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

by

P. CARDOSO

Department of Geochemistry,
University of Cape Town.

June, 1980

Thesis submitted in fulfilment of the requirements
for the degree of M.Sc. at the
University of Cape Town.

CONTENTS

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 microporphyritic 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. Eggler 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:

Kimberlite	age (m.y.)
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 μA
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 (1-2μ). (For hydrous minerals a defocussed beam of 10 - 30μ 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 µA
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, ± orthopyroxene and ± 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, ± clinopyroxene, ± 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, ∿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 corase 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 $\sim$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 ($\sim$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 $\sim$0.8 mm.), followed by orthopyroxene (one crystal $\sim$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 clino- 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 Al_2O_3 (0.7 - 4.9 wt.%), Cr_2O_3 (0.44 - 1.3 wt.%) and Na_2O (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 Na_2O content increases with increasing Al_2O_3, 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. Cr_2O_3 (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 Cr_2O_3-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 Al_2O_3 and Cr_2O_3 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 xnoliths, 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:

$$Ca(Mg,Fe)\,Si_2O_6 + (Mg,Fe)_3\,Al_2Si_3O_{12} \rightleftarrows (Mg,Fe)\,Si_2O_6 + Ca_3Al_2Si_3O_{12}$$

(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 Na_2O 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 Cr_2O_3, and an increase in the MgO contents of the garnets (Fig. IV-4 a,b,c,d).

The Na_2O content of clinopyroxenes in eclogites can sometimes be used as a differentiation index (Hatton, 1978; Shee, 1978), and with progressive fractionation, Na_2O 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 Na_2O 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 (i) (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 ($\sim$0.4 wt.%). Cr_2O_3 is usually concentrated in garnets relative to either clino- or orthopyroxene, and upon exsolution Cr_2O_3 has been concentrated in the small modal proportion of garnet exsolved in PC22 and PC25 (3.2 and 2.7 wt.% Cr_2O_3), whereas it has been "diluted" in the large modal proportion of garnet exsolved in PC34 ($\sim$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 $\lesssim 950^{\circ}$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) $(T(^{\circ}K) = \frac{3104\, X^{gt}_{ca} + 3030 + 10.86P\ (Kb)}{\ln K_D + 1.9034}$ 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°C) than those estimated according to Ellis and Green (1979) (1028 - 1161°C).

(v) Fig. IV-7 (a,b,c) shows a plot of the Mg/Fe^{2+} ratios for coexisting garnet-orthopyroxene, garnet-clinopyroxene and clino-orthopyroxene 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 Fe^{2+}-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 ($K_D = (Cr/Cr+Al)_{gt}/(Cr/Cr+Al)_{cpx}$) 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 ($2\sigma = \pm.04$), suggesting a uniform equilibration temperature:

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

PC22 = .28
PC25 = .24
PC33 = .26
PC34 = .20
PC35 = .22
PC54 = .22
PC55 = .24
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 ($^1/T = (0.26 \pm .01) \ln K_D + (0.67 \pm .01)$; $K_D = (Al^{VI}/Cr)_{opx}/(Al^{VI}/Cr)_{cpx}$) 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 ±100°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 $\sim 1100^{\circ}C$, 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 ($K_D = (Mg/Fe^{2+})_{px}/(Mg/Fe^{2+})_{gt}$) as a function of pyroxene variables reflecting their equilibration temperatures.

In Fig. IV-8 (a) ($K_{D_{cpx/gt}}$ vs. $(Al^{VI}/Cr)_{opx}/(Al^{VI}/Cr)_{cpx}$) 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 Al^{VI}/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 $(Fe/Fe+Mg)_{opx}$ and $(Fe, Mg, Ca, Mn, Na)_{gt}$ are taken into account, may be incorrect.

In Fig. IV-8 (b) ($K_{D_{cpx/gt}}$ versus $Ca/Ca+Mg_{cpx}$) there is a range in K_D despite the almost constant Ca/Ca+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), ($K_{D_{opx/gt}}$ versus $Ca/Ca+Mg_{opx}$) the K_D values remain constant regardless of a slight change in the Ca/Ca+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 (~1000°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 (∿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 $Mg/Mg+Fe^{2+}$ 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 $\sim 900^{\circ}C$.

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 (± 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.

<u>PC24A</u>, <u>PC24B</u>, <u>PC27</u> and <u>PC71</u> : 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 (En_{92} - $En_{93.8}$) (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 ($\sim$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 Al_2O_3 (2.2 - 4.3 wt.%), Na_2O (1.7 - 3.7 wt.%) and Cr_2O_3 (1.4 - 2.4 wt.%), when compared to clinopyroxenes from Type I pyroxenites. TiO_2 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 Cr_2O_3 rich (54.5 wt.%), but when compared with chromites from the concentrate it has less Cr_2O_3, MgO and more Al_2O_3 (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 Cr_2O_3 (0.08 wt.%) and TiO_2 (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 ∿<900°C up to 1070°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 ∿1030°, 970° and 1050°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 ∿1070° and <900°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 $\sim 1100^{\circ}C$.

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 ($\sim$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

K_2O (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 Al_2O_3 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:

$$m(Mg,Fe,Ca)SiO_3.nMgAl_2SiO_6 \rightleftarrows Mg_3Al_2Si_3O_{12} + (m-2)(Mg,Ca,Fe)SiO_3.(n-1)MgAl_2SiO_6$$

(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 $CaSiO_6$

(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, Cr_2O_3 and Al_2O_3 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, Al_2O_3 and Cr_2O_3 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 Al_2O_3 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, Al_2O_3 and Cr_2O_3.

Following this model, crystallisation of orthopyroxene from a magma would result in an increase in CaO and Al_2O_3 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 Cr_2O_3 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.

<u>PC30</u> : 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.%), Cr_2O_3 (0.2 - 0.5 wt.%) and Al_2O_3 (0.5 - 0.83 wt.%). Fig. IV-16 (a,b,c) illustrates a plot of Cr_2O_3, CaO and Al_2O_3 contents versus the Mg/Mg+Fe ratios. The most Cr_2O_3 and CaO-rich and Al_2O_3-poor pyroxenes have the lowest Mg/Mg+Fe ratios, and they also have the highest TiO_2 (0.05 - 0.14 wt.%).

The small orthopyroxene inclusion in a chromite grain in PC41 (see hand specimen description) has higher Cr_2O_3 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 Al_2O_3 (1.1 - 4.3 wt.%), Cr_2O_3 (1.1 - 2.8 wt.%), Na_2O (1.5 - 4.1 wt.%) and TiO_2 (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, Al_2O_3 and Cr_2O_3 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 geothermomemters 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 (∿900°C - 970°C) than PC30, PC41 and PC50 (∿1070° - 1100°C) as evidenced by the range in Ca/Ca+Mg ratios of their pyroxenes. The high Cr_2O_3 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 ∿120° (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 ∿120°. 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 ∿120°C. 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 : (∿89% opx; 10% cpx; 1% amphibole).

Both pyroxenes in the sample are relatively fresh, and grain size is variable (∿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 ∿120°. 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).

<u>PC66</u> and <u>PC23</u> : (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 : (∿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 ∿120°. 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 : ∿70% opx; ∿28% cpx; ∿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 ∿120° 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 (Mg/Mg+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 Mg/Mg+Fe ratios varying between 87.5 and 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 havelow 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 membersof 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 ($Na, Ca_2 Mg_5 Si_7AlO_{22} (OH)_2$). 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 ($<900^\circ C$), 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 cyrstals.

2.5.2 Mineral Chemistry:

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

The orthopyroxene is an enstatite ($En_{\sim 88.3}$), 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 ($Fo_{\sim 85.7}$) 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 Cr_2O_3 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 clino 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 coarsed 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 ($Fo_{92.2}$ - $Fo_{94.2}$), similar to those from granular peridotites from Lesotho (Nixon and Boyd, 1973).

The orthopyroxenes of PC44, PC61 and PC63 are enstatites ($En_{94.2}$ - $En_{95.2}$), 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 ∿940°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 Cr_2O_3 in peridotitic garnets, olivines and chromites, high K_2O 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 PJL 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 ($Fo_{91.6} - Fo_{95.4}$), 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 (Mg, Fe^{2+}) $\leftrightarrow$ 2 Cr^{3+}; this is accompanied by the substitution of the large Ca^{2+} cation for (Mg, 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.%), Na_2O (0.3 - 2.4 wt.%), Al_2O_3 (0.68 - 2.14 wt.%) and TiO_2 (N.D. - 0.07 wt.%) contents and a Cr_2O_3 content ranging between 0.8 and 3.7 wt.%. However, the K_2O 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.% K_2O) which occurs in an unfractured diamond. Inclusions cpx K18 and K18A2 have particularly high K_2O concentrations (~1.6 wt.%) and from the description of their diamond host, cpx K18A2 is a clear diopside and therefore its K_2O 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°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°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 et.%) 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 TiO_2 (0.13 - 0.42 wt.%) and the Na_2O (1.4 - 4.6 wt.%) and Al_2O_3 (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 TiO_2 and occurrence, in the same diamond, with garnets which have eclogitic characteristics.

The presence of K_2O 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 K_2O 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 Na_2O content of clinopyroxenes as a differentiation index for eclogites. Although the Koffiefontein clinopyroxene inclusions do show an increase in Na_2O 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, magnesiowüstite ?) 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 ⇄ 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; Eggler 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 ferropericlase 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. Eggler and Wendlandt, 1977).

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

The origin of the periclase 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 periclases 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 periclases (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.

(i) Olivine-chromite:

Olivine K22 (Table V-3) coexists with a chromite (Table V-6), and according to Jackson (1969) the distribution of Mg and Fe^{2+} 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 $FeCr_2O_4$ molecule and suggest the following formulation:

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

where:

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

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 ~1080°C (±50°C) using Boyd and Nixon's (1973) empirical geothermometer. Calculated pressures, for K9 and K46 orthopyroxene-garnet pairs, are 42 and 38 kb. (±3Kb) respectively, using equation 12 of Wood, 1974:

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

$$(X_{Fe})_{opx} \quad (1-2\,X^{Mi}_{Al})_{opx}$$

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:

$$CaMgSi_2O_6 + {}^1/_3\ Fe_3Al_2Si_3O_{12} \rightleftarrows CaFeSi_2O_6 + {}^1/_3\ Mg_3Al_2Si_3O_{12}$$

diopside almardine hedenbergite pyrope

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), Na_2O and Al_2O_3 in the clinopyroxenes, and the amount of Fe^{3+} 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) ($T = \frac{3686+28,35P_{ks}}{2,33+\ln K_D}$) 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^oK), 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-TiO_2 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 Na_2O (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 ($En_{88.7}$ - $En_{91.9}$) 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 $1150^{\circ}C$ and for clinopyroxenes from $\sim 1285^{\circ}C$ to $1390^{\circ}C$. 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 (Cahpter 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°
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°C) than at Monastery (maximum range : 297°C). Also, with the exception of Fe-rich olivines the crystallisation of megacrysts at Monastery ceased at ~1150°C, 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 TiO_2, 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. invervals, 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 ($\lesssim$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 $\sim$7 wt.%, and Cr_2O_3 values between 1.8 and 8.3 wt.% (with three exceptions, with <1.1 wt.% Cr_2O_3). Both Na_2O (N.D. - 0.10 wt.%) and TiO_2 (<0.2 wt.%, with two values at 0.36 - Fig. VII-2) are low, and the Mg/Mg+Fe ratio is lower than in (a) above, varying between 86.9 - 77.2. There is an overall decrease in FeO with increasing Cr_2O_3 (Fig. VII-3). The grossular component is higher ($\sim$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 Mg/Mg+Fe ratio with respect to TiO_2 (Figs. VII-4 and VII-2 respectively). They have lower Mg/Mg+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 Mg/Mg+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 3 7 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 Al_2O_3 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 ($\sim En_{93}$) 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, Cr_2O_3 contents and Ca-Mg-Fe variation (see dotted fields in Figs. VII-7, 8 and 10), but TiO_2 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 thouse 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.%), $Mg/Mg+Fe^{2+}$ 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 $Mg/Mg+Fe^{2+}$ varies between 49 and 68. This and the $Fe^{3+}/Fe^{3+}+Cr+Al$ ratios are almost identical to those shown by chromites from kimberlite xenoliths (Basu and MacGregor, 1975), but these have slightly lower Cr/Cr+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 $Fe^{3+}/Fe^{3+}+Al+Cr$ 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 unmixing 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 continuouslly 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 compositionsof 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.

ACKNOWLEDGEMENTS

I would like to express my particular gratitude to Drs. John Gurney and Anton le Roex. The former, my supervisor, was an invaluable mentor and continued source of encouragement; the latter, a great friend, whose support helped me to further and continued efforts.

I am indebted also to numerous people who have made valuable contributions to this thesis. Mr. G. Hutchinson of the Anglo-American Corporation Laboratories kindly undertook microprobe analyses of a few rock samples. In the Geology Department, University of Cape Town, Dr. J. Macpherson and Mr. C. Basson found themselves responsible for the photographic work, which was skilfully done. The preparation and coating of microprobe slides was ably performed by Mr. D. Wilson and Mr. R. Mitchell of the Geochemistry Department, University of Cape Town. Some of the diamond inclusion data I have used was taken from the unpublished work of R.S. Rickard and Dr. J.W. Harris to whom I owe thanks.

I would like to warmly thank Drs. John Gurney and Anton le Roex (editors) and Mrs. G. Verblun (typist) who transformed rough manuscripts into a more tidily typed thesis.

Grateful acknowledgements are given to the De Beers Consolidated Mines Ltd. for providing financial assistance and logistical support. J.B. Hawthorne (Consulting Geologist D.B.C.M. Kimberley) and his staff are especially thanked for that logistical support which came from the Geology Office in Kimberley. Len Kleinjan, Mine Geologist at Koffiefontein arranged for and assisted with the collection of the rock samples studied here.

REFERENCES

Albee,A.L. and Ray,L. (1970) Correction factors for the electron probe microanalysis of silicates, oxides, carbonates, phosphates and sulphates. Analytical Chem. 42, 1408-1414.

Akella,J. (1976) Garnet pyroxene equilibria in the syatem $CaSiO_3$-$MgSiO_3$-Al_2O_3 and in a natural mineral mixture. Amer. Mineral. 61, 589-598.

Akella,J. and Boyd,F.R. (1974) Petrogenetic grid for garnet peridotites. Geophys. Lab., Carnegie Inst., Washington Yearb. 73, 236-266.

Arai,S. (1978) Chromium spinel lamellae in olivine from The Iwanai-Dake peridotite mass, Hokkaido, Japan. Earth Planet. Sci. Lett. 30, 267-273.

Banno,S. (1967) Effect of jadeite components on the paragenesis of eclogitic rocks. Earth Planet. Sci. Lett. 2, 248-254.

Banno.S. (1970) Classification of eclogites in terms of physical conditions of their origin. Phys. Earth Planet. Interiors 3, 405-421.

Basu,A.R. and MacGregor,I.D. (1975) Chromite spinels from ultramafic xenoliths. Geochim. Cosmochim. Acta 39, 937-945.

Beeson,M.H. and Jackson,E.D. (1970) Origin of the garnet pyroxenite xenoliths at the Salt Lake Crater, Oahu. Mineral. Soc. Spec. Pap. 3,95-110.

Bence,A.L. and Albee,A.L. (1968) Empirical correction for the electron microanalysis of silicates and oxides. J. Geol. 76, 382-403.

Borley,G.D. and Suddaby,P. (1973) Pyroxenite xenoliths from the kimberlite of Jagersfontein Mine. Extended Abstracts, 1st Int. Kimb. Conf., Cape Town.

Boyd,F.R. (1970) Garnet peridotites and the system $CaSiO_3$-$MgSiO_3$-Al_2O_3. Mineral. Soc. Amer. Pap. 3, 63-75.

Boyd,F.R. (1973a) Ultramafic nodules from the Frank Smith kimberlite pipe,South Africa. Geophys. Lab., Carnegie Inst., Washington Yearb. 73, 285-294.

Boyd,F.R. (1973b) A pyroxene geotherm. Geochim. Cosmochim. Acta 37, 2533-2546.

Boyd,F.R., Fujii,T. and Danchin,R.V. (1976) A non-inflected geotherm for the Udachnaya kimberlite pipe,U.S.S.R. Geophys. Lab.,Carnegie Inst., Washington Yearb. 75, 523

Boyd,F.R. and Nixon,P.H. (1973) Origin of the ilmenite-silicate nodules in kimberlites from Lesotho and South Africa. In: Lesotho Kimberlites. P.H. Nixon(ed.), Lesotho National Development Corporation, 254-268.

Bundy,F.B., Bovenkirk,H.P., Strong,H.M. and Wentorf,R.H. (1961) Diamond-graphite equilibrium line from growth and graphitisation of diamond. J. Chem. Phys. 35, 383-391.

Burns,R.G.(1970) Site preferences of transition metal ions in silicate crystal structures. Chem. Geol. 5,275-283.

Burns,R.G. (1973) The partitioning of trace transition elements in crystal structures: a provocative review with application to mantle geochemistry. Geochim. Cosmochim. Acta 37, 2395-2403.

Burns,R.G. (1975) On the occurrence and stabil ity of divalent chromium in olivines included in diamonds. Contr. Mineral. Petrol. 5, 213-221.

Carmichael,D.M. (1969) Mechanism of metamorphic reactions in pelitic rocks. Contr. Mineral. Petrol. 20, 244-267.

Carswell,D.A. (1973) Garnet pyroxenite lens within the Ugelvik layered garnet peridotite. Earth Planet. Sci. Lett. 20, 347-352.

Carswell,D.A. (1978) Paleogeotherms: implications of disequilibrium in garnet lherzolite xenoliths. Nature 276, 737.

Carver,R.E. (1971) Procedures in Sedimentary Petrology. Wiley-interscience, New York, 653p.

Clark,S.P.,Jr. and Ringwood,A.E. (1964) Density distribution and constitution of the mantle. Reviews Geophys. 2, 35-88.

Clement,C.R., Skinner,E.M.W. and Scott,B.H. (1977) Kimberlite redefined. Extended Abstracts, 2nd Int.Kimb. Conf.,Santa Fe, New Mexico.

Curtis, C.D. (1964) Applications of the crystal field theory to the inclusion of trace transition elements in minerals during magmatic differentiation. Geochim. Cosmochim. Acta 28, 389-402.

Davis, B.T. and Boyd, F.R. (1966) The join $Mg_2Si_2O_6$-$CaMgSi_2O_6$ at 30 kbs pressure and its application to pyroxenes from kimberlites. J. Geophys. Res. 71, 3567-3576.

Davis, G.L. (1977) The ages and uranium contents of zircons from kimberlites and associated rocks. Extended Abstracts, 2nd Int. Kimb. Conf., Santa Fé, New Mexico.

Dawson, J.B. and Smith, J.V. (1973) Garnet exsolution from stressed orthopyroxene in garnet lherzolite from the Monastery Mine. Extended Abstracts, 1st Int. Kimb. Conf., Cape Town.

Dawson, J.B. and Smith, J.V. (1975) Occurrence of diamond in a mica-garnet lherzolite in kimberlite. Nature 254, 580-581.

Eggler, D.H. and Wendlandt, R.F. (1977) Experimental studies on the relationship between kimberlite magmas and partial melting of peridotite. Phys. Chem. Earth 9, 330-338.

Ellis, D.J. and Green, D.H. (1979) An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria. Contr. Mineral. Petrol. 71, 13-22.

Erlank, A.J. (1973) Kimberlite potassic richterite and the distribution of potassium in the upper mantle. Extended Abstracts, 1st Int. Kimb. Conf., Cape Town.

Erlank, A.J. and Kushiro, I. (1970) Potassium contents of synthetic pyroxenes at high temperatures and pressures. Geophys. Lab., Carnegie Inst., Washington Yearb. 68, 439-442.

Fesq, H.W., Bibby, D.M., Erasmus, C.S., Kable, E.J.D. and Sellschop, J.P.F. (1977) A comparative trace element study of diamonds from Premier, Finsch and Jagersfontein Mines, South Africa. Phys. Chem. Earth 9, 817-836.

Fraser, D.G. and Lawless, P.J. (1978) Paleogeotherms: implications of disequilibrium in garnet lherzolite xenoliths. Nature 273, 220-221.

