6	6	6	6	6	6	6	6	6	6
ST	1.990	1.973	1.990	1.987	1.989	2.003	1.993	2.008	2.002	2.003
TI	0.04	0.07	0.07	0.07	0.07	0.07	0.03	0.06	0.06	0.06
AL	0.02	0.12	0.12	0.10	0.07	0.35	0.15	0.39	0.12	0.09
Ca	0.64	0.81	0.71	0.88	0.54	0.42	0.37	0.61	0.80	0.81
CaF2+	0.64	0.66	0.66	0.42	0.75	0.75	0.44	0.75	0.64	0.51
MNO	0.75	0.83	0.83	0.85	0.83	0.82	0.83	0.83	0.82	0.83
MG	0.75	0.72	0.72	0.72	0.73	0.82	0.88	0.78	0.80	0.85
CA	1.80	1.44	1.44	1.24	1.22	1.22	1.29	1.22	1.22	1.22
NA	0.01	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01
SUM	4.014	4.031	4.005	4.002	4.000	4.000	3.993	3.998	4.004	3.995
MO	43.64	45.74	42.14	40.94	42.17	45.53	45.94	44.25	44.87	43.62
EN	52.10	50.11	53.73	50.96	53.52	50.32	51.48	51.46	51.08	53.21
FS	3.45	4.14	4.13	2.40	4.31	4.15	2.58	4.28	4.05	3.17
M:	92.94	92.56	92.86	95.50	92.55	92.59	95.23	92.31	92.95	94.38
C:	05.66	47.72	03.96	47.79	44.07	47.50	47.16	46.23	46.76	45.05

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11	CPX KF50	16	CPX KF57
12	CPX KF50	17	CPX KF58
13	CPX KF53	18	CPX KF59
14	CPX KF54	19	CPX KF60
15	CPX KF56	20	CPX KF61

** ND = NOT DETECTED **

TABLE VII-A ANALYSES OF CHROMITES FROM THE KOFFIEFONTEIN CONCENTRATE

	1	2	3	4	5	6	7	8	9	10
STO2	.02	.04	NO	.07	.10	.25	.28	.28	.28	.30
AL2O3	1.69	2.30	.77	1.50	2.50	2.25	1.36	2.42	1.19	.57
CP2O3	6.03	7.73	2.73	7.57	7.73	8.15	7.76	5.64	2.04	.58
FFO	54.03	57.54	65.25	52.67	54.27	59.32	59.81	60.81	60.79	62.61
FFU	6.16	7.40	5.25	6.91	6.50	4.63	4.43	3.98	5.99	3.62
MPO	14.79	17.43	12.98	14.50	15.63	15.33	13.85	13.62	19.26	12.43
MGU	12.77	10.82	13.22	10.52	13.09	13.39	14.03	14.54	9.53	14.53
CAU	12.41	10.80	13.22	10.52	13.09	13.39	14.03	14.54	9.53	14.53
NA2O	-	-	-	-	-	-	-	-	-	-
K2O	-	-	-	-	-	-	-	-	-	-
TOTAL	100.53	100.15	100.22	99.77	99.95	101.40	101.52	101.29	99.88	101.04

** ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS **

OX YGEN	4	4	4	4	4	4	4	4	4	4
ST	.001	.001	.010	.002	.003	.009	.009	.009	.010	.010
AL	.040	.040	.107	.040	.064	.055	.033	.033	.031	.024
CP	.237	.237	.721	.292	.298	.235	.293	.215	.115	.250
FF3+	1.153	1.153	1.362	1.392	1.406	1.522	1.516	1.553	1.655	1.596
FF2+	.008	.008	.023	.022	.024	.014	.017	.007	.007	.008
MU	.022	.022	.037	.031	.028	.016	.011	.007	.007	.008
MG	.611	.611	.637	.525	.539	.648	.670	.700	.487	.698
CA	-	-	-	-	-	-	-	-	-	-
NA	-	-	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-	-	-
SUM	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
CR	.87	.91	.94	.82	.87	.87	.84	.88	.93	.86
MG	.60	.52	.64	.50	.60	.61	.64	.66	.47	.68
FF	.09	.10	.07	.12	.00	.06	.06	.05	.08	.05

A * * S A M P L E D I R E C T O R Y * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	CHROMITE 2	6	CHROMITE 11
2	CHROMITE 5	7	CHROMITE 13
3	CHROMITE 7	8	CHROMITE 14
4	CHROMITE 9	9	CHROMITE 15
5	CHROMITE 10	10	CHROMITE 16

** NO = NOT DEFLECTED **

TABLE VII-B ANALYSES OF CHROMITES FROM THE KOFFIEFONTEIN CONCENTRATE

	11	12	13	14	15	16	17	18	19	20
STU2	.24	.26	.30	.29	.23	.25	.26	.06	.05	.04
TIU2	.05	.34	.74	1.51	.61	.61	1.04	3.66	3.40	3.37
ALP2O3	6.74	3.54	3.54	6.83	10.45	2.74	3.73	4.49	5.21	5.50
CP2O3	6.15	6.14	5.54	59.57	59.57	69.74	63.73	55.49	54.17	54.06
FFU	1.20	2.49	6.26	5.04	3.60	3.30	3.38	4.80	5.24	5.68
FFU	13.40	13.04	16.00	13.31	13.28	14.30	12.82	19.24	18.63	18.68
MNO	13.50	12.76	12.88	14.20	13.88	12.05	14.21	10.66	10.81	10.79
MGO	-	-	-	-	-	-	-	-	-	-
CAO	-	-	-	-	-	-	-	-	-	-
NA2O	-	-	-	-	-	-	-	-	-	-
K2O	-	-	-	-	-	-	-	-	-	-
TOTAL	94.48	100.43	99.22	100.70	101.04	101.06	100.73	98.34	97.55	97.72