Ganguli, J. (1979) Garnet and clinopyroxene solid solutions, a geothermometer based on Fe-Mg distribution coefficients. Geochim. Cosmochim. Acta 43, 1021-1029.

Goetze, C. (1975) Sheared lherzolites : from the point of view of rock mechanics. Geology 3, 172-173.

Green, D.H. (1966) The origin of the "eclogites" from Salt Lake Crater, Hawaii. Earth Planet. Sci. Lett. 1, 414-420.

Green, D.H. and Ringwood, A.E. (1969) The stability of aluminous pyroxene peridotite and their relevance in upper mantle structure. Earth Planet. Sci. Lett. 3, 151-160.

Gurney, J.J. The origin of kimberlite: Modern Concepts. Trans. Geol. Soc. S. Afr. 77, 353-361.

Gurney, J.J., Harte, B. and Cox, K.G. (1975) Mantle xenoliths in the Matsoku kimberlite pipe. Phys. Chem. Earth 9, 507-523.

Gurney, J.J. Harris, J.W. and Rickard, R.S. (1979) Silicate and oxide inclusions in diamonds from the Finsch kimberlite pipe. A.G.U. Vol. : Proc. 2nd Int. Kimb. Conf., Vol. I, 1-15.

Gurney, J.J., Harris, J.W. and Rickard, R.S. (1979) Inclusions in Southern African diamonds and their relationship to the xenoliths. Kimb. Symp. II, Cambridge, July 1979.

Gurney, J.J., Harris, J.W., Rickard, R.S. (in prep.) Inclusions in diamonds from the Premier Mine. Proc. of XI Int. I.M.A. Conf., Novosibirsk, 1978.

Gurney, J.J., Jakob, W.R.O. and Dawson, J.B. (1977) Megacrysts from the Monastery Mine. Extended Abstracts, 2nd Int. Kimb. Conf., Santa Fé, New Mexico.

Gurney, J.J. and Switzer, G.S. (1973) The discovery of garnets closely related to diamonds in the Finsch pipe, South Africa. Contr. Mineral. Petrol 39, 103-116.

Harris,J.W. and Gurney,J.J. (1979) Inclusions in Diamond. In : Physical Properties of the Diamond, J.G. Field (ed.). Academic Press, London, 555-591

Harte,B. (1978) Kimberlite nodules, upper mantle petrology and geotherms. Philos. Transact. Royal Soc. London, Vol. A-288, 287-500.

Harte,B. and Gurney,J.J. (1975) Evolution of clinopyroxene and garnet in an eclogite nodule from the Roberts Victor kimberlite pipe, South Africa. Phys. Chem.Earth 9, 367-387.

Harte,B., Gurney,J.J. and Cox,K.G. (1977) Clinopyroxene-rich sheets in garnet-peridotite: xenolith specimens from the Matsoku kimberlite pipe, Lesotho. Extended Abstracts, 2nd Int.Kimb. Conf., Santa Fé, New Mexico.

Harte,B., Gurney,J.J. and Harris (1979) The origin of Ca-poor silicate inclusions in diamonds. Kimb. Symposium II, Cambridge, July 1979.

Harte,B., Gurney,J.J. and Harris,J.W. (in press) The formation of peridotitic suite inclusions in diamonds. Contr. Mineral. Petrol.

Hatton,C.J. (1978) The geochemistry and origin of xenoliths from the Roberts Victor Mine. Unpublished Ph.D. thesis, University of Cape Town,South Africa.

Hawthorne,J.B. (1975) Model of a kimberlite pipe. Phys. Chem. Earth 9, 1-16.

Hawthorne,J.B., Harris,J.W., Gurney,J.J. and Rickard,R.S. (in prep) Inclusions in diamonds from Southern Africa. Proc. of Xi int. I.M.A. Conf., Novosirsk, 1978.

Hensen,B.J. (1973) Pyroxenes and garnets as thermometers and barometers. Geophys. Lab., Carnegie Inst., Washington Yearb. 72, 527-534.

Herzberg,C.T. (1978) The bearing of phase equilibria in simple and complex systems on the origin and evolution of some well-documented garnet websterites. Contr. Mineral. Petrol. 66, 375-382.

Irving,A.J.(1978) A review of experimental studies of crystal/liquid trace element partitioning. Geochim Cosmochim. Acta 42, 743-770.

Irving,A.J. and Green,D.H. (1970) Experimental duplication of mineral assemblages in basic inclusions in basic inclusions og the Delegate Breccia Pipes. Phys. Earth Planet. Interiors 3, 385-389.

Jackson,E.D. (1969) Chemical variation in coexisting chromite and olivine in chrometite zones of the Stillwater Complex. Econ. Geol. Mono. 4, 41-71.

Jakob,W.R.O. (1977) Geochemical aspects of the megacryst suite from the Monastery kimberlite pipe. Unpublished M.Sc. thesis, University of Cape Town, South Africa.

Kennedy,G.C. and Nordlie,B.E. (1968) The genesis of diamond deposits. Econ. Geol. 63, 495-503.

Kuno,H. and Aoki,K.-I. (1970) Chemistry of ultramafic nodules and their bearing on the origin of basaltic magmas. Phys. Earth Planet. Int. 3, 273-301.

Kushiro,I. (1969) The system forsterite-diopside-silica with and without water at high pressures. Amer. J. Sci. 267A, 269-294.

Kushiro,I. and Aoki,K.-I. (1968) Origin of some eclogite inclusions in kimberlite. Amer. Minearl. 53, 1347-1367.

Kushiro,I., Satake,H. and Akimoto,S. (1975) Carbonate -silicate teactions at high pressure and possible presence of dolomite and magnesite in the upper mantle. Earth Planet. Sci. Lett. 28,116-120.

Kramers,J.D. (1977) Lead and strontium isotopes in inclusions in diamonds and in mantle-derived xenoliths from Southern Africa. Extended Abstracts, 2nd Int. Kimb. Conf., Santa Fé, New Mexico.

Lambert,I.B. and Wyllie,P.J. (1968) Stability of hornblende and a model for the low velocity zone. Nature 219, 1240-1241.

Lawless,P.J. (1974) Some aspects of the geochemistry of kimberlite xenocrysts. Unpublished M.Sc. thesis, University of Cape Town, South Africa.

Lawless,P.J. (1978) Some aspects of the mineral chemistry of peridotitic xenoliths from the Bultfontein Mine. Unpublished Ph.D. thesis, University of Cape Twon, South Africa.

Le Roex,A.P. (1980) Geochemistry and mineralogy of selected Atlantic Ocean basalts. Unpublished Ph.D. thesis, University of Cape Town,South Africa.

Lindsley,D.H. and Munoz,J.L. (1969) Subsolidus relations along the join hedenbergite-ferrosilite. Amer. J. Sci. 267A, 295-324.

Liu, L.G. (1975) Post-oxide phases of olivine and pyroxene and mineralogy of the mantle. Nature 258, 510-512.

Lovering,J.F. and White, A.J.R. (1969) Granulitic and eclogitic inclusions from basic pipes at Delegate, Australia. Contr.Minerla. Petrol. 21, 9-52.

MacGregor,I.D. (1967) Mineralogy of model mantle compositions. In: P.J. Wyllie, Ultramafic and related rocks. J. Wylley & Sons, New York, 382-393.

MacGregor,I.D. (1970) An hypothesis for the origin of kimberlite. Mineral. Soc. Amer. Spec. Pap. 3, 51-62.

MacGregor,I.D. and Basu,R. (1976) Geological problems in estimating mantle geothermal gradients. Amer. Mineral 61, 715-724.

Meyer,H.O. and Boyd,F.R. (1972) Composition and origin of crystalline inclusions in natural diamonds. Geochim. Cosmochim. Acta 36, 1255-1273.

Meyer,H.O. and Svisero,D.P. (1975) Mineral inclusions in Brazilian diamonds. Phys. Chem. Earth 9, 785-795.

Meyer,H.O. and Tsai,H.-M. (1976) The nature and significance of mineral inclusions in natural diamonds : a review. Minerals Sci. Engng 8, 242-261.

Mitchell,R.H. (1977) Ultramafic xenoliths from the Eldwin Bay kimberlite: the first Canadian paleogeotherm. Can. J. Earth Sci. 14, 1202-1210.

Modreski,P.J. (1972) The melting of phlogopite in the presence of enstatite, aluminous enstatite, diopside, spinel, corundum and pyrope. Geophys. Lab., Carnegie Inst., Washington Yearb. 71, 392-396.

Moreland,G. Ingram,F. and Banks,H.H. ,Jr. (1971) Preparation of doubly-polished thin sections. Smithsonian Contr. to Earth Sciences, No. 9, 93.

Mori,T. and Green,D.H. (1975) Pyroxenes in the system $Mg_2Si_2O_6$-$CaMgSi_2O_6$ at high pressure. Earth Planet. Sci. Lett. 26, 277-286.

Mysen,B.O. (1976) Experimental determination of some geochemical parameters relating to conditions of equilibration of peridotite in the upper mantle. Amer. Mineral. 61, 677-683.

Mysen,B.O. and Boettcher,A.L. (1976) Melting of a hydrous mantle. III. Phase relations of garnet-websterite + H_2O at high pressures and temperatures. J. Petrol. 17, 1-14.

Nehru,C.E. (1976) Pressure dependence of the enstatite limb of the enstatite-diopside solvus. Amer. Mineral. 61, 578-581.

Newton,M.G. and Melton,C.E. (1977) Mineral inclusions in an Arkansas diamond. Amer. Mineral. 62, 583-586.

Nixon,P.H. and Boyd,F.R. (1973) The discrete nodule association in kimberlites from Northern Lesotho. In: Lesotho Kimberlites, P.H. Nixon (ed.), Cape and Transvaal Printers Ltd., Cape Twon, Lesotho National Development Corporation. 67-75.

Nixon, P.H. and Boyd,F.R. (1973a) Petrogenesis of the granular and sheared ultrabasic nodule suite in kimberlites. In: Lesotho Kimberlites, P.H. Nixon (ed.) Cape and Transvaal Printers Ltd., Cape Town, Lesotho National Development Corporation. 48-56

Nixon,P.H., Boyd,F.R. and Boullier,A.-M. (1973) The evidence of kimberlite and its inclusions on the constitution of the outer part of the earth. In: Lesotho Kimberlites, P.H. Nixon (ed.), Cape and Transvaal Printers Ltd., Cape Twon, Lesotho National Development Corporation.312-318.

Norrish,K. and Hutton,J.T. (1969) An accurate x-ray spectrographic method for the analysis of a wide range of geological samples. Geochim. Cosmochim. Acta 33, 431-453.

O'Hara,M.J. (1969) The origin of eclogite and ariégite nodules in basalt. Geol. Mag. 106, 322-330.

O'Hara,M.J. and Mercy,E.L. (1963) Petrology and petrogenesis of some garnetiferous peridotites. Trans. Roy. Soc. Edinburgh 65,251-314.

O'Hara, M.J. and Schrairer (1963)

Papike,J.J., Cameron,K.L. and Baldwin,K. (1974) Amphiboles and pyroxenes: characterization of other than qadrilateral components and estimates of ferric iron from microprobe data. Abstracts with Programs, Annual Meetings, Miami Beach, Florida,1053p.

Pettijohn,F.J. (1975) Sedimentary Rocks. Harper & Row, New York(3rd ed.),628p.

Pokhilenko,N.P., Sobolev,N.V. and Lavrent'ev,Y.G. (1977) Xenoliths of diamondiferous ultramafic rocks from Yakutian kimberlites. Extended Abstracts, 2nd Int. Kim. Conf., Santa Fé, New Mexico.

Presnal,D.C. (1969) The geometrical analysis of partial fusion. Amer. J. Sci. 267, 1178-1194.

Prinz,M., Manson,D.V., Hlava,P.F. and Keil,K. (1975) Inclusions in diamonds: Garnet lherzolite and eclogite assemblages. Phys. Chem. Earth 9,797-815.

Råheim,A. and Green,D.H. (1974) Experimental determination of the temperature and pressure dependence of the Fe-Mg partition coefficient for coexisting garnet and clinopyroxene. Contr. Mineral Petrol. 48, 179-203.

Reid,A.M. and Hanor,J.J. (1970) Pyrope in kimberlite. Amer. Mineral. 55, 1374-1379.

Reid,D.L. Geochemistry of Precambrian igneous rocks in the lower Orange river region. Unpublished Ph.D. thesis, University of Cape Town, South Africa.

Ringwood,A.E. (1975) Composition and petrology of the Earth's mantle.

Roedder,P.L., Campbell,I.H. and Jameson,H.E. (1979) A re-evaluation of the olivine-spinel geothermometer. Contr. Mineral. Petrol. 68, 325-334.

Shee,S.R. (1978) The mineral chemistry of xenoliths from the Orapa kimberlite pipe, Botswana. Unpublished M.Sc. thesis, University of Cape Town,South Africa.

Shervais,J.W., Wilshire,H.G. and Schwarzman,E.C. (1973) Garnet clinopyroxenite xenoliths from Dish Hill, California. Earth Planet. Sci. Lett. 19,120-130.

Shimizu, (1971) Potassium contents o f synthetic clinopyroxenes at high pressures and temperatures. Earth Planet. Sci. Lett. 11, 374-380.

Sigurdsson,H. (1977) Spinels in Leg 37 basalts and peridotites : phase chemistry and zoning. Initial Rep. of Deep Sea Drilling Proj., Vol. XXXVII; Washington (U.S. Gvt. Printing Office) 883-891.

Sobolev,N.V. (1970) Eclogites and pyrope peridotites from the kimberlites of Yakutia. Phys. Earth Planet. Int. 3, 398-404.

Sobolev,N.V. (1977) Deep seated inclusions in kimberlites and the problem of the composition of the upper mantle. Amer Geophys. Union, Washington D.C., F.R. Boyd (ed.), English Translation.

Sobolev,N.V., Pokhilenko,N.P., Lavrentyev,Y.G. and Usova,L.V. (1975) Composition peculiarities of chrome spinellides from diamonds and kimberlites of Yakutia. Geologiya:Geofizika 11, 7-24.

Solomon,M. and Green,R. (1965) A chart for designing modal analysis by point counting. Geologischen Rundschan 55, 844-848.

Spry,A. (1969) Metamorphic Textures. Pergamon Press.

Sutton,J.R.(1928) Diamond. A descriptive treatise. Thomas Murly & Co., 1 Fleet Lane, E.C. 4 London, 118p.

Thompson,R.N. (1974) Some high pressure pyroxenes. Mineral. Magazine 39, 768-787.

Tilley,C.E. and Yoder,H.S.(Jr.) (1964) Pyroxene fractionation in mafic magmas at high pressures and its bearing on basalt genesis. Geophys. Lab., Carnegie Inst., Washington Yearb. 63, 114-121.

Wagner,P.A. (1914) The diamond fields of Southern Africa. C.Struik (PTY) Ltd., Cape Town, 355p.

Wells,P.R.A. (1977) Pyroxene thermometry in simple and complex systems. Contr. Mineral. Petrol. 62, 129-139.

Wilkinson,J.F.G. (1973) Pyroxenite xenoliths from an alkali trachybasalt in the Glen Innes Area, Northeastern New South Wales. Contr. Mineral. Petrol. 42, 15-32.

Williams,A.F. (1932) The genesis of the diamond. Vols. 1 and 2. Ernest Benn Ltd., London: Bouverie House,E.C. 4.

Willis,J.P.,Ahrens,L.H., Danchin,R.V., Erlank,A.J., Gurney,J.J., Hofmeyer, P.K., McCarthy,T.S. and Orren,M.J. (1971) Some interelement relationships between lunar rocks and fines and stoney meteorites. Proc. Second Lunar Sci. Conf., 1123-1138.

Willis,J.P.,Erlank,A.J., Gurney,J.J., Theil,R.H. and Ahrens,L.H. (1972) Major, minor and trace element data for some Apollo 11,12,14 and 15 samples. Proc. Third Lunar Sci. Conf., 1269-1273.

Wilshire,H.G. and Jackson,E.D. (1975) Problems in determining mantle geotherms from pyroxene compositions of ultramafic rocks. J.Geol.83, 313-329.

Wood,B.J. (1974) The solubility of alumina in orthopyroxene coexisting with garnet. Contr. Mineral. Petrol. 46, 1-15.

Wood,B.J. and Banno,S.(1973) Garnet-orthopyroxene and orthopyroxene-clinopyroxene relationships in simple and complex systems. Contr. Mineral. Petrol. 42, 109-124.

Wyllie,P.J. (1971) The Dynamic Earth. John Wiley & Sons, Inc., New York,

Wyllie,P.J. and Huang,W.-L. (1975) Influence of mantle CO_2 in the generation of carbonatites and kimberlites. Nature 257, 297-299.

Yoder,H.S. (Jr.) and Tilley,C.E. (1962) Origin of basaltic magmas: an experimental study of natural and synthetic rock systems. J. Petrol. 3, 342-532.

APPENDIX

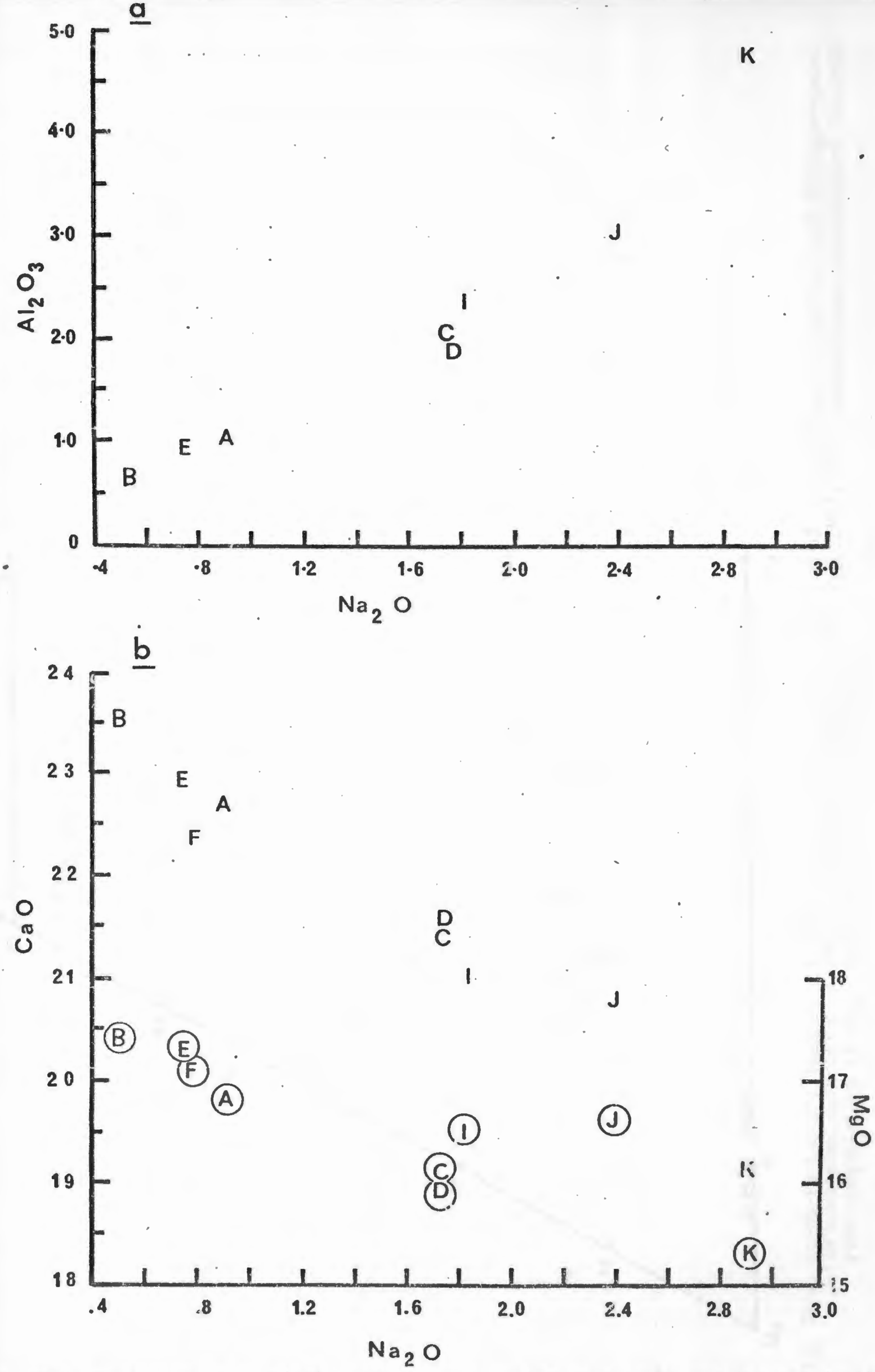

Fig. IV-1. Variation of Na$_2$O(wt%) with respect to (a) Al$_2$O$_3$(wt%) and (b) CaO (wt%) and MgO(wt%) (encircled) contents for clinopyroxenes from Type I pyroxenites. Symbols: A-PC22; B-PC25; C-PC33; D-PC54; E-PC55; F-PC21; I-PC35; J-PC58; K-PC34.