A A ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

	4	4	4	4	4	4	4	4	4	4
OXYGEN	4	4	4	4	4	4	4	4	4	4
ST	.008	.009	.010	.009	.007	.008	.008	.002	.002	.001
TI	.014	.069	.294	.037	.006	.015	.032	.094	.088	.087
AL	.335	.130	.294	.260	.392	.103	.194	.179	.211	.213
CR	1.764	1.394	1.394	1.525	1.086	1.754	.643	1.504	1.473	1.479
FF2+	.032	.062	.156	1.123	1.086	1.027	1.083	1.124	1.137	1.131
FF2+	.305	.366	.445	.361	.354	.397	.350	.552	.536	.536
MN	.650	.632	.634	.686	.659	.626	.691	.545	.554	.552
MG	-	-	-	-	-	-	-	-	-	-
CA	-	-	-	-	-	-	-	-	-	-
NA	-	-	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-	-	-
SUM	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
CR	.83	.93	.83	.85	.79	.94	.89	.89	.87	.87
MG	.64	.62	.59	.66	.65	.61	.66	.50	.51	.51
FF	.02	.03	.08	.06	.04	.05	.04	.07	.08	.07

A A A SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION
11	CHROMITE 17
12	CHROMITE 18
13	CHROMITE 19
14	CHROMITE 20
15	CHROMITE 21
16	CHROMITE 22
17	CHROMITE 23
18	CHROMITE 26
19	CHROMITE 27
20	CHROMITE 28

TABLE VII-8 ANALYSES OF CHROMITES FROM THE KOFFIEFONJIN CONCENTRATE

	21	22	23	24	25	26	27	28
STO2	1.07	ND	.02	.05	ND	.02	.03	.04
TI	4.44	17	.04	1.87	42	2.43	.62	2.53
AL	43.07	2.21	9.04	5.50	9.31	4.41	3.87	9.84
CF2O3	2.34	44.8A	61.30	58.86	59.87	61.04	63.57	57.70
FFO	14.87	5.01	1.40	4.14	3.08	3.08	4.14	3.53
MNO	11.82	12.70	13.82	16.07	13.14	13.80	13.95	13.19
CAU	-	12.00	12.50	11.77	12.99	13.02	11.85	13.75
NA2O	-	-	-	-	-	-	-	-
K2O	-	-	-	-	-	-	-	-
TOTAL	97.83	97.70	98.12	98.25	99.26	98.55	98.72	98.20

* * ATOMIC PROPORTIONS BASED ON SELECTED NU. OF OXYGENS * *

	4	4	4	4	4	4	4	4
OXYGEN	4	4	4	4	4	4	4	4
SI	.028	.004	.001	.002	.010	.001	.001	.001
AL	1.705	.090	.001	.048	.354	.081	.016	.063
FF2+	1.060	1.770	1.608	2.20	1.544	1.173	1.57	.268
FF3+	.72	1.130	.035	1.105	.076	.078	1.707	1.515
MN	.602	.022	.384	.455	.019	.368	.106	.088
CA	-	.617	.618	.594	.633	.653	.021	.018
NA	-	-	-	-	-	-	.600	.681
K	-	-	-	-	-	-	-	-
SUM	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
CR	.90	.95	.82	.88	.81	.90	.92	.85
MG	.50	.63	.62	.57	.60	.63	.60	.65
FE	.03	.07	.02	.06	.04	.04	.05	.05

* * * SAMPLE DIRECTORY * *

ANALYSIS NO.	DESCRIPTION
21	CHROMITE 29
22	CHROMITE 30
23	CHROMITE 31
24	CHROMITE 33
25	CHROMITE 34
26	CHROMITE 35
27	CHROMITE 36
28	CHROMITE 37

** ND = NOT DETECTED **

TABLE VII-9 ANALYSES OF ILMENITES FROM THE KOFFEONIFIN CONCENTRATE

	1	2	3	4	5	6
SiO2	55.90	ND	ND	ND	ND	ND
TiO2	2.14	54.92	56.93	55.99	55.11	55.85
Al2O3	2.12	.68	2.71	.12	.09	.07
Cr2O3	2.05	3.85	1.01	.43	1.89	2.32
FeO	24.88	24.88	24.81	26.33	26.05	26.95
MnO	14.53	13.26	14.27	15.31	13.33	15.34
MgO	-	13.26	14.26	15.42	13.01	15.43
CaO	-	-	-	-	-	-
Na2O	-	-	-	-	-	-
K2O	-	-	-	-	-	-
TOTAL	99.72	98.92	100.60	99.20	98.60	100.25

A * ATOMIC PROPORTIONS BASED ON SELECTED NO. OF OXYGENS * *

OXYGEN	3	5	3	3	3	3
Si	.056	.051	.060	.070	.063	.055
Ti	.004	.019	.006	.003	.002	.002
Al	.034	.012	.015	.015	.035	.042
Cr	.045	.067	.018	.041	.037	.045
Fe	.058	.079	.067	.073	.066	.042
Mn	.006	.005	.005	.006	.006	.007
Mg	.043	.067	.062	.061	.050	.057
Ca	-	-	-	-	-	-
Na	-	-	-	-	-	-
K	-	-	-	-	-	-
SUM	2.000	2.000	2.000	2.000	2.000	2.000

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11 07.37	ILMENITE 1	11 50.96	ILMENITE 8
GK 50.51	ILMENITE 3	GK 46.71	ILMENITE 12
HM 2.32	ILMENITE 5	HM 1.88	ILMENITE 32

* * * SAMPLE DIRECTORY * * *

* * NO = NOT DETECTED * *

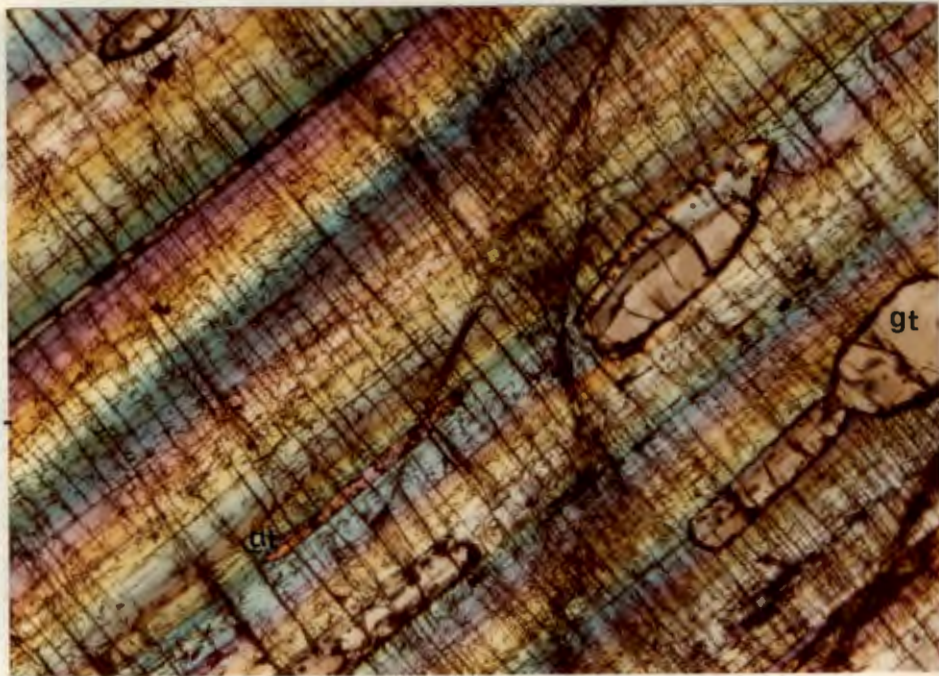


Plate 1. Illustration of clinopyroxene megacryst PC21, exsolving orthopyroxene and garnet. The orthopyroxene occurs as bands of variable width, recognised by its straight extinction, but there are no defined grain boundaries between the orthopyroxene and the clinopyroxene host. Garnet occurs as parallel long thin lamellae (top left hand side of plate) and as rod shaped inclusions (eg. see garnet -gt- on right hand side of plate).

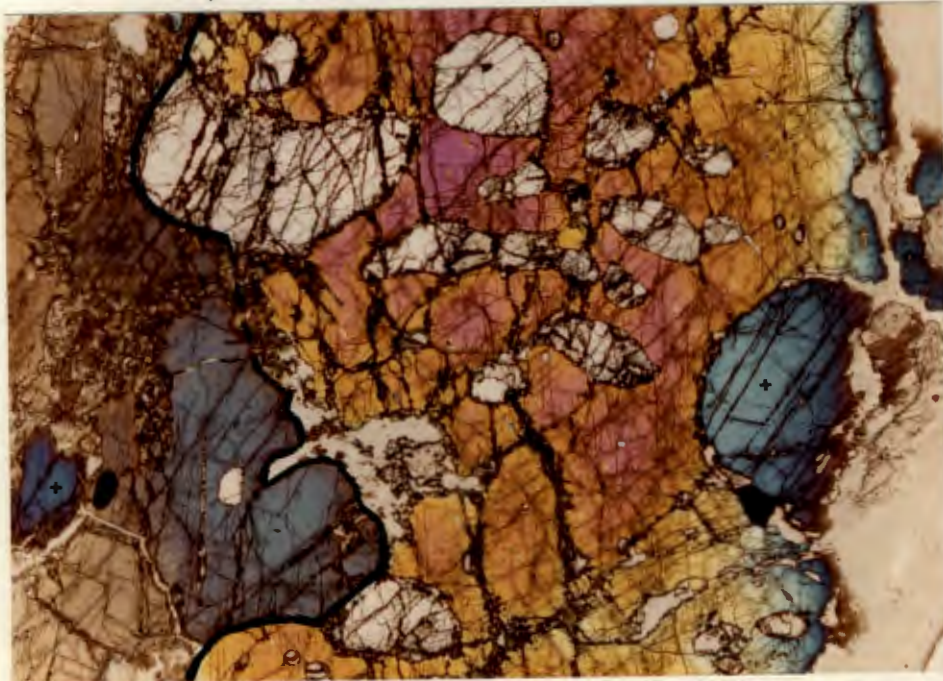


Plate 2. Two large clinopyroxene crystals (delineated in thick black ink and marked →) with inclusions of orthopyroxene of variable shape and size. With the exception of the orthopyroxenes marked +, they all extinguish simultaneously within each crystal, suggesting structural control by the clinopyroxene hosts. (Xenolith PC22)

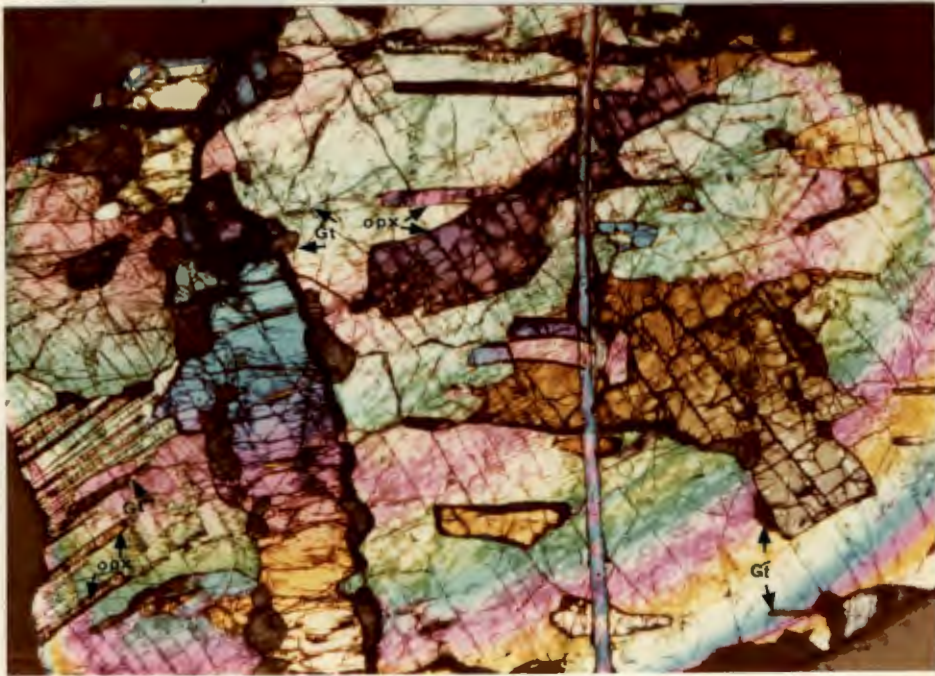


Plate 3. Clinopyroxene exsolving garnet and orthopyroxene (PC25). Note the variation in orthopyroxene size and shape, and the coalescence of lamellae and rod shaped grains with larger orthopyroxene inclusions; they all extinguish simultaneously. Garnet occurs as thin lamellae and as larger grains along orthopyroxene-clinopyroxene boundaries, and within large orthopyroxenes. A "finger" of orthopyroxene separates the two clinopyroxene crystals.