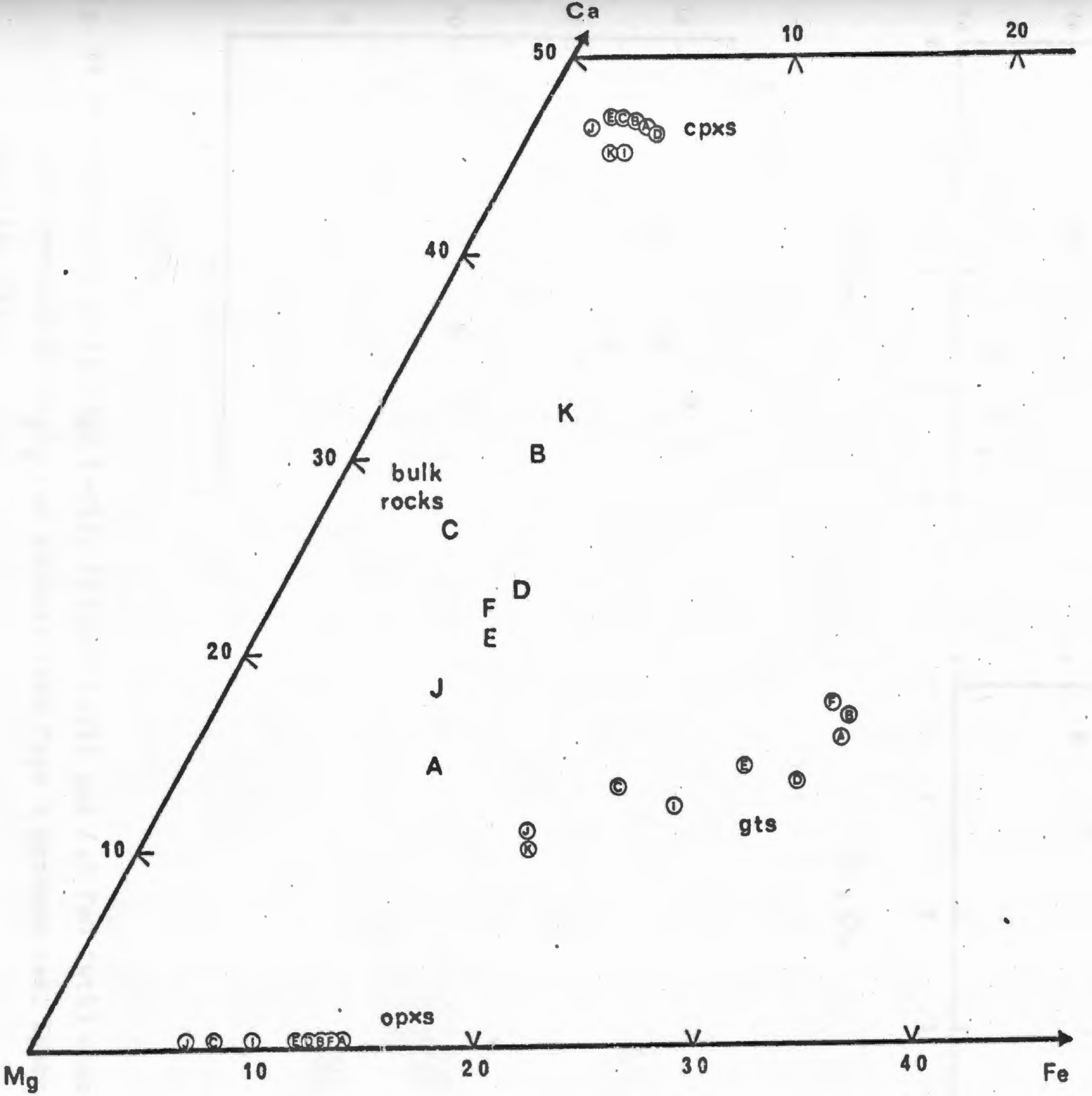

Fig. IV-2. Ca-Mg-Fe ternary diagram illustrating the compositional variation of clinopyroxenes, garnets and orthopyroxenes (in encircled symbols) from Type I pyroxenites. Symbols as for Fig. IV-1. The compositional variation of the bulk rock compositions of these xenoliths are also illustrated.

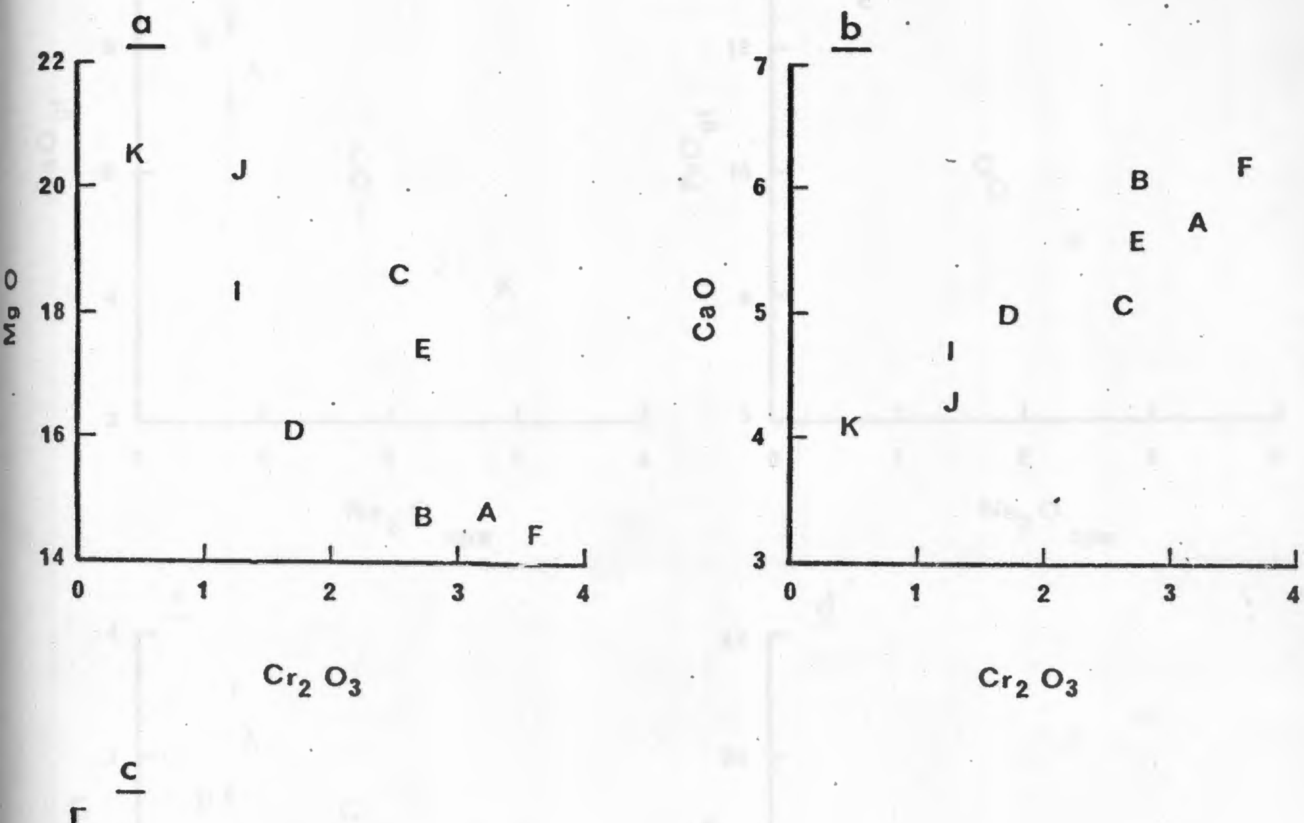

Fig. IV -3. Variation of (a) MgO (wt%), (b) CaO (wt%) and (c) FeO (wt%) contents with respect to Cr_2O_3 for garnets from Type I pyroxenites. Symbols as for Fig. IV-1.

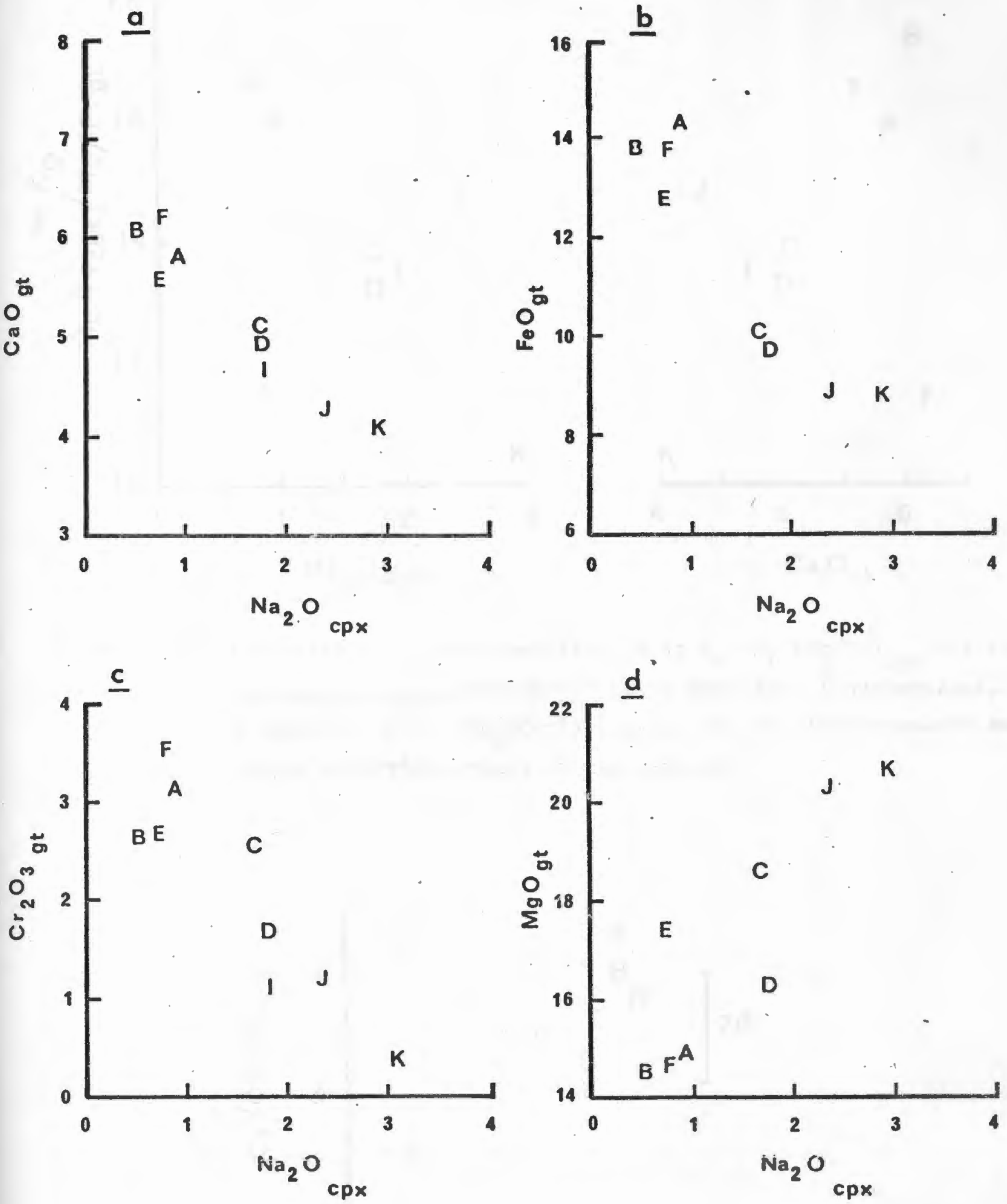

Fig. IV-4. Variation of the (a) CaO(wt%) (b) FeO(wt%) (c) Cr_2O_3(wt%) and (d) MgO(wt%) contents of the garnets from Type I pyroxenites as a function og the Na_2O(wt%) contents of their coexisting clinopyroxenes. Symbols as for Fig. IV-1.

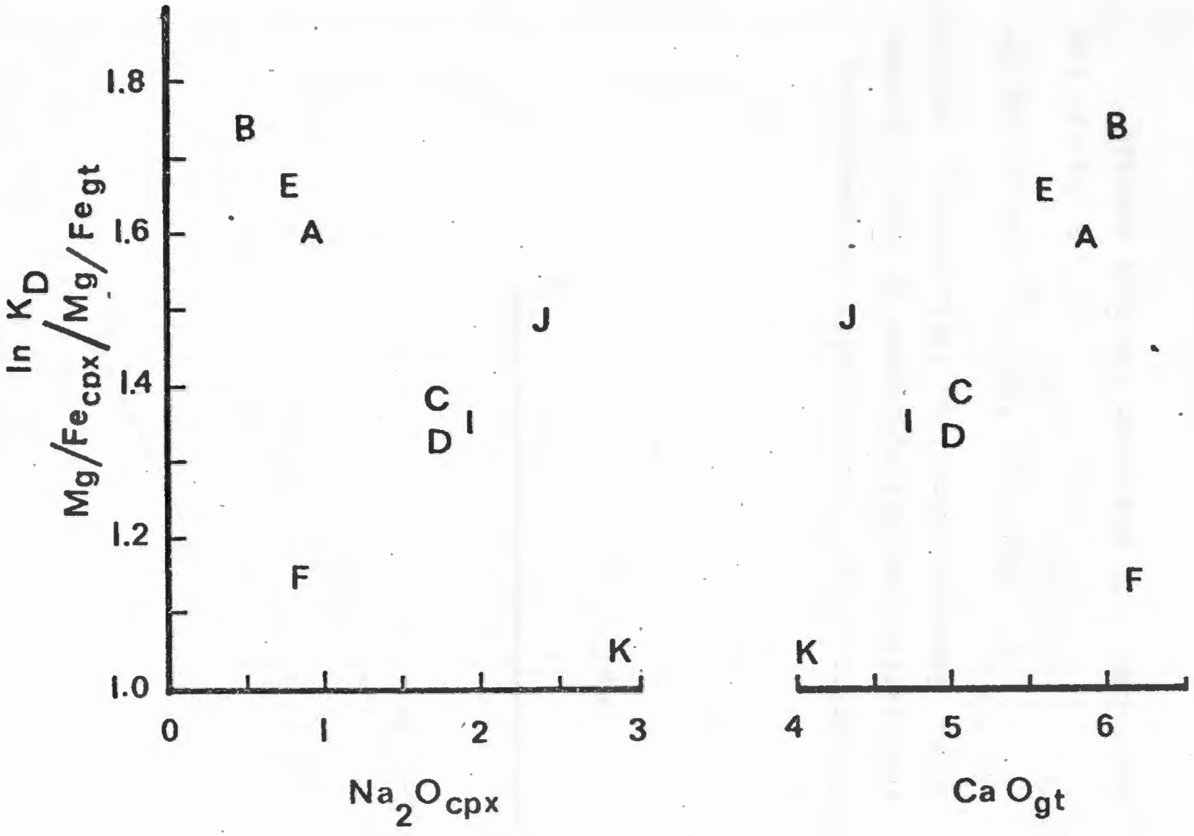

Fig. IV-6.Illustration of the variation of ln K_D (K_D=$(Mg/Fe)_{cpx}/(Mg/Fe)_{gt}$) between clinopyroxene-garnet pairs from Type I pyroxenites, as a function of the Na_2O(wt%) content of the clinopyroxenes and of the CaO(wt%) content of the garnets.

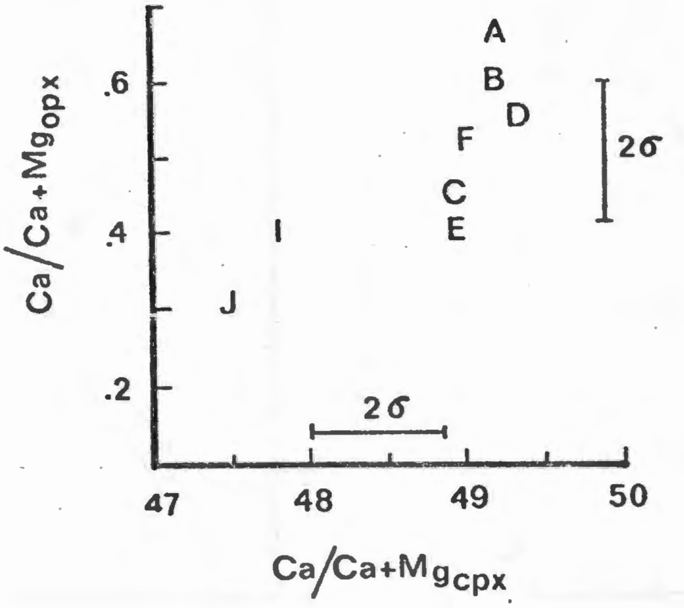

Fig. IV-5. Illustration of the variation of the Ca/Ca+Mg ratios of coexisting ortho and clinopyroxenes from Type I pyroxenites. Symbols as for Fif. IV-1.