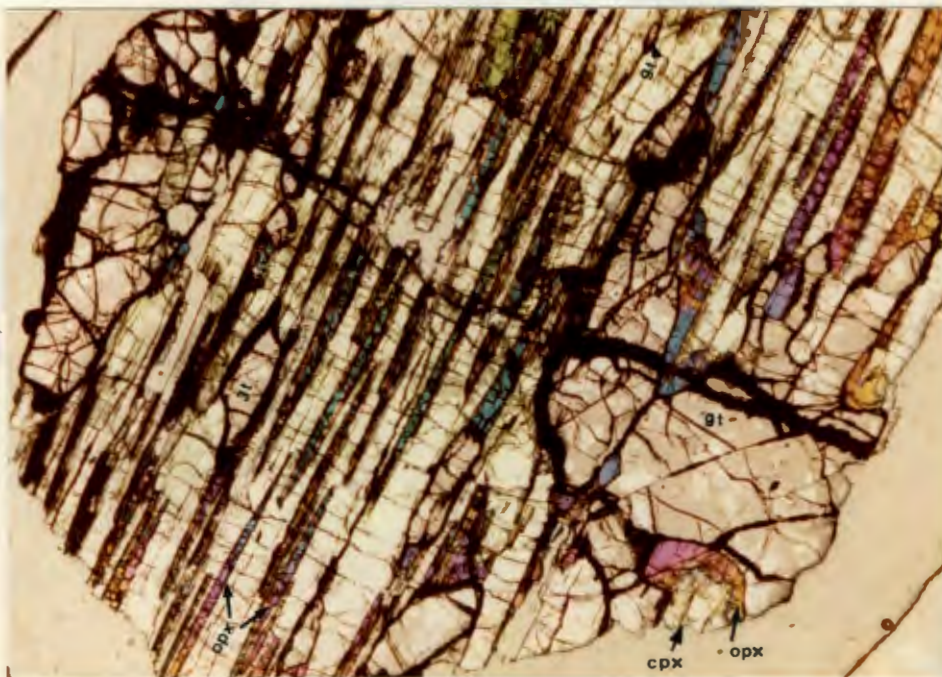


Plate 4. Xenolith PC33 . Clinopyroxene exsolving orthopyroxene and garnet. The larger garnets may be primary, but the finger-like intergrowth of the largest garnet with the clinopyroxene host (bottom right hand side of plate) suggests exsolution followed by coarsening. Also note the grain with a centre of clinopyroxene surrounded by a rim of orthopyroxene, with no visible grain boundaries between the two (bottom right hand side).

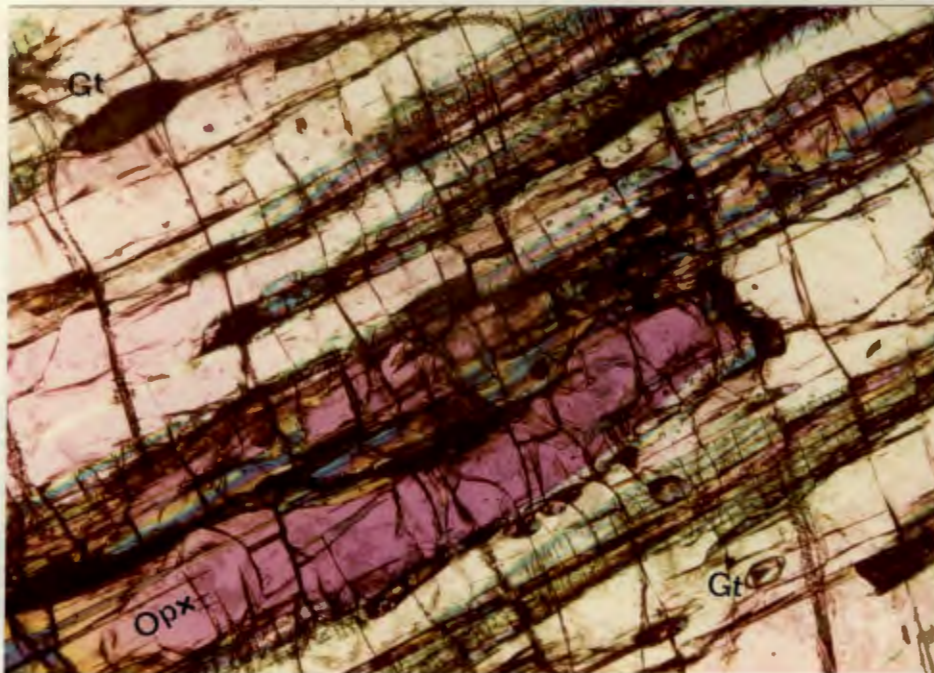


Plate 5. Further illustration of garnet and orthopyroxene exsolution from clinopyroxene in xenolith: PC33.

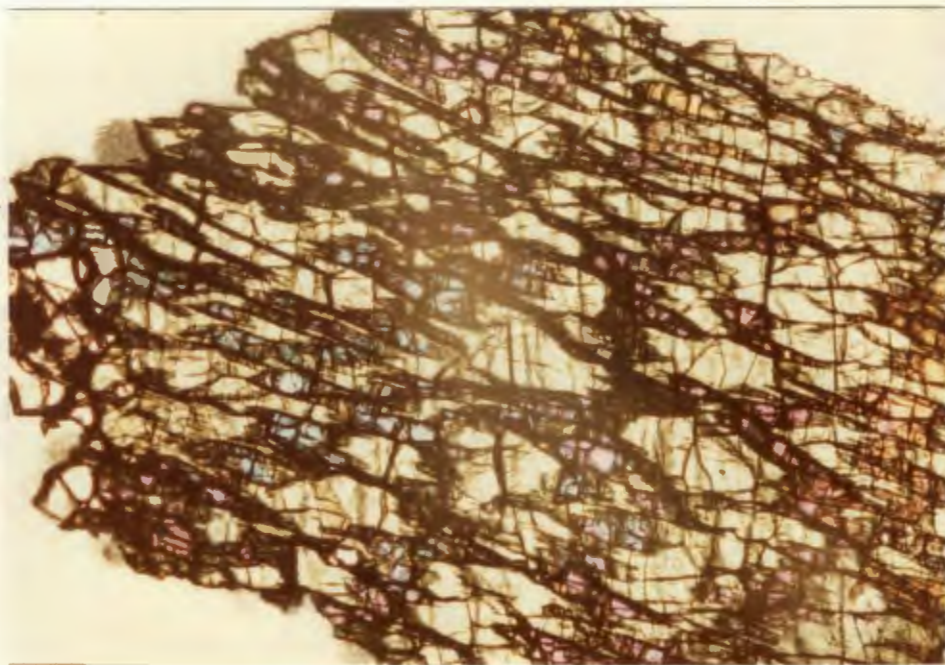


Plate 6. Xenolith PC54. Single clinopyroxene crystal with exsolved orthopyroxene and small blebs of garnet. Garnet is also present as two larger crystals (one is shown on the left hand side of plate) along the edges, and these could be primary phases.

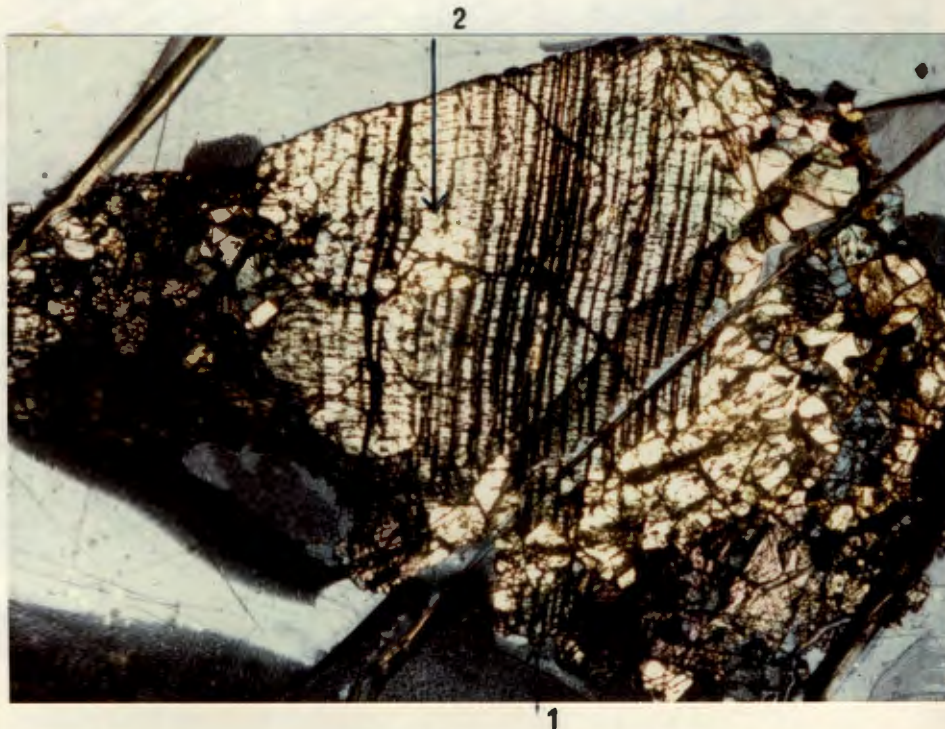


Plate 7. Single clinopyroxene crystal PC55, showing different textures in the centre and along the margins. The centre shows parallel bands of altered orthopyroxene, and small blebs of garnet and chromite (exsolved phases). Along the margin there are small polygonal grains of clinopyroxene and orthopyroxene, and roundish garnet and chromite grains (both coarser grained than the ones in the central region). Note that within the marginal zone there are areas (1 and 2) resembling the core (area 2 is rotated at an angle relative to the centre) and that within the central zone a small portion of the clinopyroxene has started to develop a similar appearance to the edge. This rock demonstrates the significant role that deformation and recrystallisation can play in the obliteration of relict textures of former higher temperatures of equilibration.

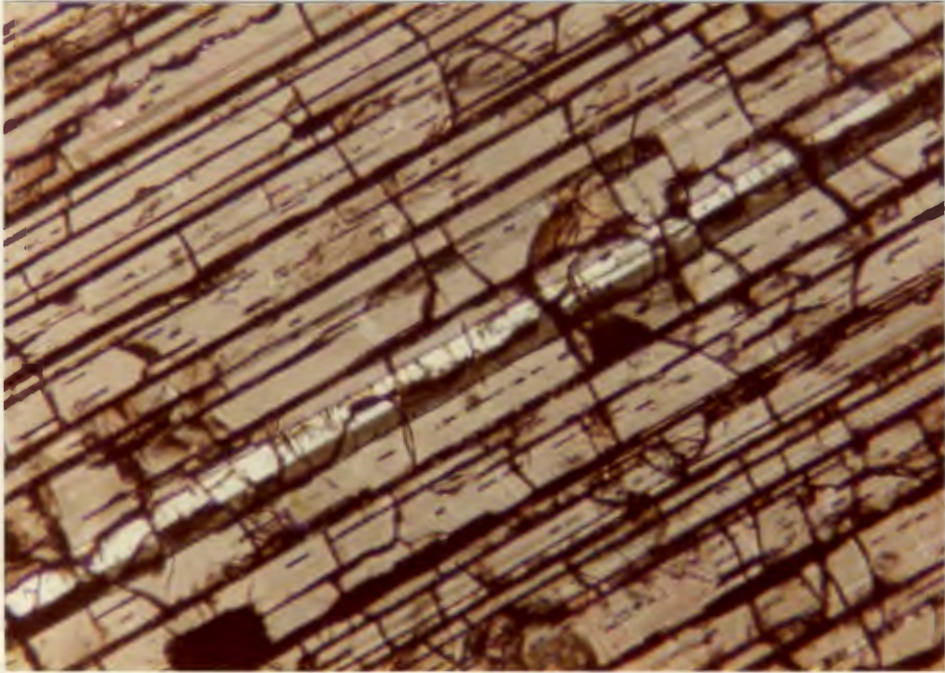


Plate 8. Orthopyroxene megacryst PC20B showing well developed cleavage and exsolution of clinopyroxene lamellae.