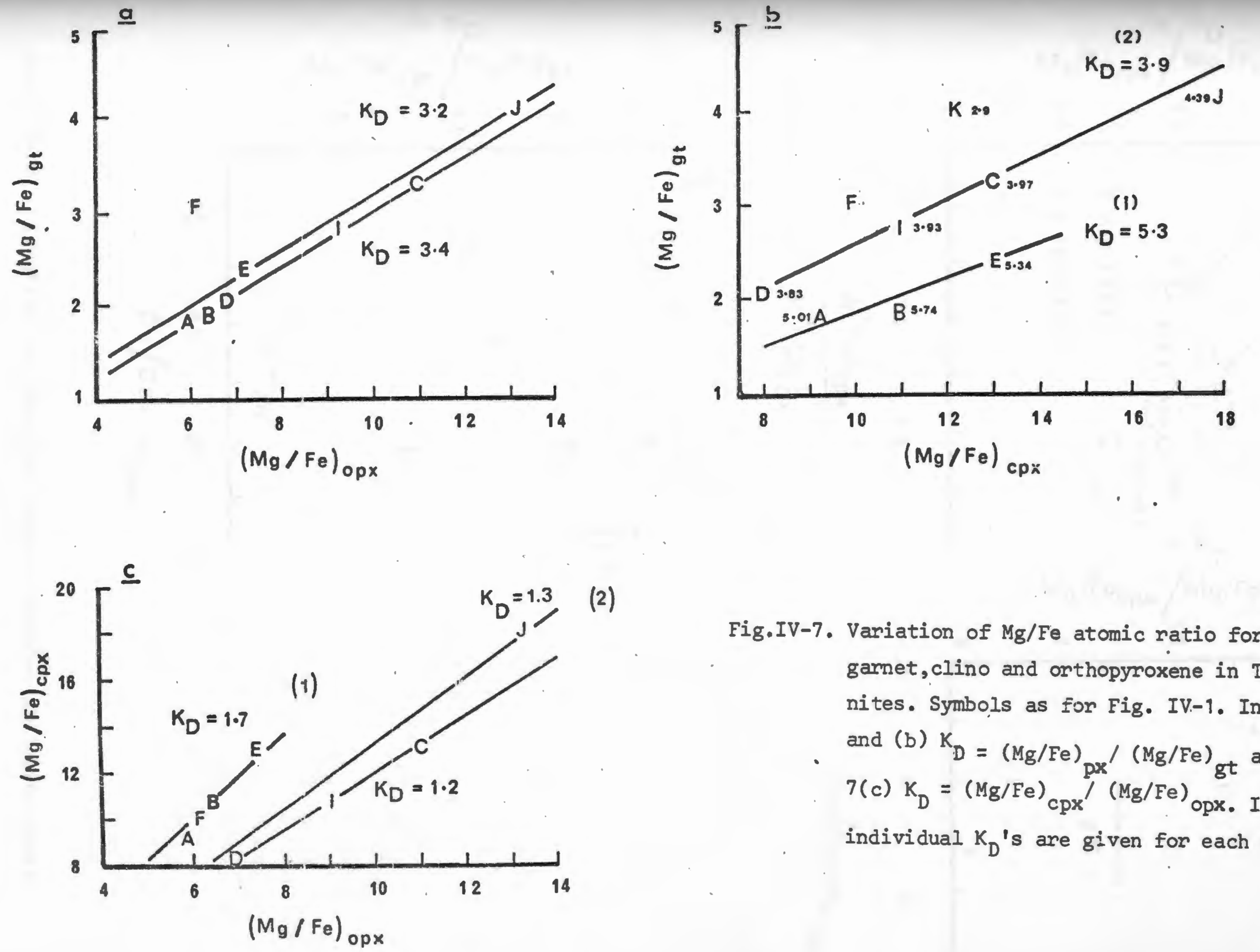

Fig.IV-7. Variation of Mg/Fe atomic ratio for coexisting garnet, clino and orthopyroxene in Type I pyroxenites. Symbols as for Fig. IV-1. In Fig. IV-7 (a) and (b) $K_D = (Mg/Fe)_{px} / (Mg/Fe)_{gt}$ and in Fig. IV-7(c) $K_D = (Mg/Fe)_{cpx} / (Mg/Fe)_{opx}$. In Fig. (b) the individual K_D's are given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

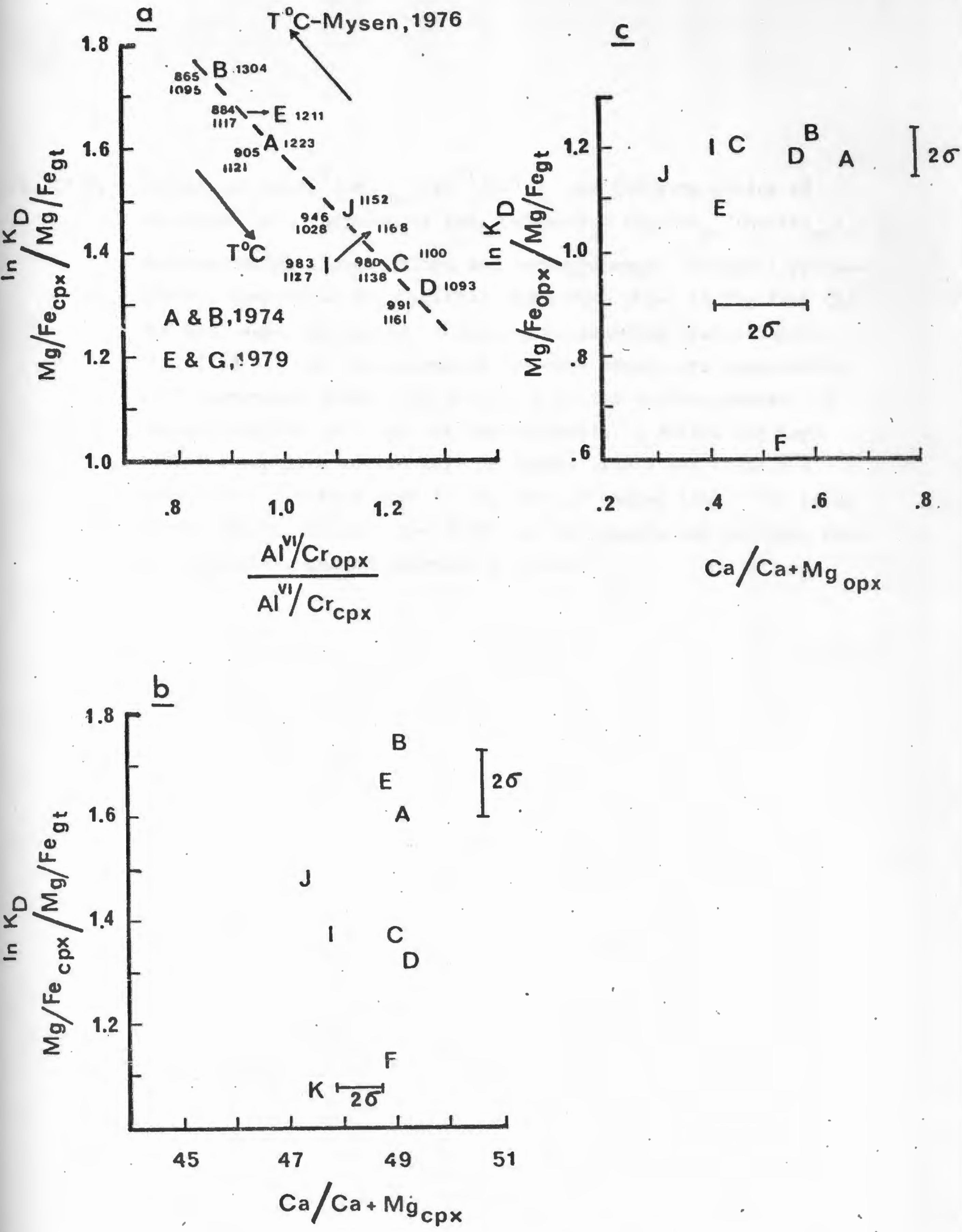

Fig. IV- 8.   (caption to this Fig. is given in the following page).

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 (°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 $\longrightarrow$ T°C indicate the direction of temperature increase when the respective geothermometers ar used.

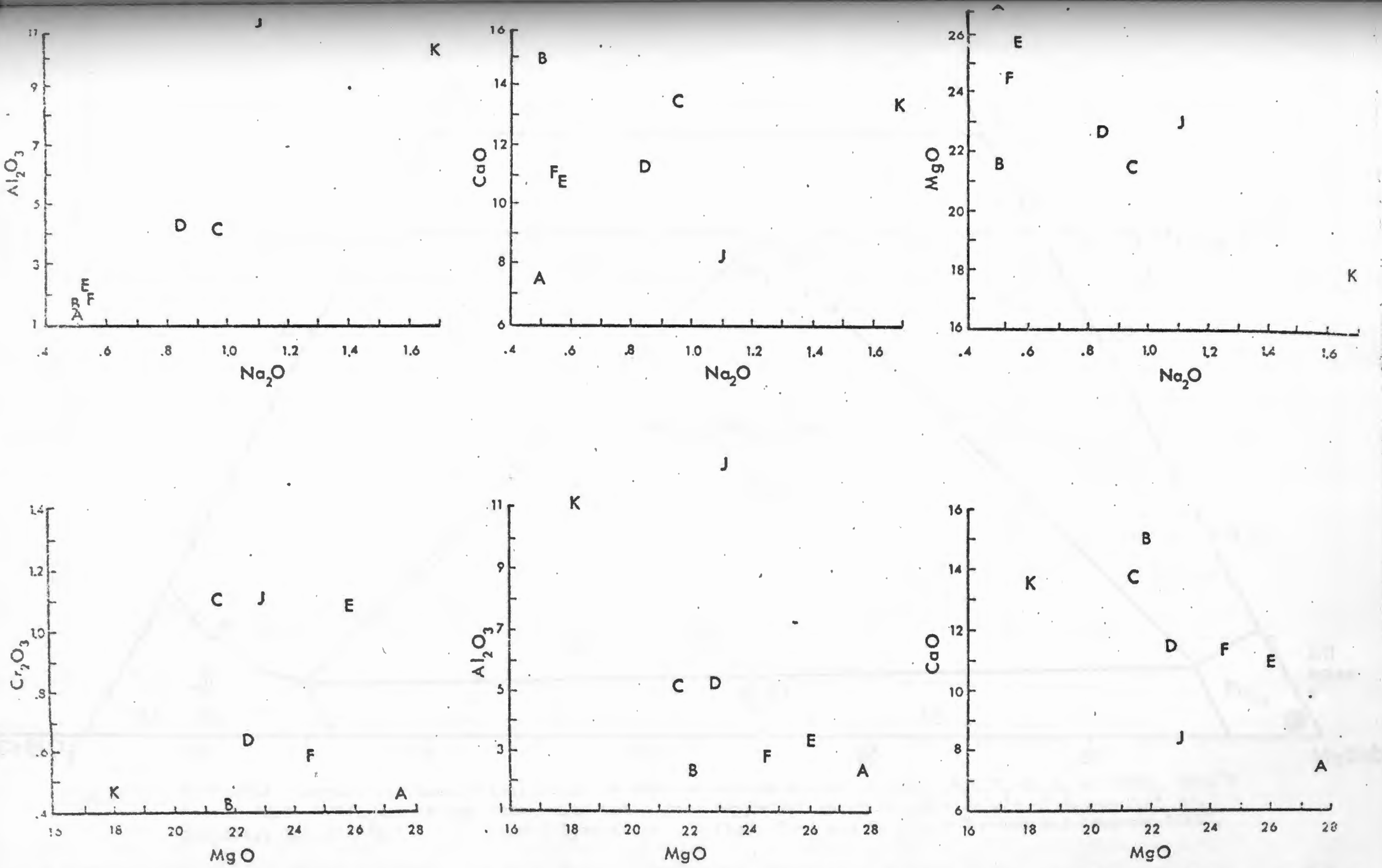

Fig.IV.-9. Illustration of the variation of Al_2O_3(wt%), CaO(wt%) and MgO(wt%) as a function of Na_2O(wt%) and of the variation of Cr_2O_3, Al_2O_3 and CaO (wt%) as a function of MgO(wt%) for Type I pyroxenites(bulk rocks)

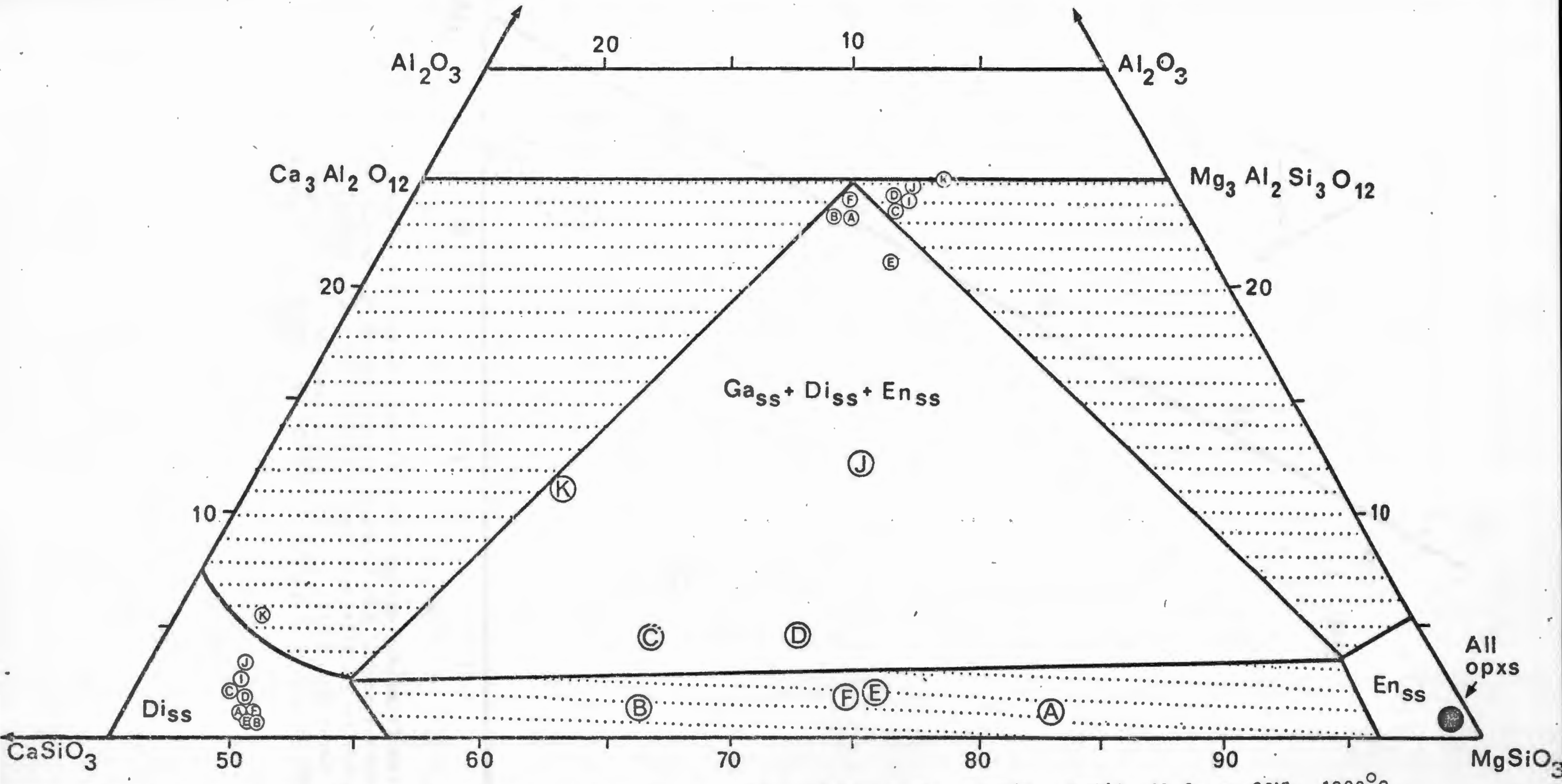

Fig.IV-10. Synthesis diagram for phase relations in a portion of the system $CaSiO_3$- $MgSiO_3$-Al_2O_3 at 30Kb, 1200°C (after Boyd,1970). Weight per cent, with total iron expressed as equivalent weight of magnesium. Di- diopside; En- enstatite; Gt- garnet. Symbols as in Figs. IV-1 and 2. (after Beeson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

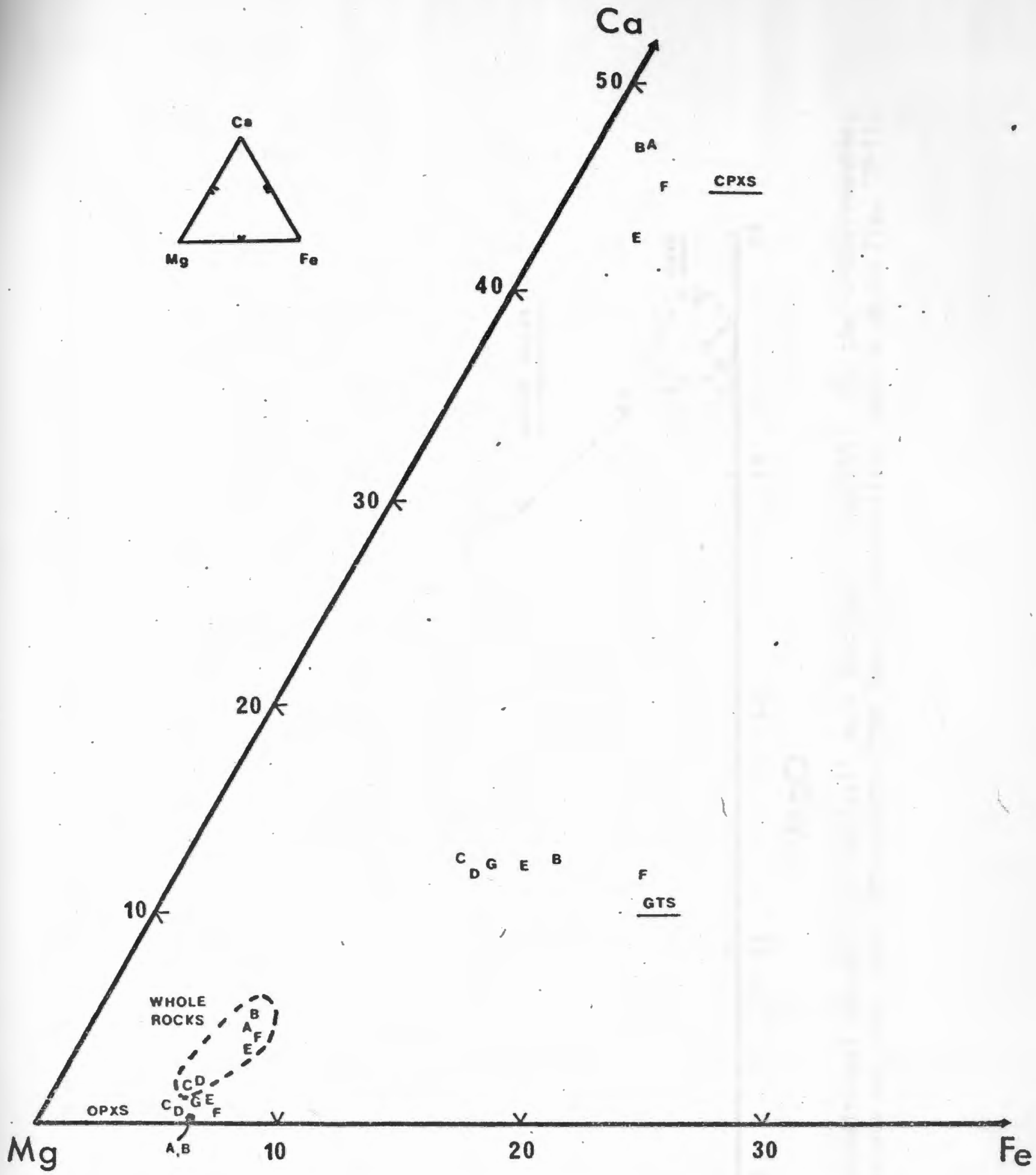

Fig.IV-11. Ca-Mg-Fe ternary diagram illustrting the compositional variation of coexisting orthopyroxens, garnets and clinopyroxenes from type II pyroxenites. The Compositional variation of of the bulk rock compositions of these xenoliths are also illustrated.
Symbols: A- PC20A; B- PC20B; C- Pc24A; D- PC24B; E- PC27; F-PC28; G- PC71.

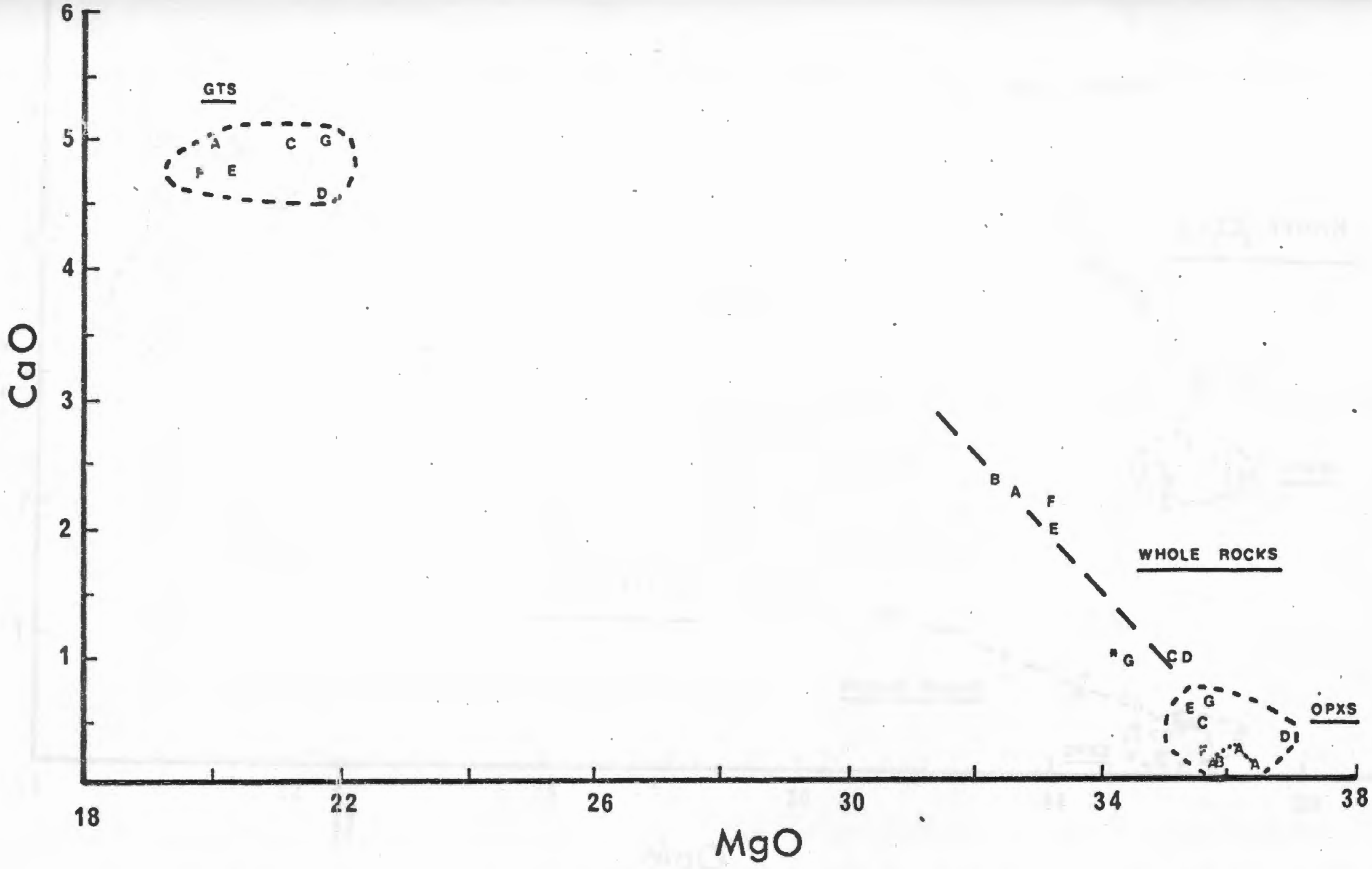

Fig. IV-12 (a). Compositional variation of CaO(wt%) as a function of MgO(wt%) for the orthopyroxenes, garnets and bulk rock compositions from Type II pyroxenites. Symbols as in Fig. IV-11.

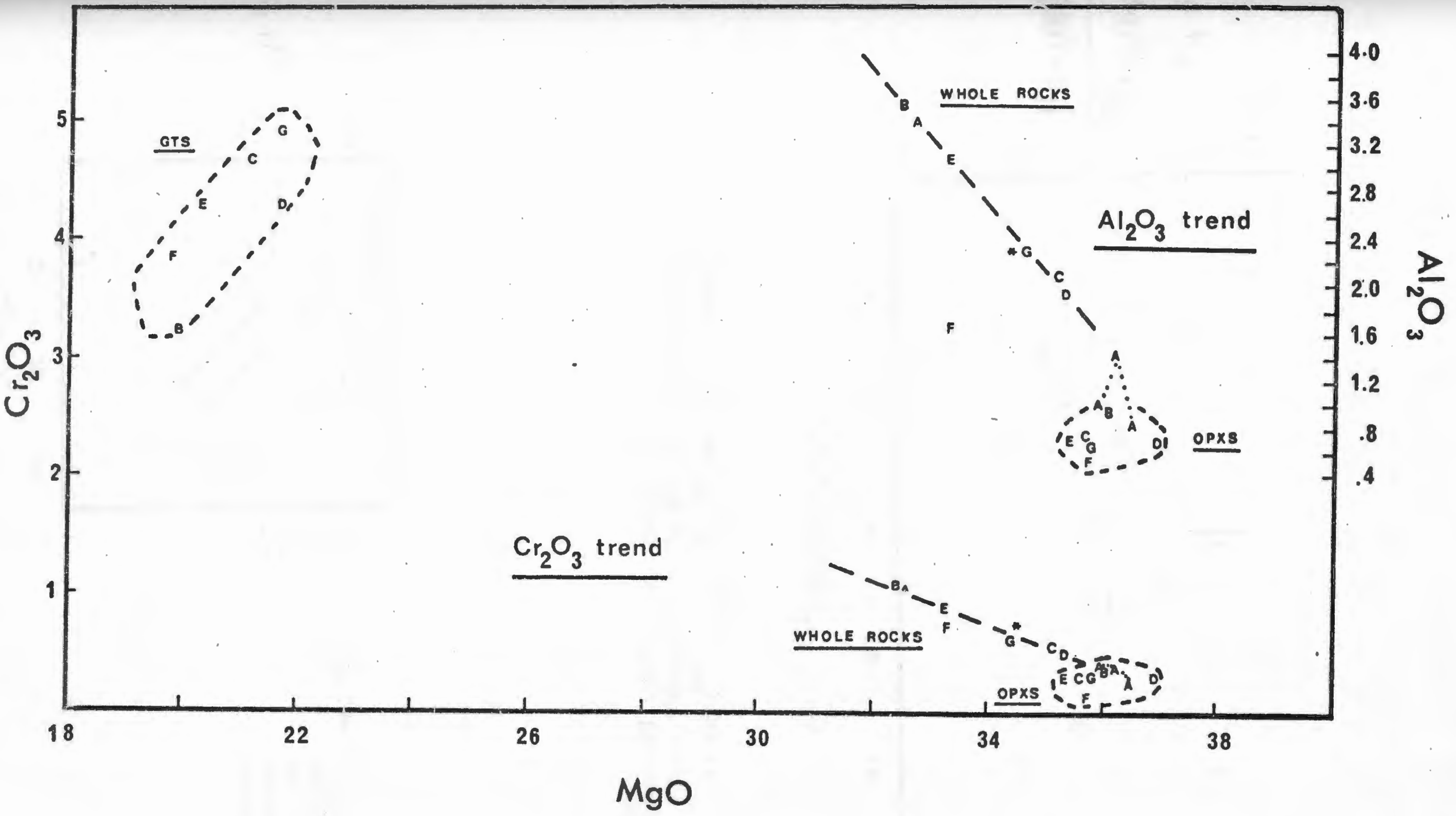

Fig. IV-12 (b). Compositional variation of Cr_2O_3(wt%) and Al_2O_3(wt%) contents of orthopyroxenes, garnets and and bulk rock compositions as a function of their MgO(wt%) contents, for Type II Pyroxenites. Symbols as in Fig. IV-11.

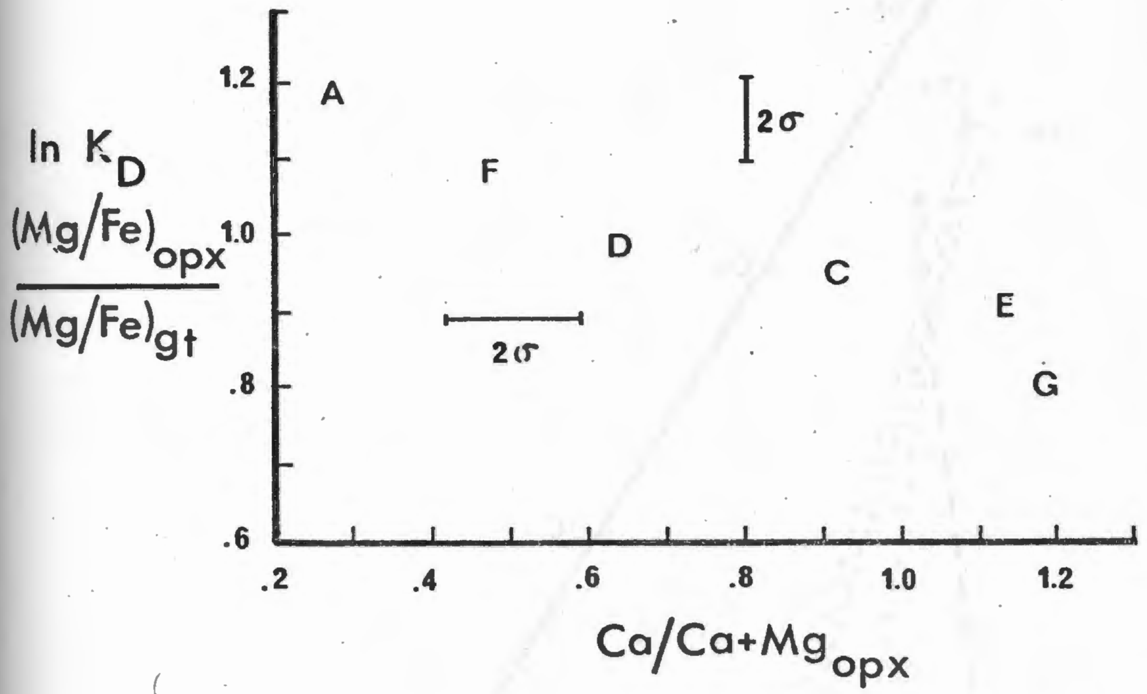

Fig. IV-13. Variation of the ln K_D (K_D= $(Mg/Fe)_{opx}/(Mg/Fe)_{gt}$) between orthopyroxene-garnet pairs as a function of the Ca/Ca+Mg ratio of the orthopyroxenes, for TypeII pyroxenites.

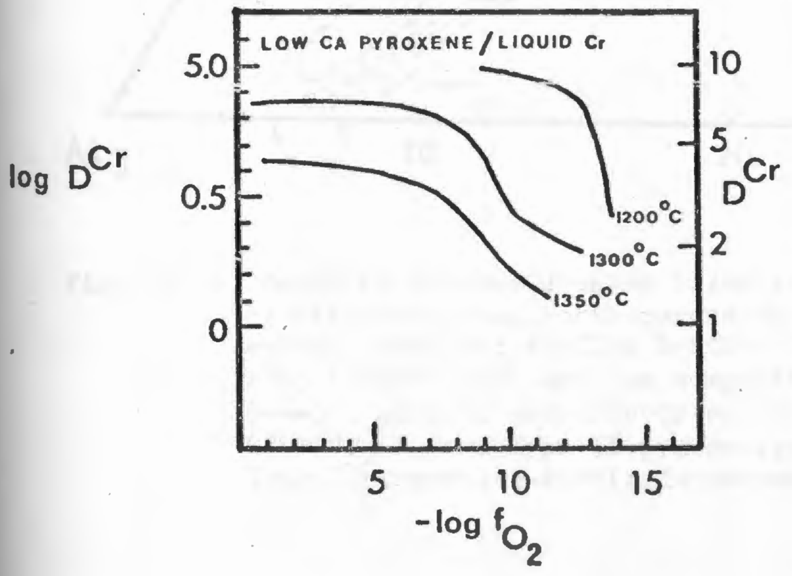

Fig.IV-14. Plot of log(Cr) for orthopyroxenes (or subcalcic clinopyroxene) versus log oxygen fugacity(after Irving,1978).

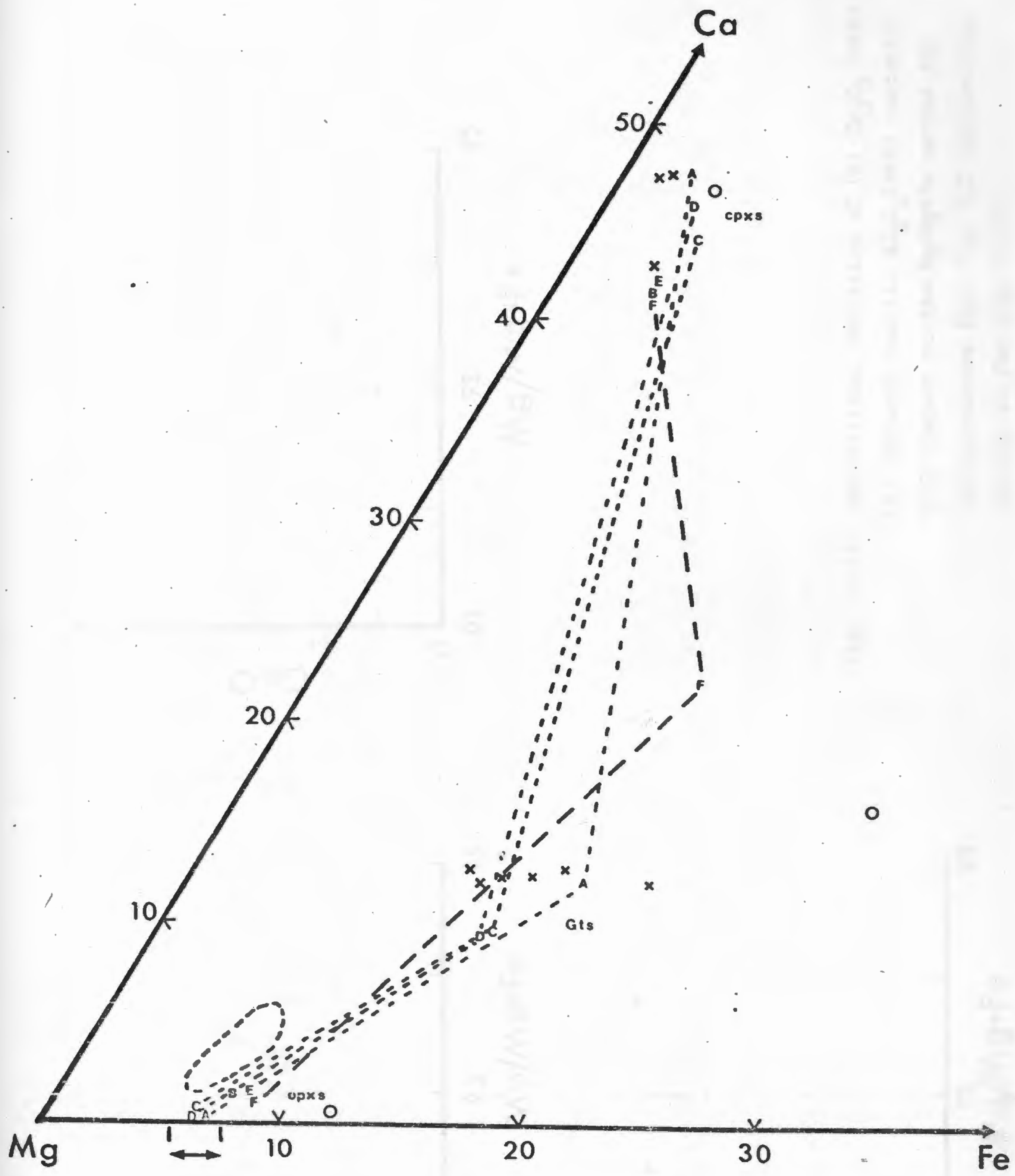

Fig. IV-15. Ca-Mg-Fe ternary diagram illustrating the compositional variation of clinopyroxenes, orthopyroxenes and garnets from Type III pyroxenites. Symbols: A-PC29; B-PC30; C-PC31; D-PC39; E-PC41; F-PC50. Also illustrated are the compositional variations of orthopyroxenes (↔), garnets and clinopyroxenes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

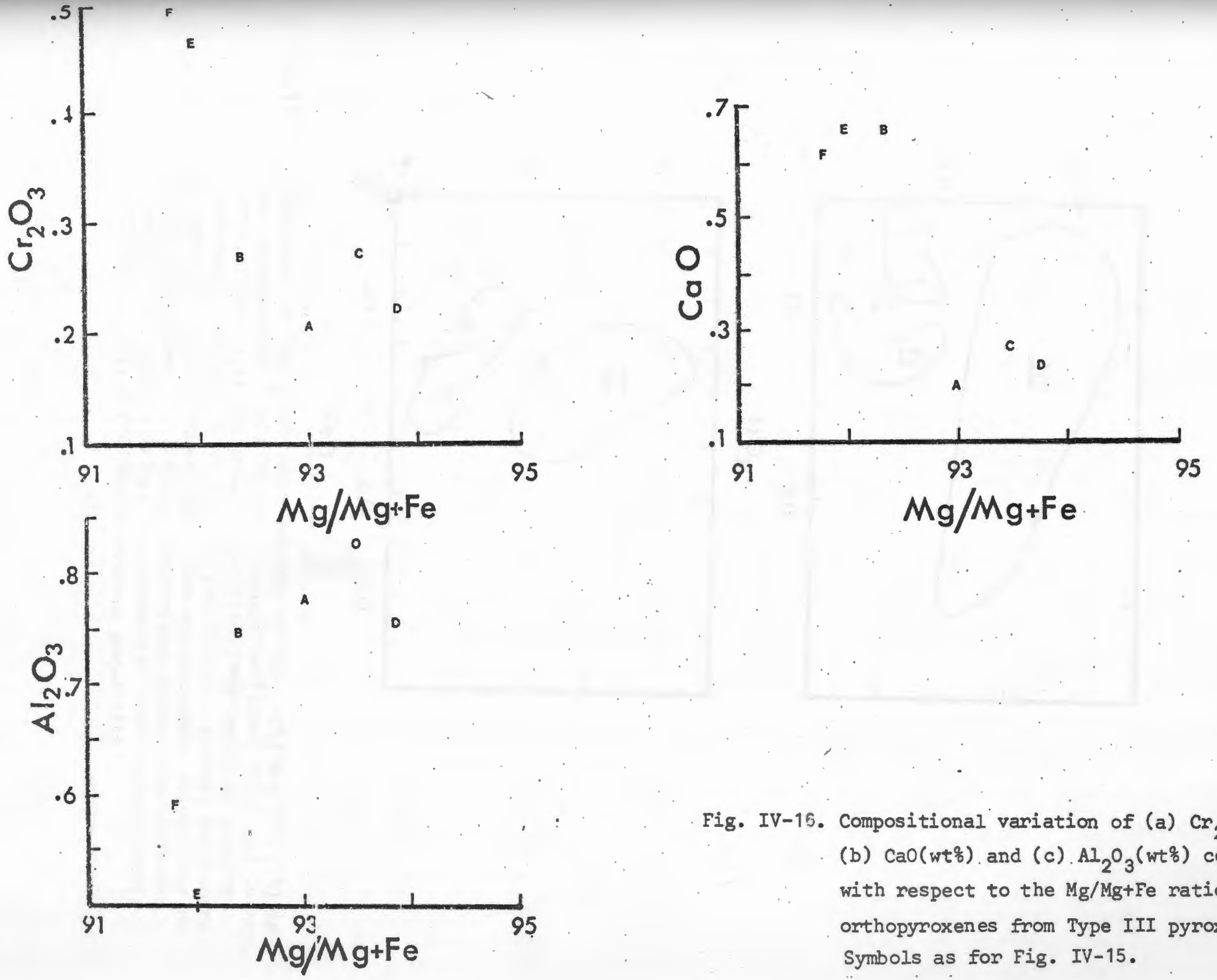

Fig. IV-16. Compositional variation of (a) Cr_2O_3 (wt%) (b) CaO(wt%) and (c) Al_2O_3(wt%) contents with respect to the Mg/Mg+Fe ratios for orthopyroxenes from Type III pyroxenites. Symbols as for Fig. IV-15.