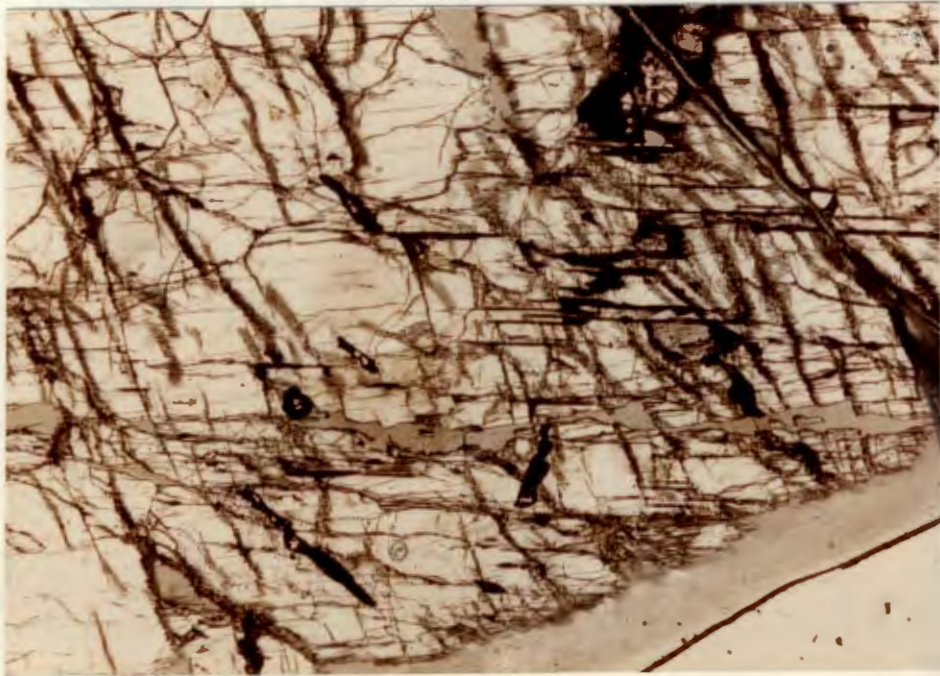


Plate 9. Orthopyroxene megacryst PC24B with roundish to elongated exsolved garnets.

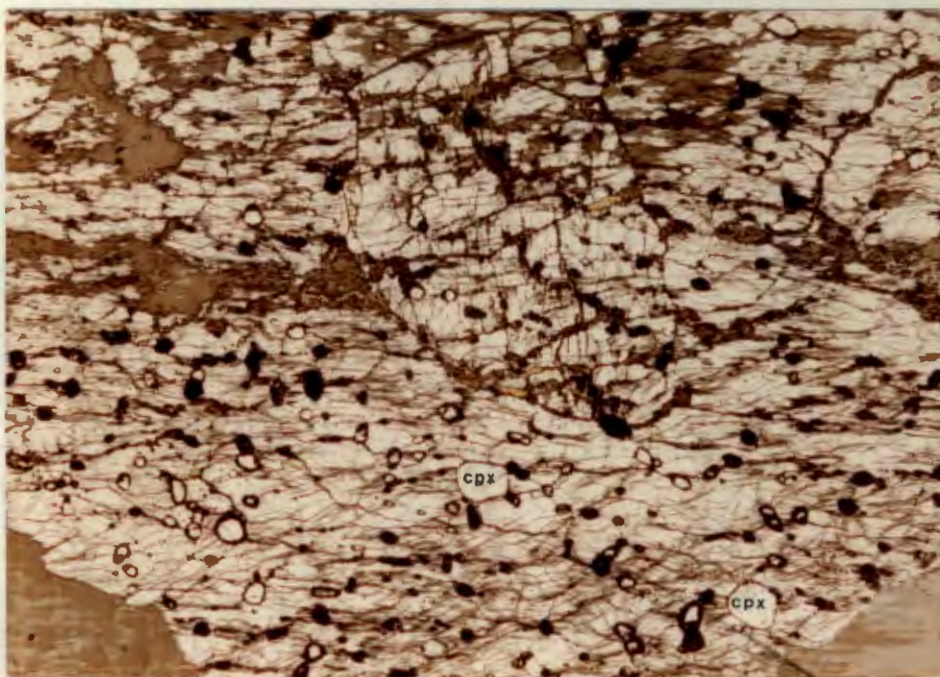


Plate 10. Orthopyroxene megacryst PC27 with small roundish exsolved garnets and three inclusions of clinopyroxene(cpx). Readjustment of this crystal as a result of deformation has resulted in limited recrystallization along deformation bands (centre and right Hand side of top part of plate).