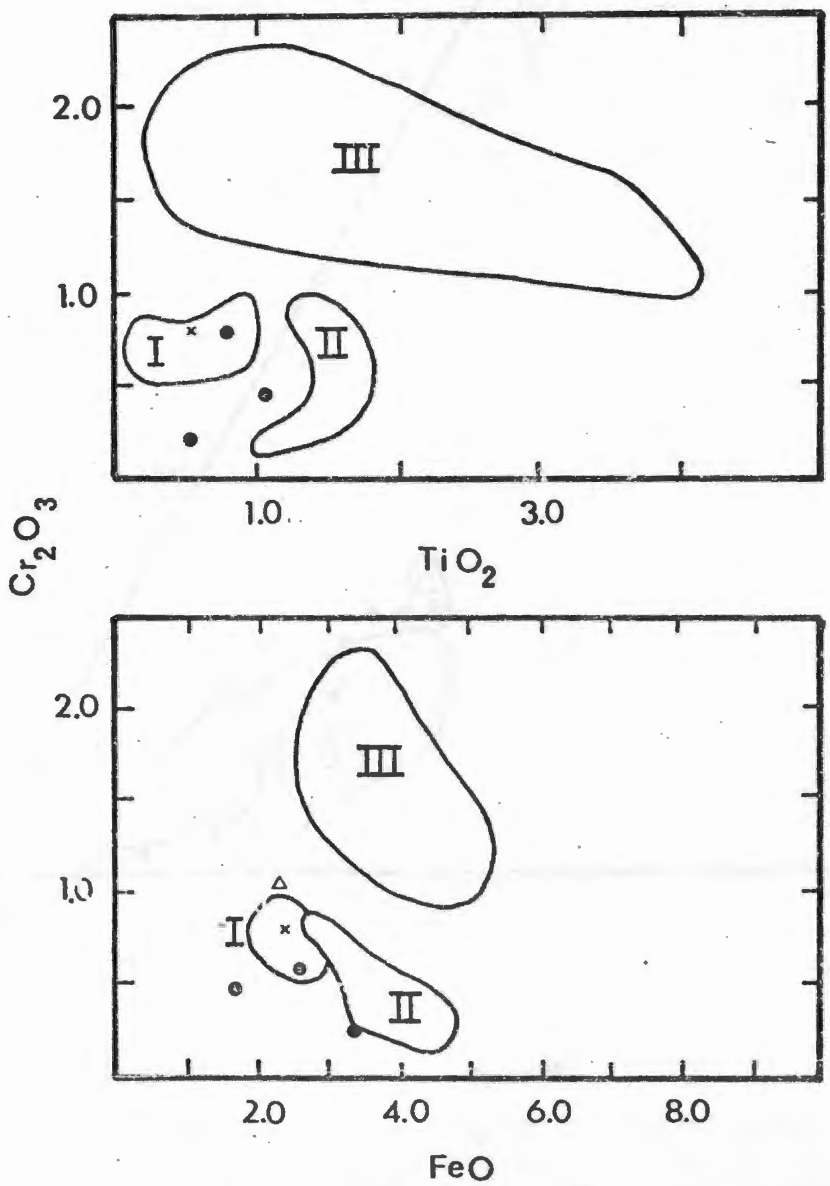

Fig.IV-17. Variation of Cr_2O_3(wt%) with respect to TiO_2(wt%) and FeO(wt%) in some phlogopites from kimberlite xenoliths (after Harte and Gurney, 1975). Fields I,II,III show compositional variation of primary-metasomatic phlogopite in Matsoku peridotites, primary phlogopite in peridotites from other 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).

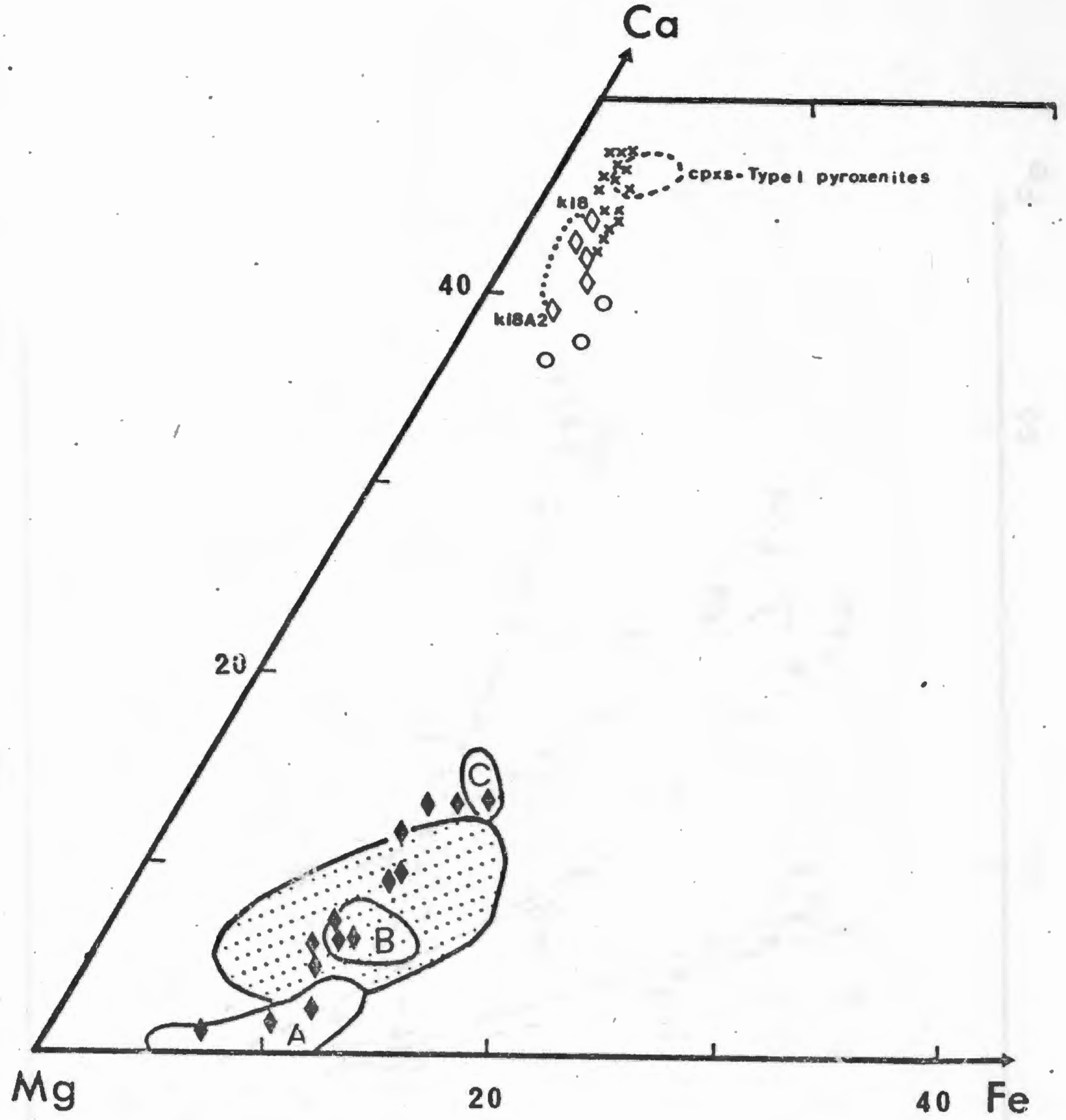

Fig. V-1. Ca-Mg-Fe ternary diagram illustrating compositional variation in peridotitic garnet and clinopyroxene inclusions in Koffiefontein diamonds. Symbols: ♦ garnets; ◊ clinopyroxenes; ○ diopside diamond inclusions(Meyer and Tsai,1976); × clinopyroxenes from the Koffiefontein concentrate. Compositional 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). ▨ Field of diamond inclusions from several kimberlite localities, as defined by the data of Lawless(1974).

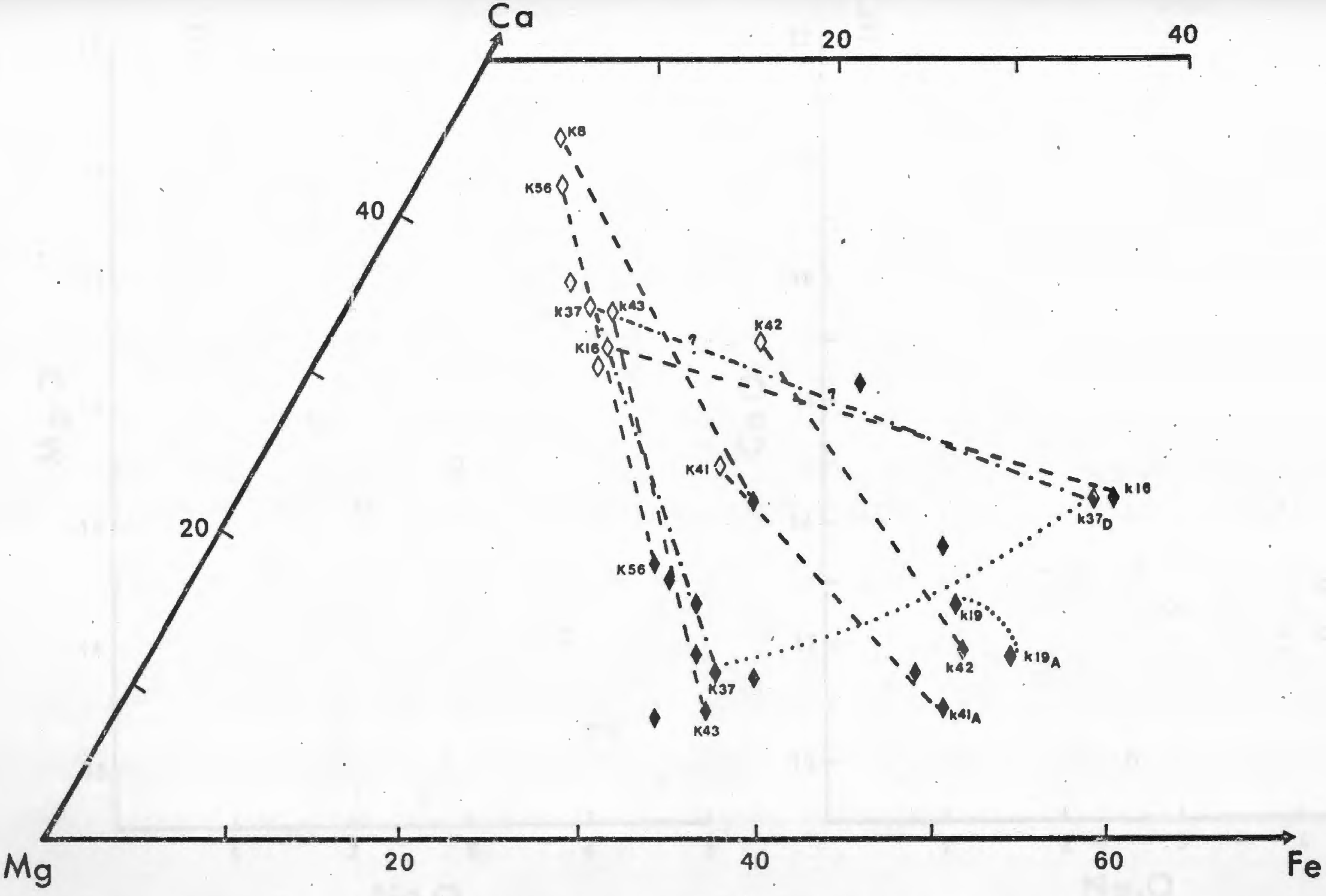

Fig. V-2. Ca-Mg-Fe ternary diagram illustrating compositional variation in eclogitic garnet and clinopyroxene inclusions in Koffiefontein diamonds. Symbols: ♦ garnets; ◊ clinopyroxenes.

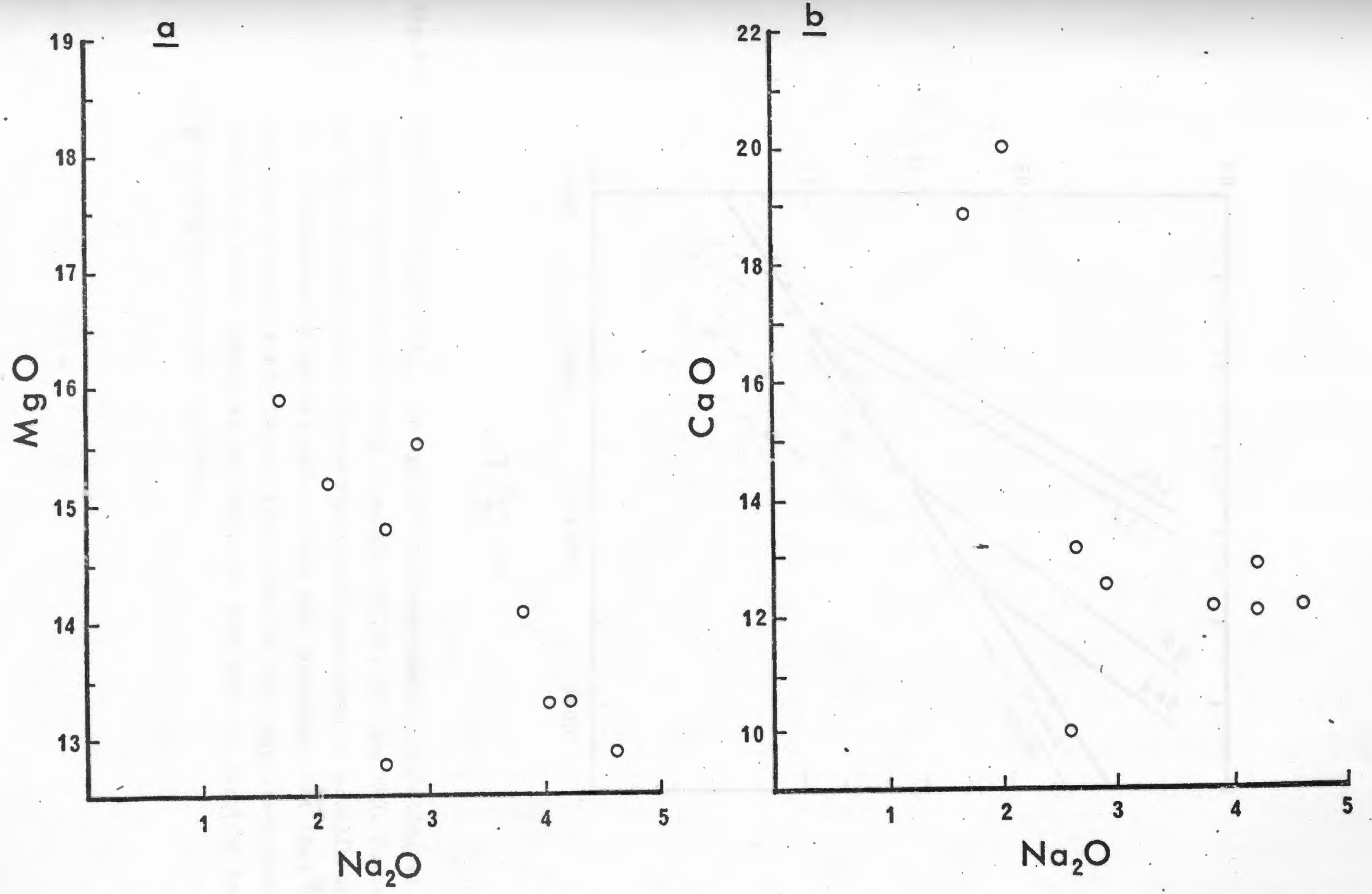

Fig. V-3. Variation of (a) MgO(wt%) and (b) CaO (wt%) with respect to Na_2O in eclogitic clinopyroxene inclusions in Koffiefontein diamons.

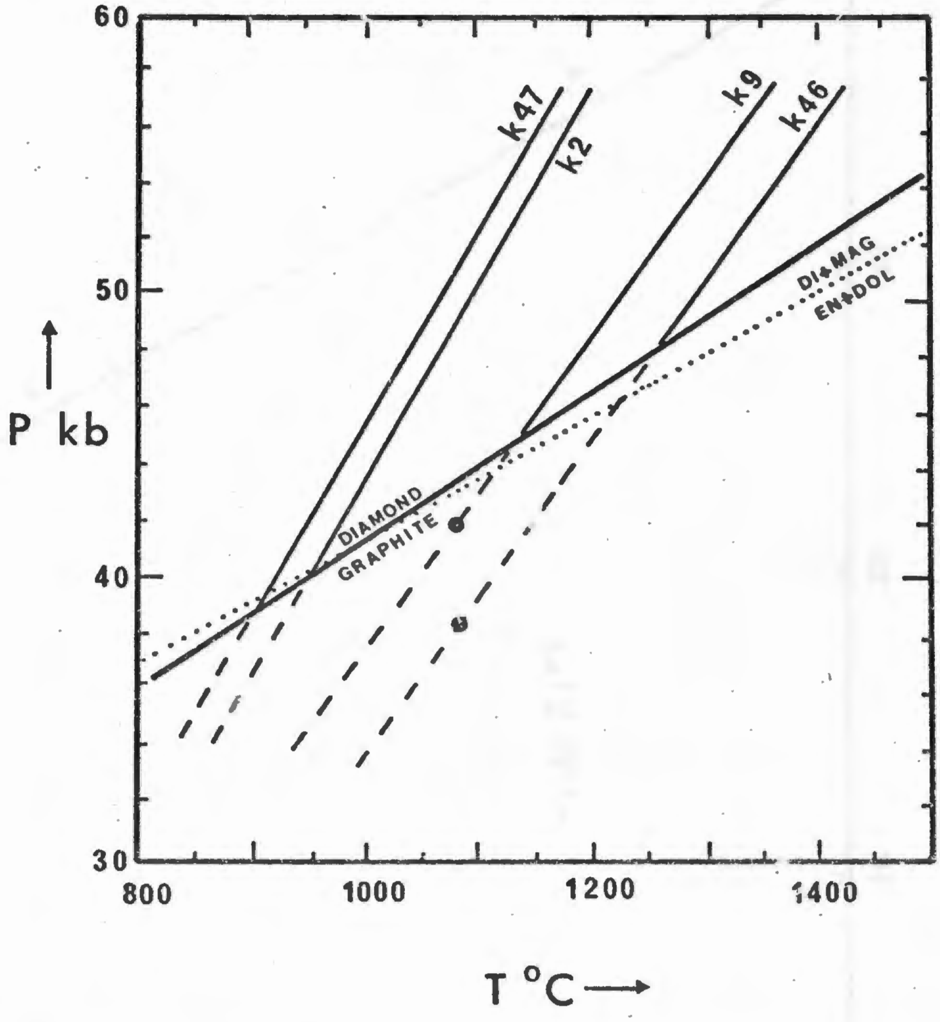

Fig.V-4. Lines of constant K_D for garnet-orthopyroxenes coexisting as inclusions in the following diamonds: K2,K9, K46 and K47. Points ● indicate calculated temperatures and pressures of equilibration for orthopyroxene-garnet pairs K9and K46, assuming that they represent equilibrium assemblages. Also shown is the graphite-diamond stability curve(Bundy et al,1961) and that for the reaction En+Dol ⇄ Di+Mag.(Kushiro et al,1975).

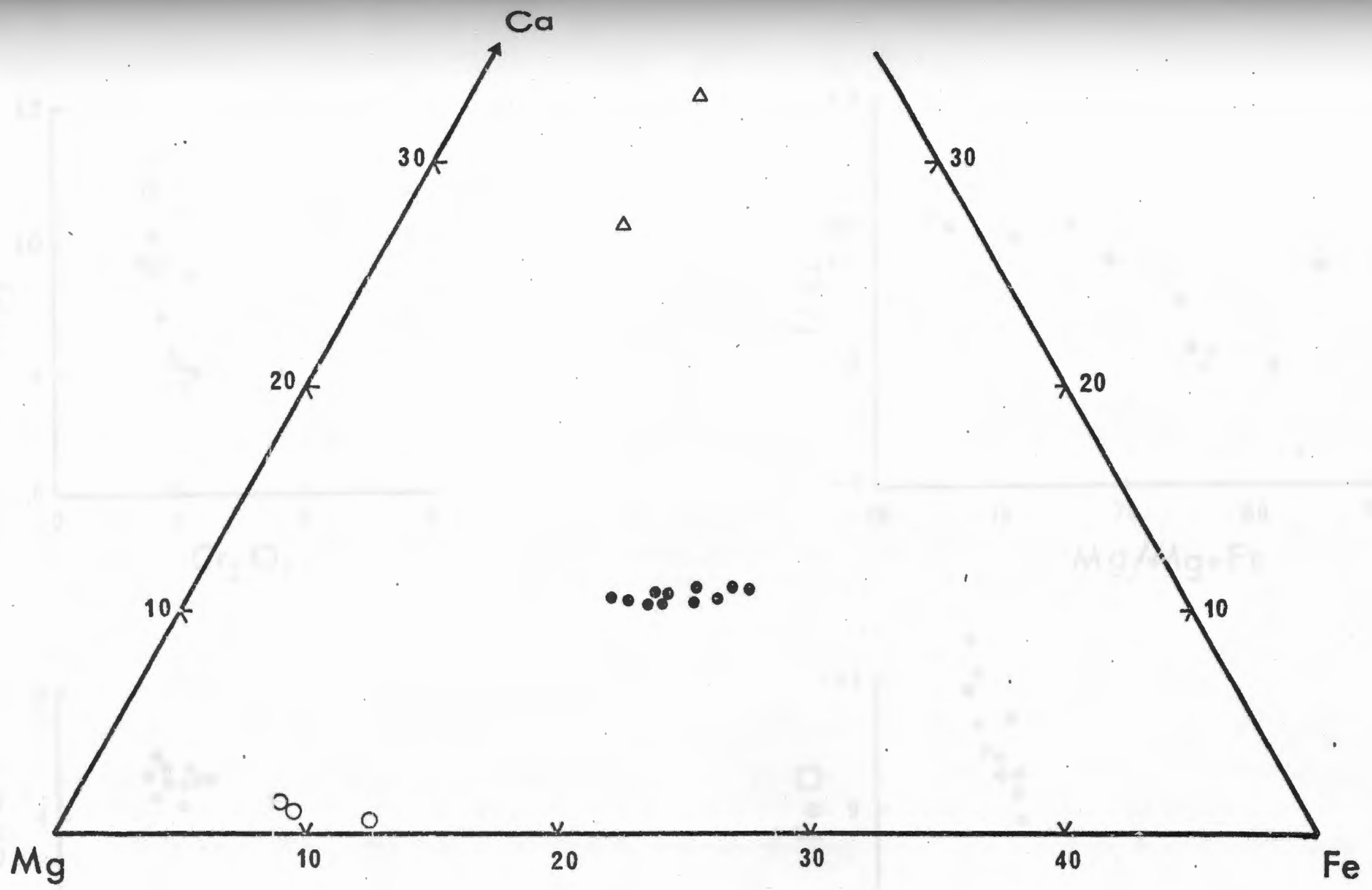

Fig. VI-1. Compositional variation of Koffiefontein megacrysts in terms of Ca-Mg-Fe.