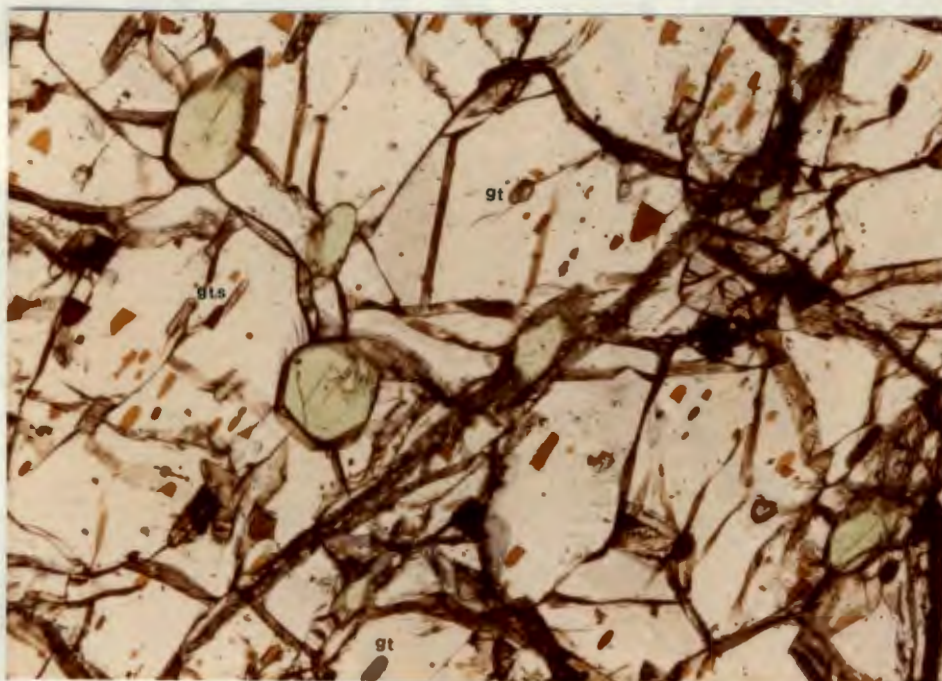


Plate 11. Orthopyroxene megacryst PC28 with inclusions of clinopyroxene (green), chromite(brown) and garnet (colourless-gt). The parallel and preferred orientation of these phases and the simultaneous extinction of the clinopyroxene suggest structural control by the orthopyroxene host.

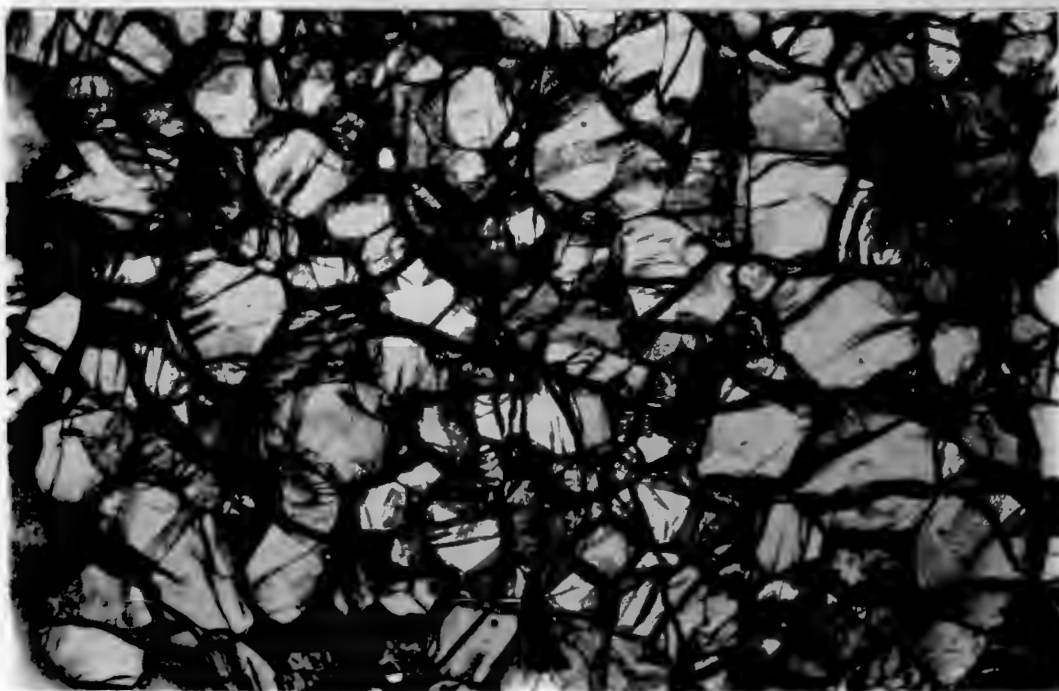


Plate 12. Xenolith PC65, illustrating the extreme case in Type IV pyroxenites, where all orthopyroxenes show signs of polygonisation. The grains are equant, with a bimodal size distribution and with slightly curved to straight grain boundaries joining at $\sim 120^\circ$ triple junctions.

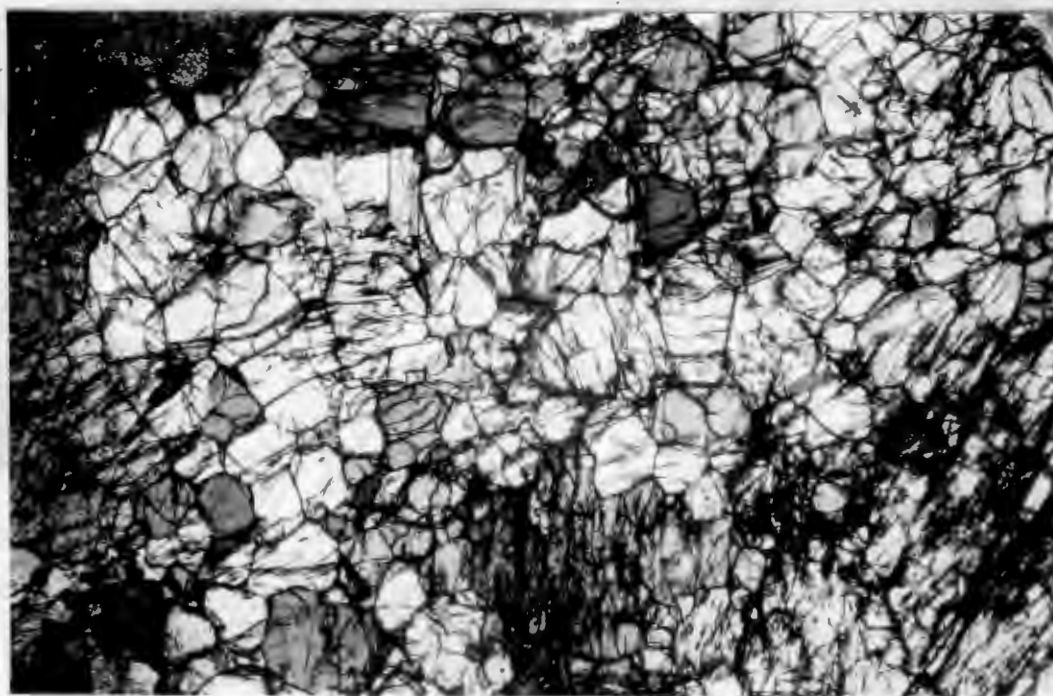


Plate 13. Xenolith PC60, illustrating the large orthopyroxene grains with irregular grain boundaries and a cracked appearance in contrast to the enclosed or partially enclosed smaller grains which have regular grain boundaries, smoothly curved or straight and frequently display 120° triple points.



Plate 14. Xenolith PC43, where orthopyroxenes of variable size and shape can be observed, with polygonisation of the smaller grains. Note bending and widening of lamellae (grains 1 and 2, respectively) of clinopyroxene along kink bands.



Plate 15. Kink band across an orthopyroxene grain in pyroxenite PC 43. Note development of lamellae (clinopyroxene) at the kink band plane.

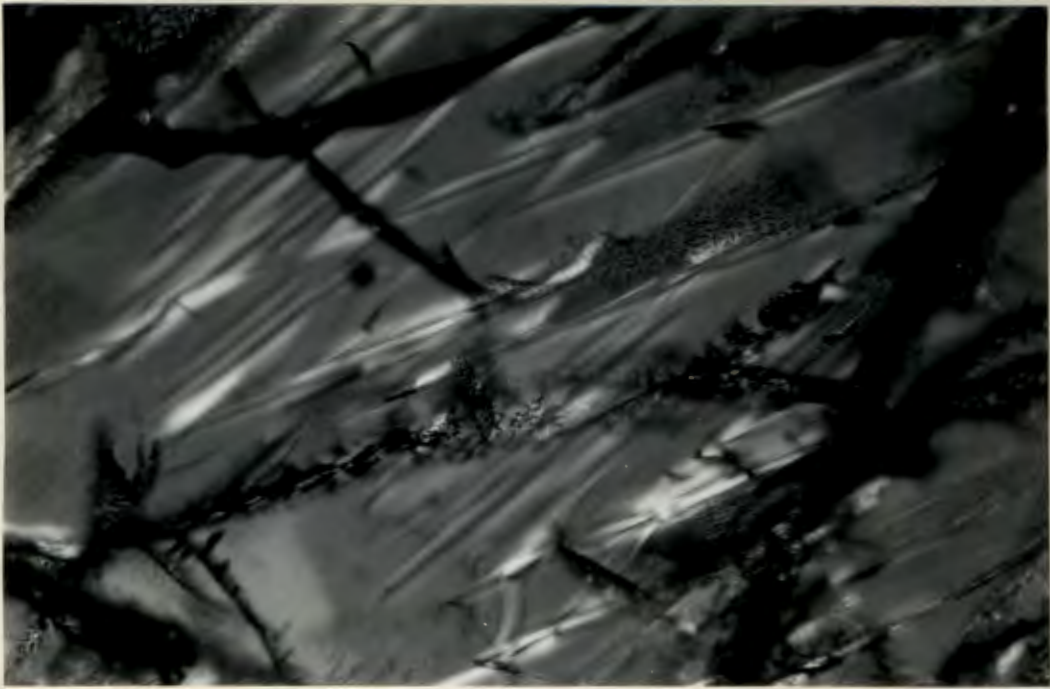


Plate 16. Illustration of two sets of lamellae in clinopyroxene crystal from xenolith PC26. The same phenomena is also observed in clinopyroxenes of pyroxenite PC43.

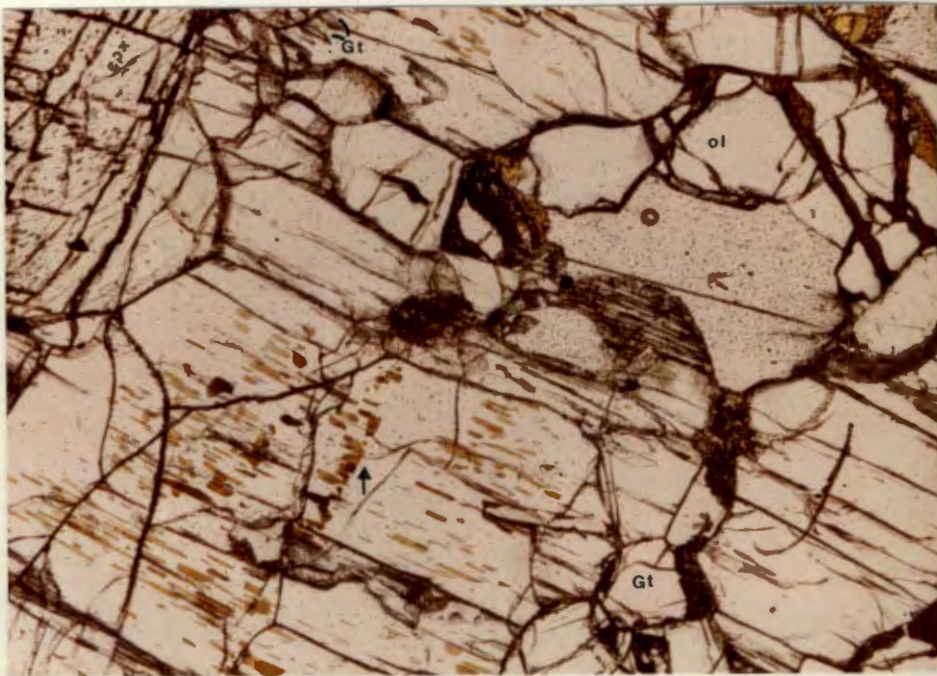


Plate 17. Illustration of chromite lamellae in orthopyroxene in olivine bearing pyroxenite(PC47); note exsolution of chromite along an incipient kink band (→). A few very small garnet lamellae can also be seen in this microphotograph (eg. gt- in top part of plate). Discrete grains of garnet, clinopyroxene and olivine are also illustrated.