Symbols: ● garnets; ○ orthopyroxenes; △ clinopyroxenes.

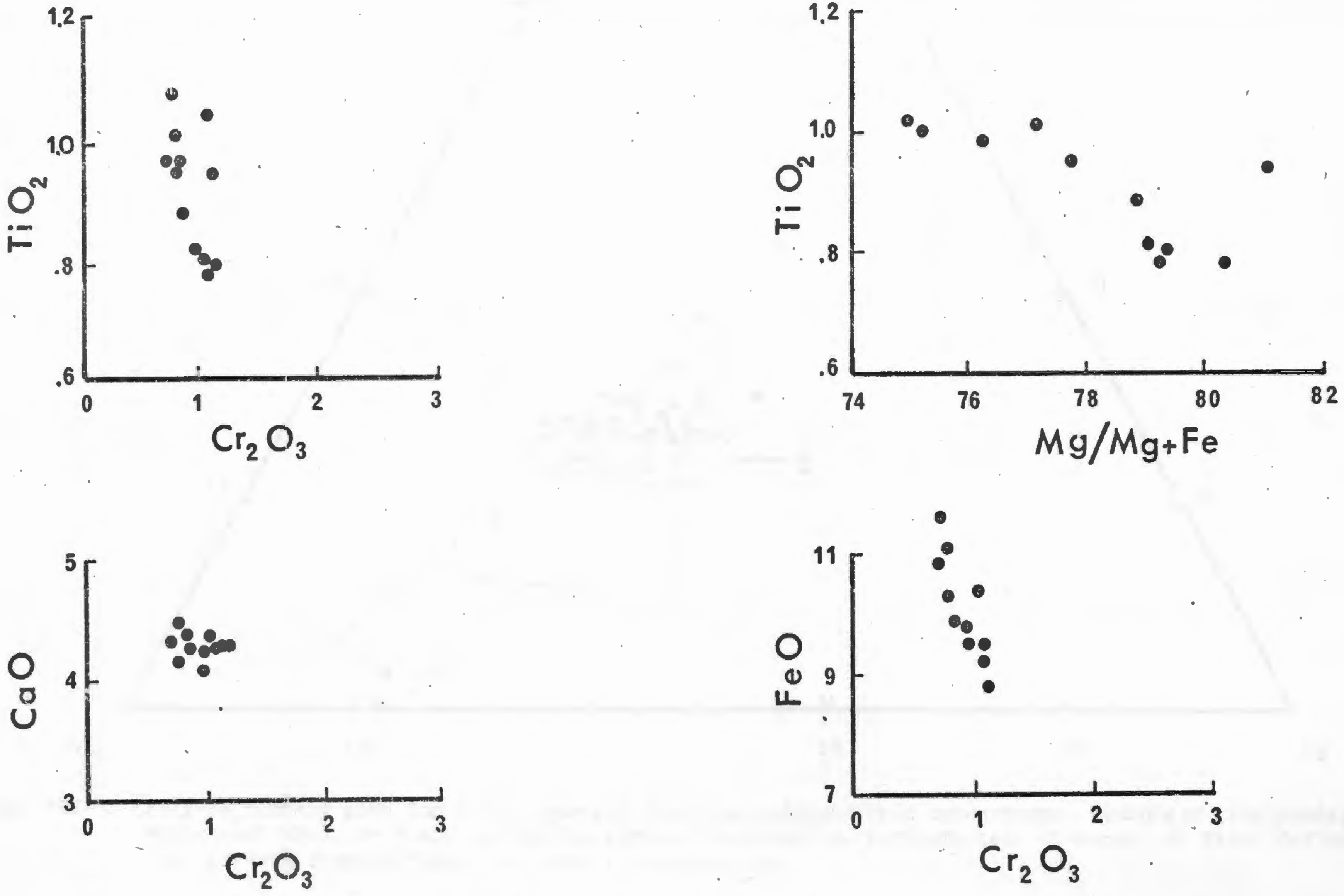

Fig. VI-2. Variation of TiO_2(wt%), CaO(wt%) and FeO(wt%) with respect to Cr_2O_3 contents, together with the variation of TiO_2(wt%) as a function of the Mg/Mg+Fe ratio, for the Koffiefontein garnet megacrysts.

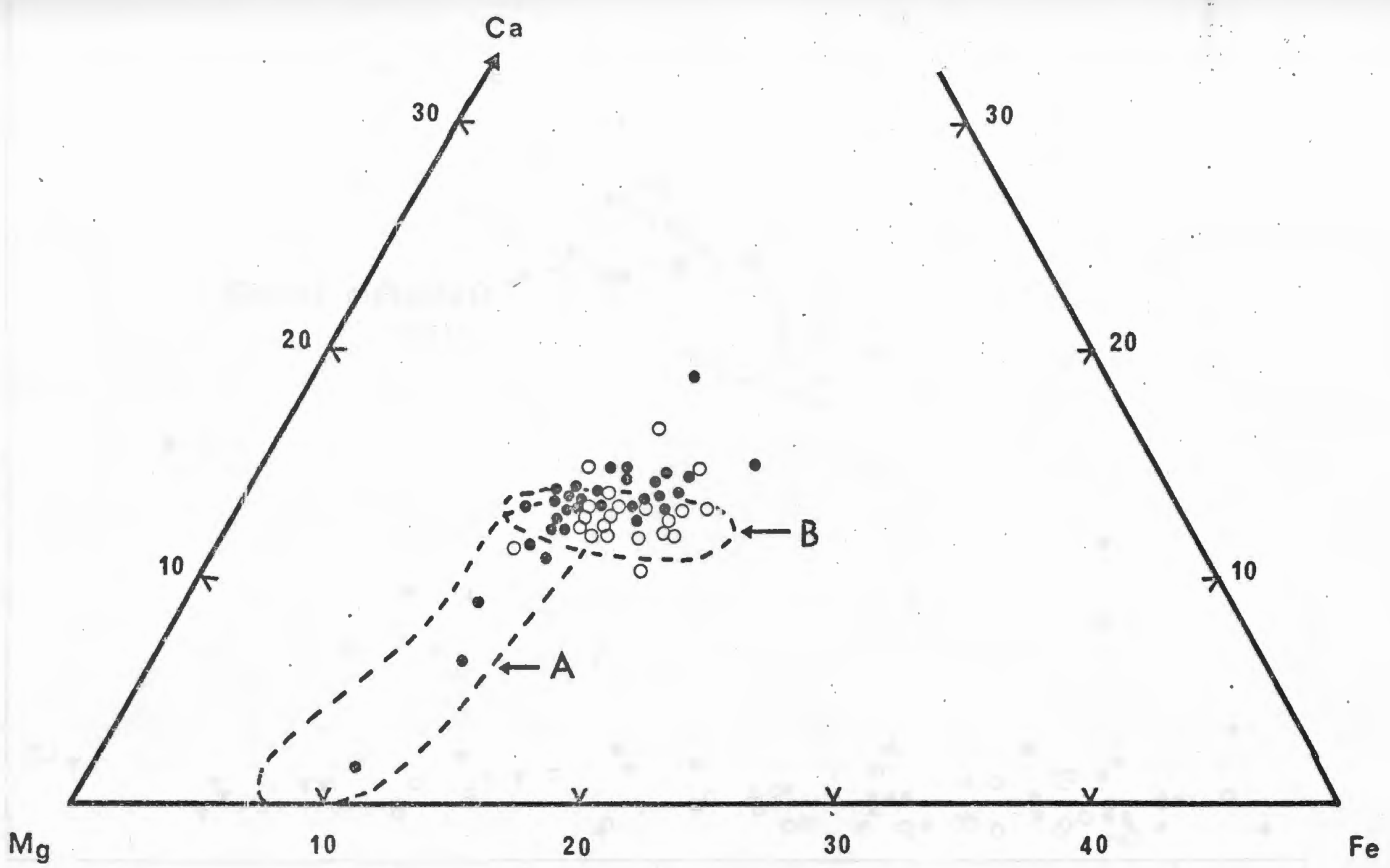

Fig. VII-1. Ca-Mg-Fe ternary plot for purple garnets from the Koffiefontein concentrate. Symbols: ○ this study; ● Lawless(1974). A- field defined by garnet inclusions in Koffiefontein diamonds; B- field defined by garnets from Koffiefontein Type II pyroxenites.

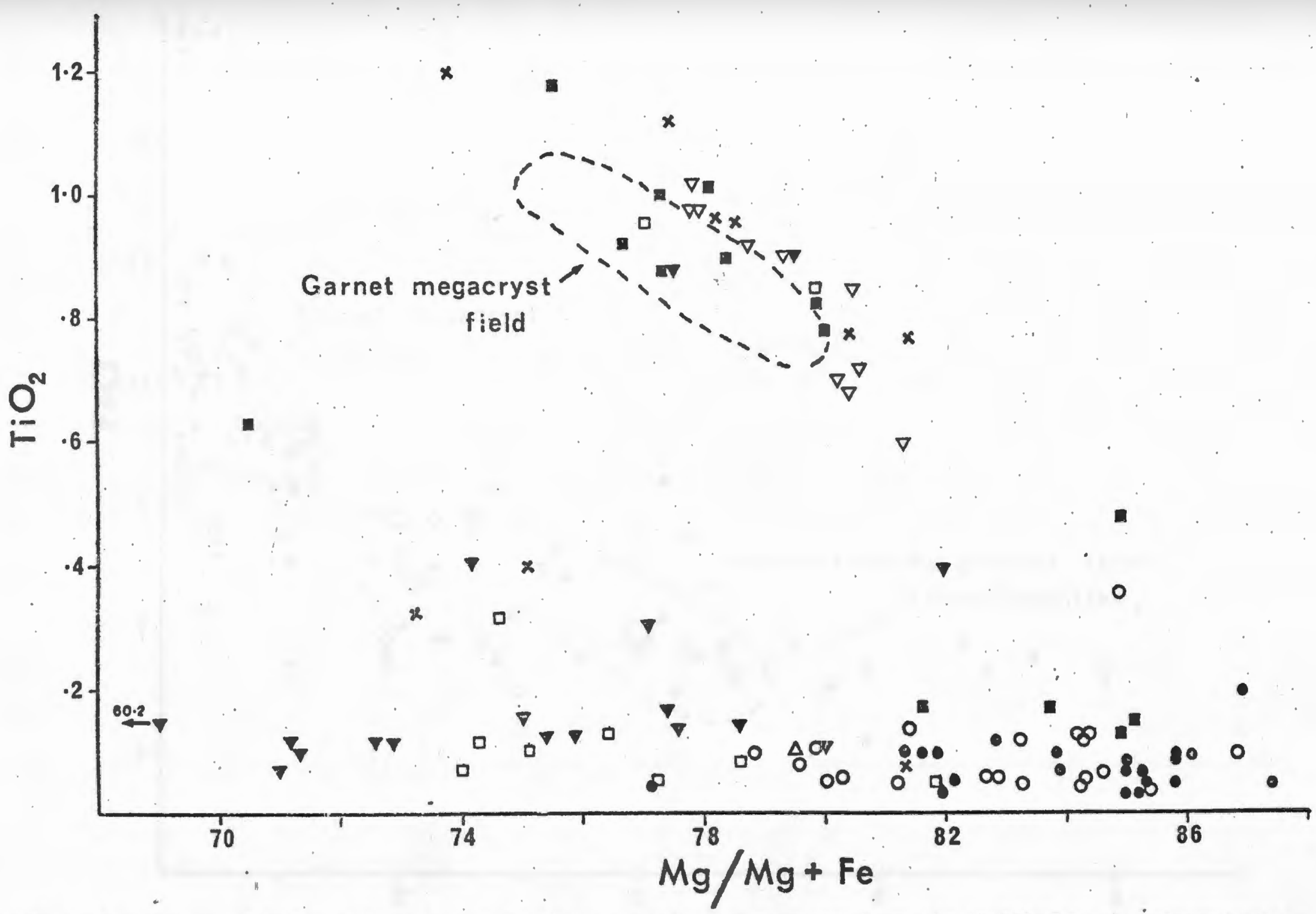

Fig. VII-2. Variation of TiO$_2$ with repect to Mg/Mg+Fe ratio for garnets from the Koffiefontein concentrate. Symbols: purple garnets ○ this study; ■ Lawless(1974); orange garnets ▼ this study; □ Lawless (1974-red) red garnets ▽ this study ; ■ Lawless(1974-orange); red-brown garnets × this study.

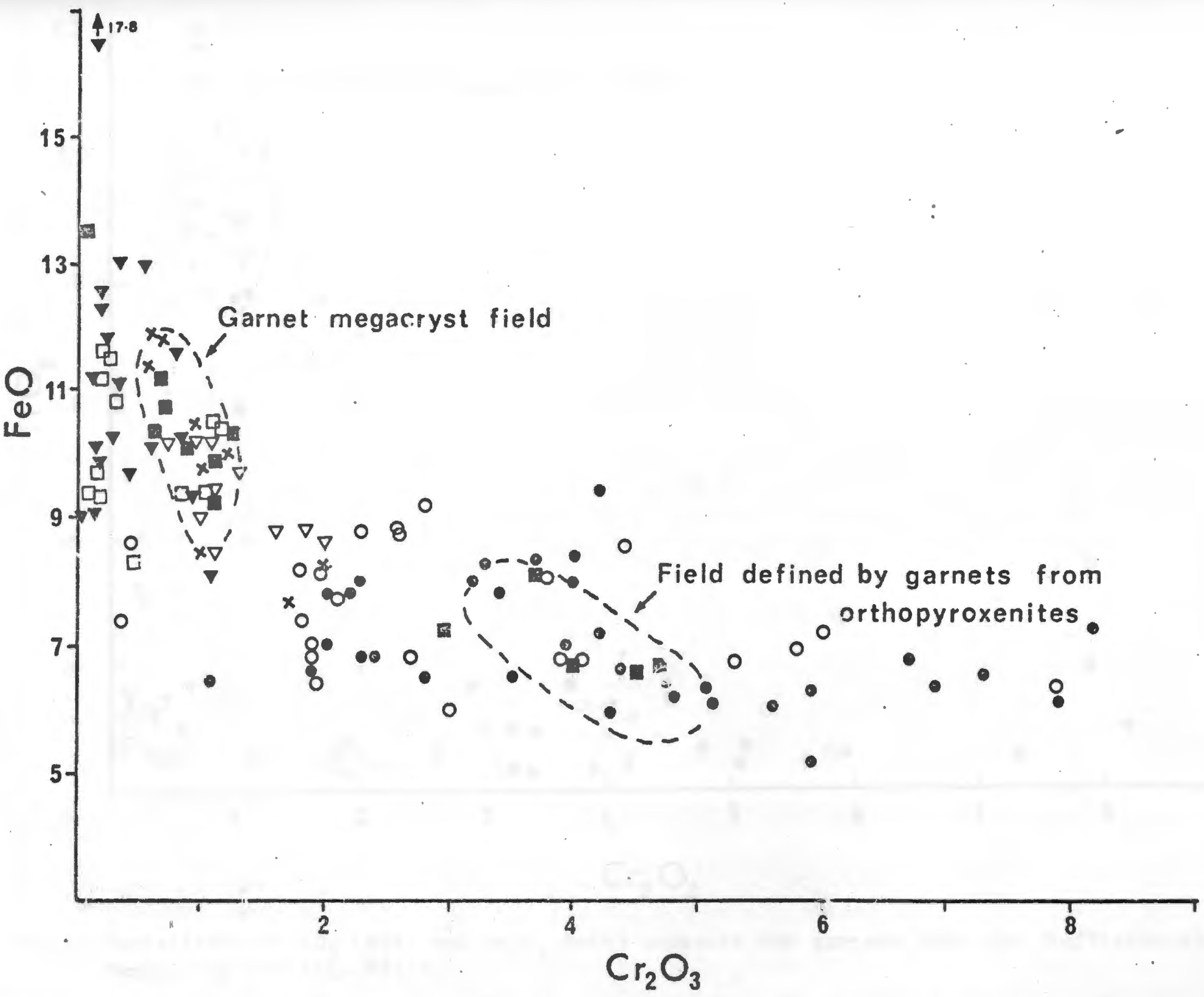

Fig. VII-3. Variation of FeO(wt%) as a function of Cr_2O_3 (wt%) for garnets from the Koffiefontein concentrate. Symbols as for Fig. VII-2.

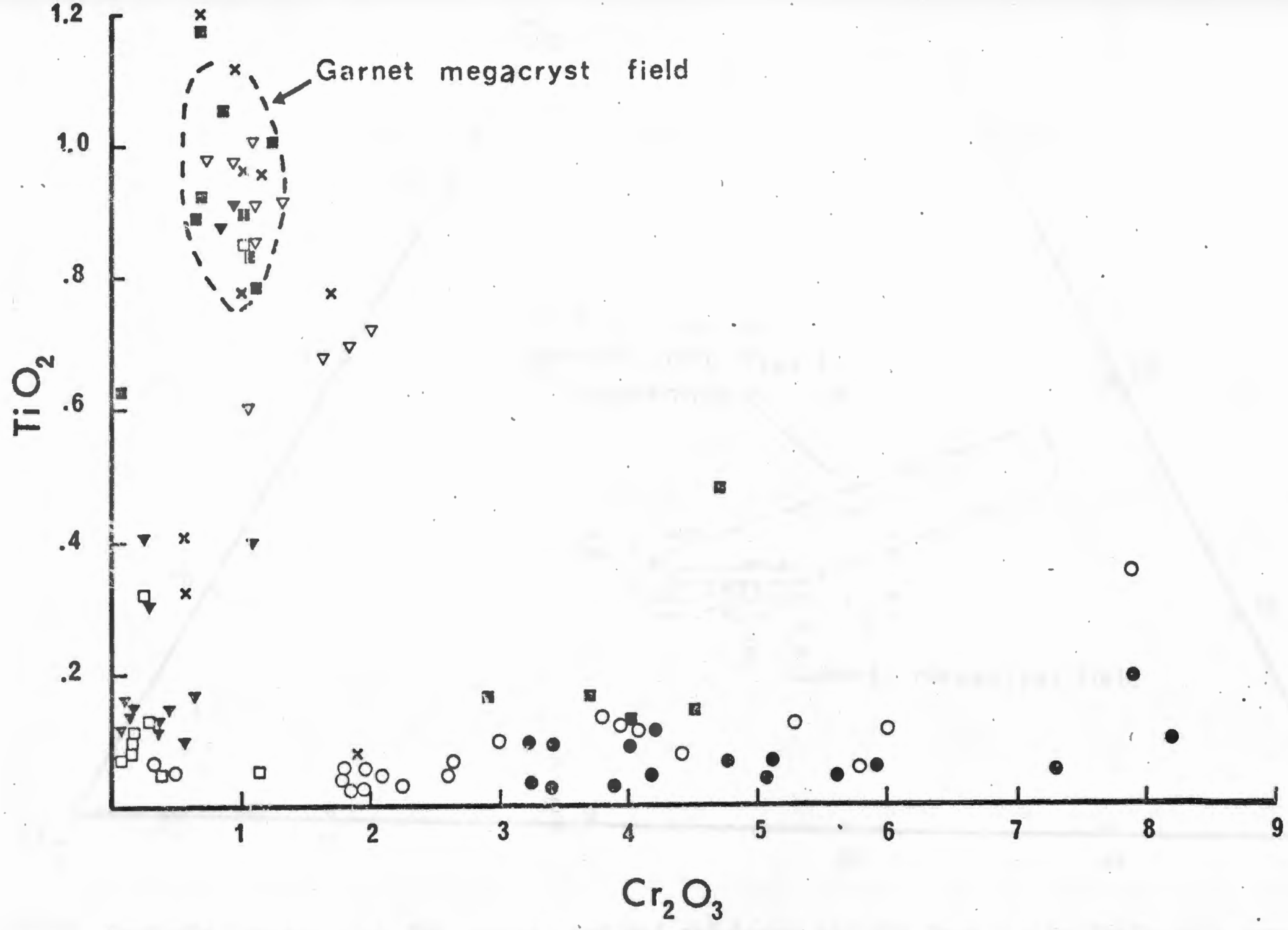

Fig. VII-4. Variaition of TiO_2 (wt%) and Cr_2O_3 (wt%) contents for garnets from the Koffiefontein concentrate. Symbols as for Fig. VII-2.

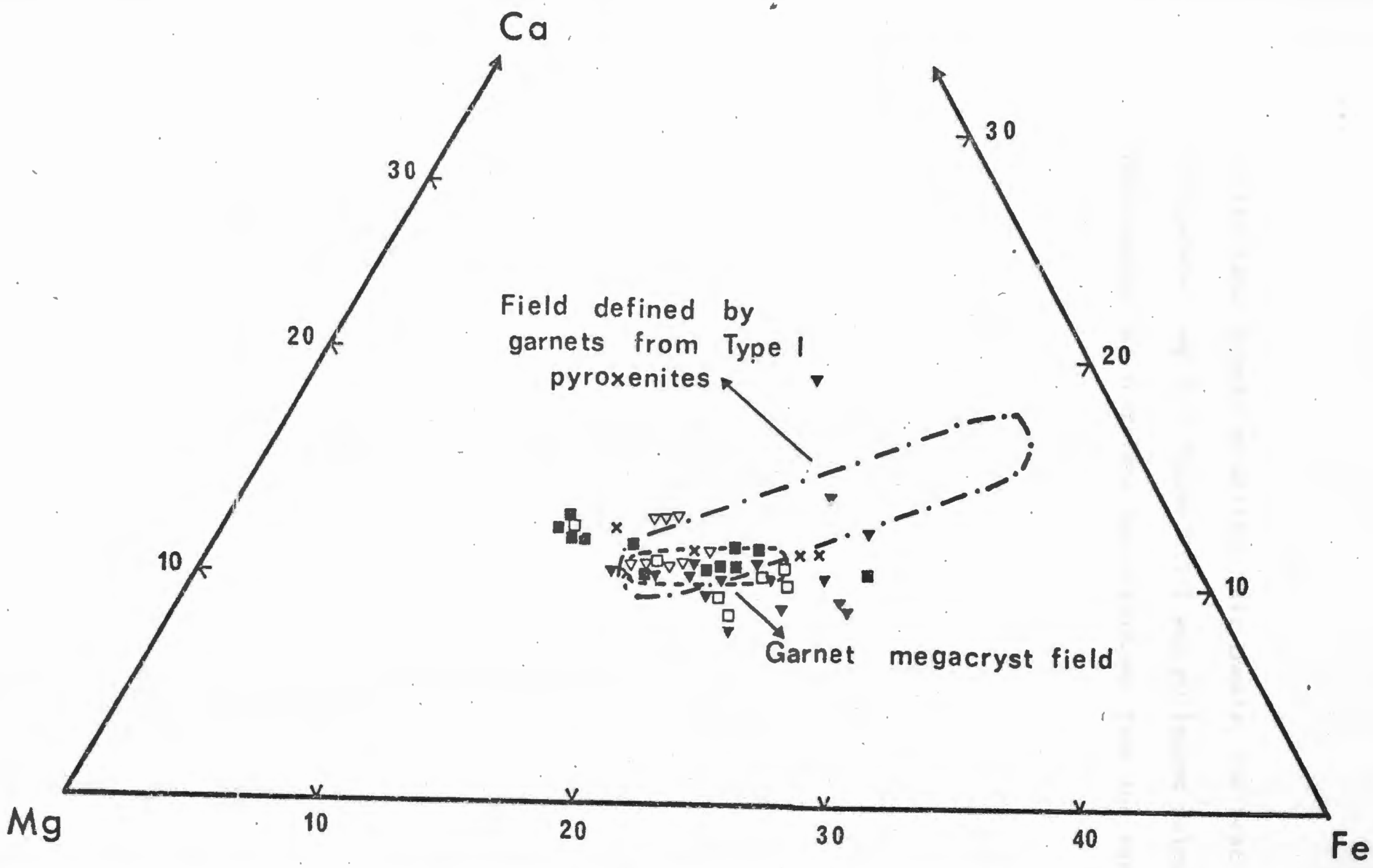

Fig.VII-5. Ca-Mg-Fe ternary plot for orange, red and red-brown garnets from the Koffiefontein concentrate. Symbols as for Fig. VII-2. Fields defined by garnet megacrysts and garnets from Type I pyroxenites from Koffiefontein are also illustrated for comparison.

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.

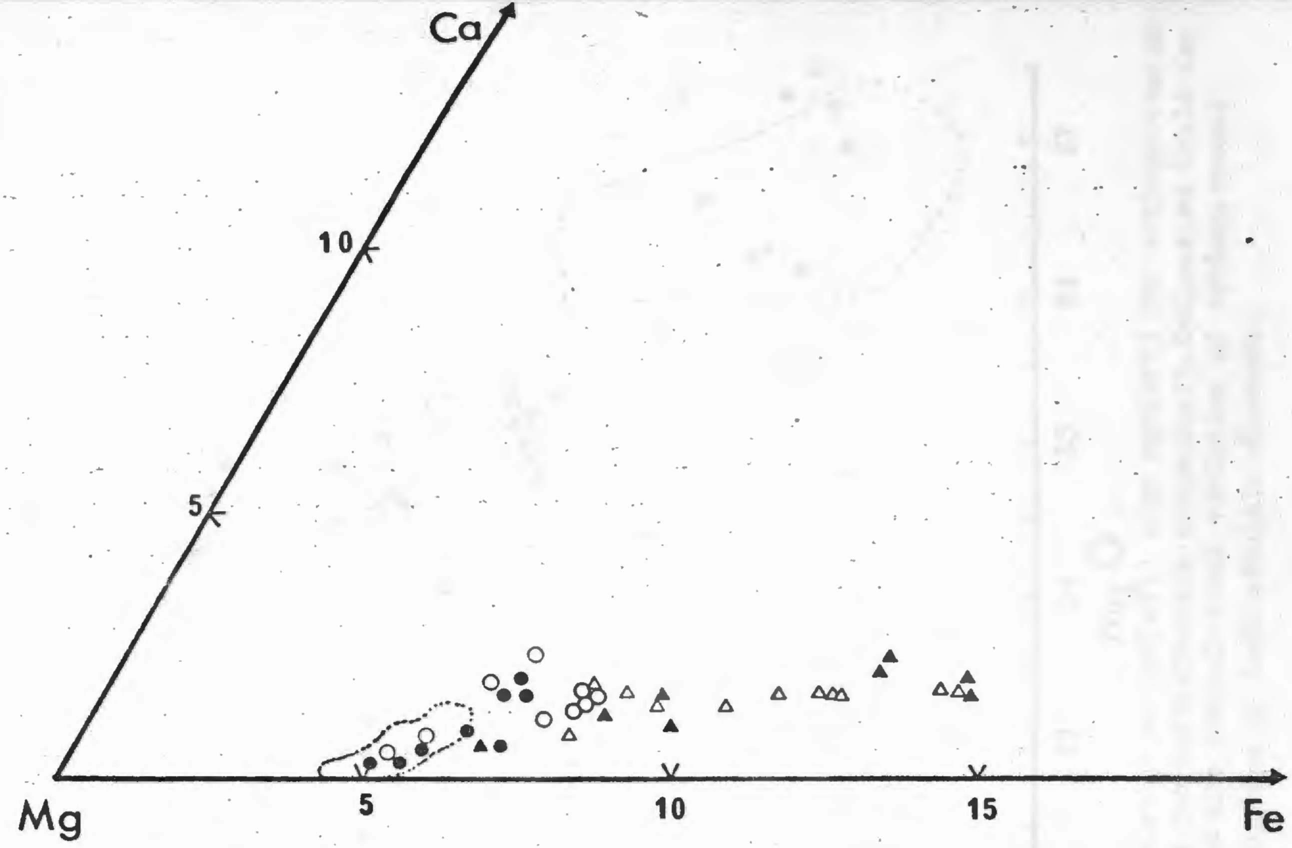

Fig. VII-7. Ca-Mg-Fe ternary plot for orthopyroxenes from the Koffiefontein concentrate. Symbols: ○ green(glassy); ● green (with cleavage); △ brown(glassy); ▲ brown (with cleavage). Delineated field represents the compositional variation of orthopyroxene inclusions in Koffiefontein diamonds.

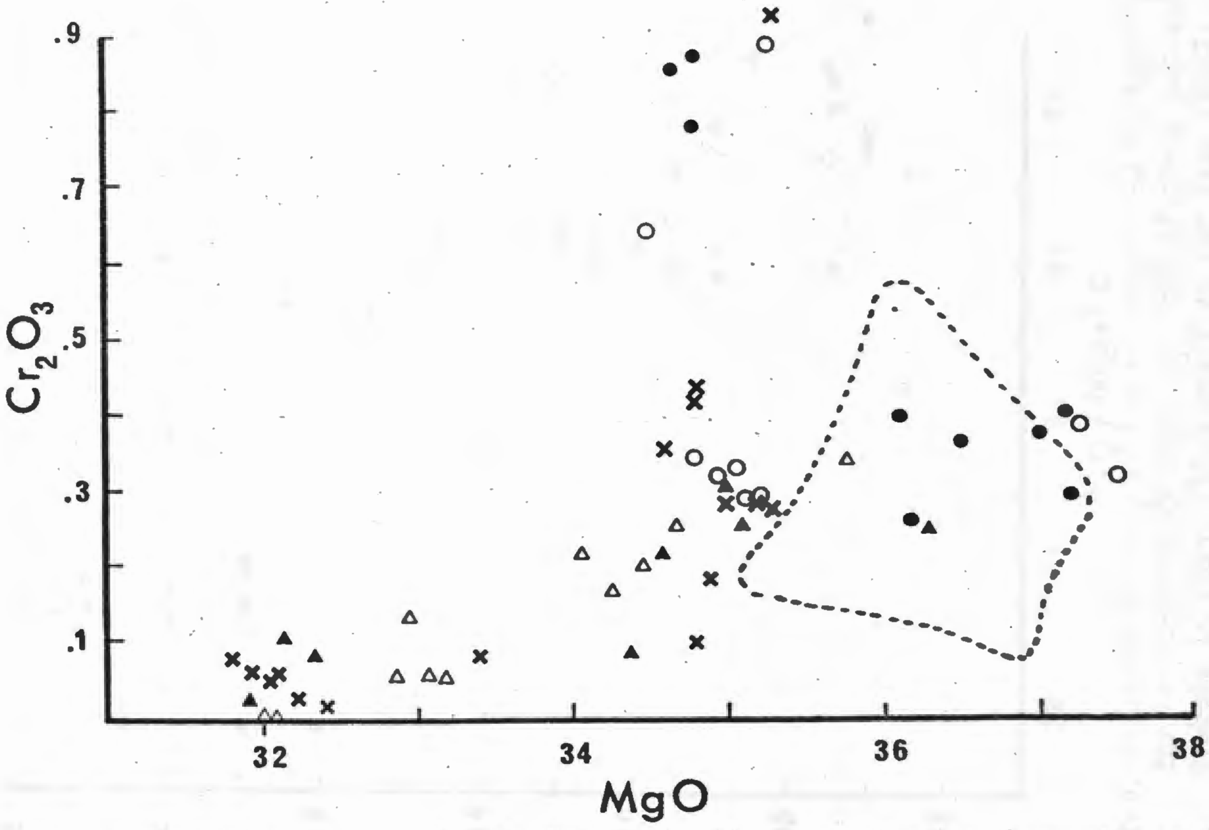

Fig. VII-8. Variation of Cr_2O_3(wt%) with MgO(wt%) content of orthopyroxenes from the Koffiefontein concentrate. Symbols as for Fig. VII-7. Delineated field represents the compositional variation of orthopyroxene inclusions in Koffiefontein diamonds. X = data from Lawless (1974).

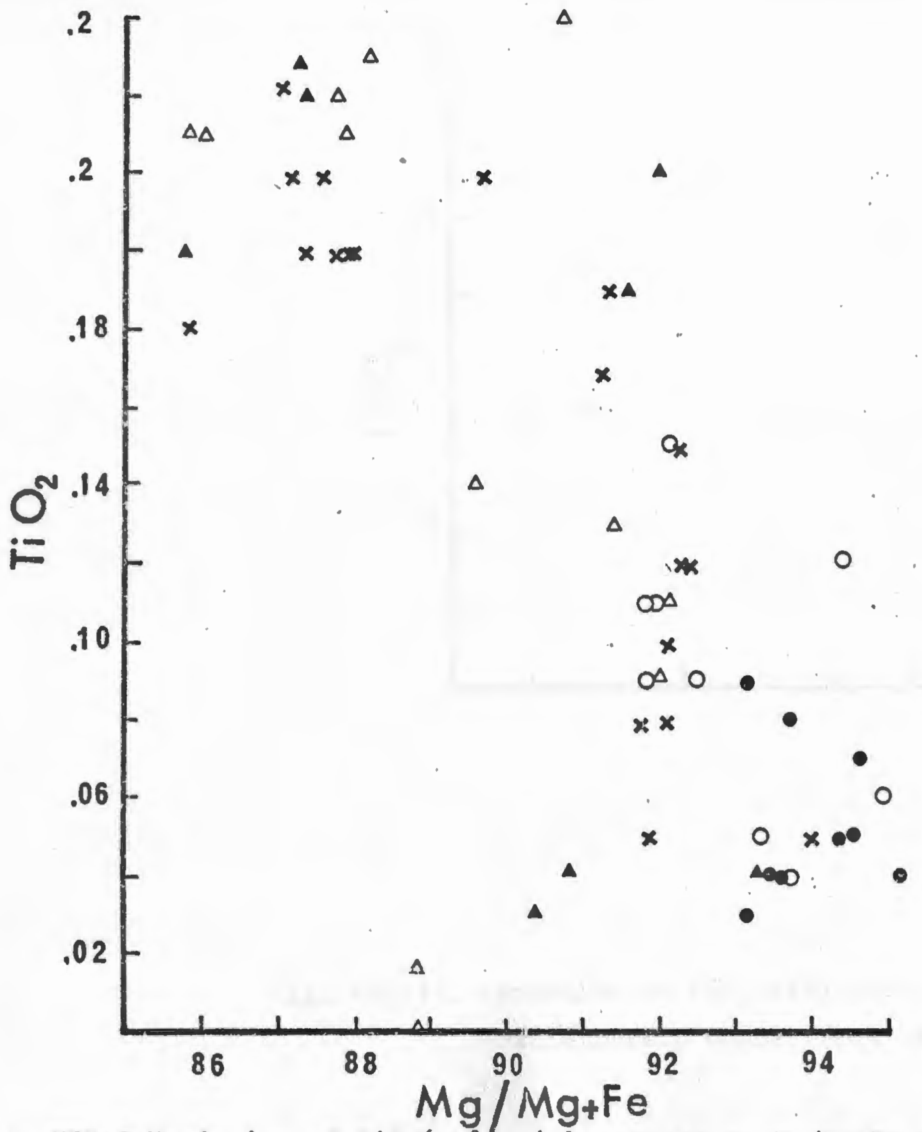

Fig. VII-9. Variation of TiO$_2$(wt%) with respect to Mg/Mg+Fe ratio for orthopyroxenes from the Koffiefontein concentrate. Symbols in Figs. VII-9 and10 as for Fig. VII-7.

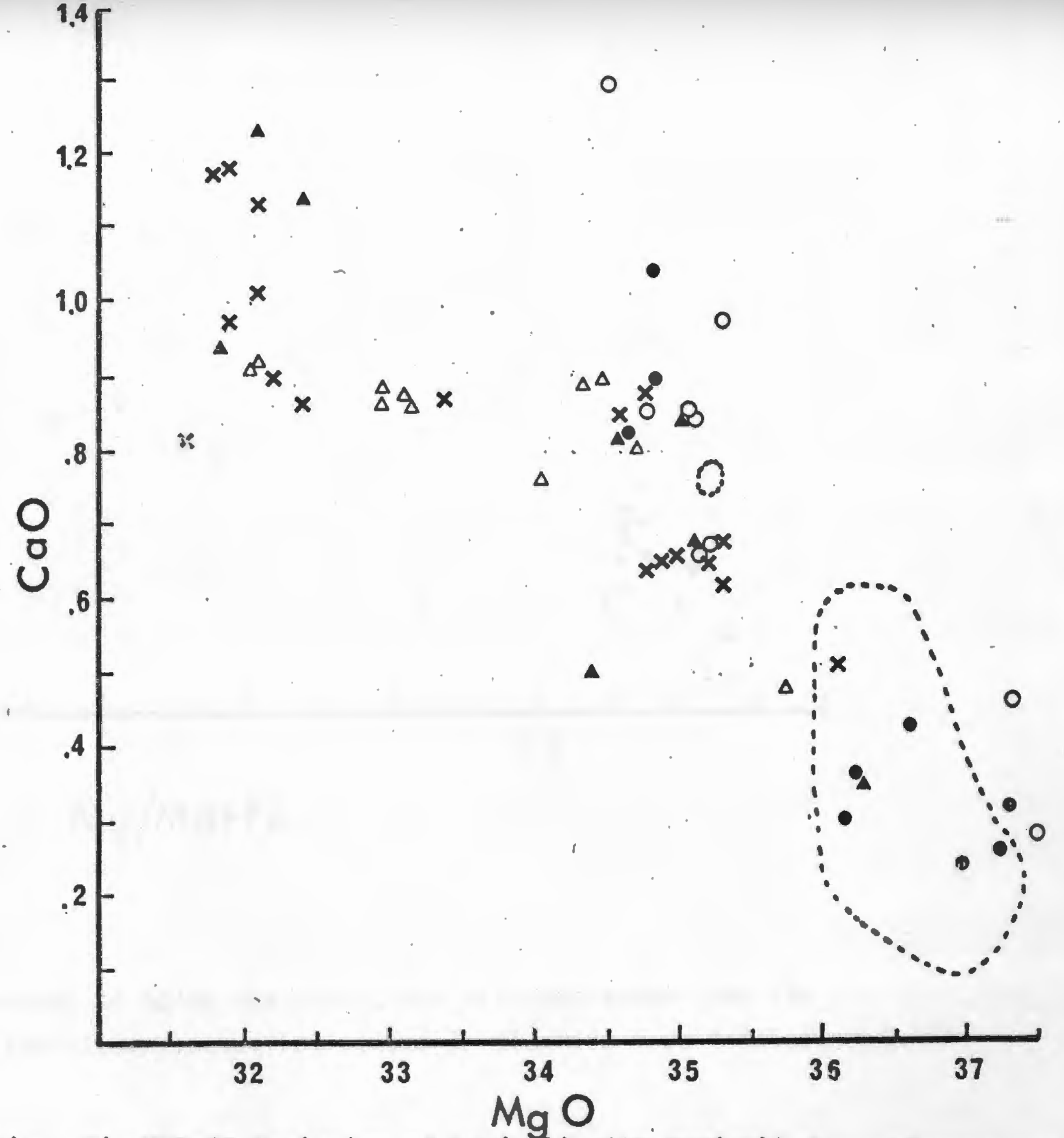

Fig. VII-10. Variation of CaO(wt%) with MgO(wt%) for orthopyroxenes from the Koffiefontein concentrate. Delineated field defines the compositional variation of orthopyroxene inclusions in Koffiefontein diamonds.

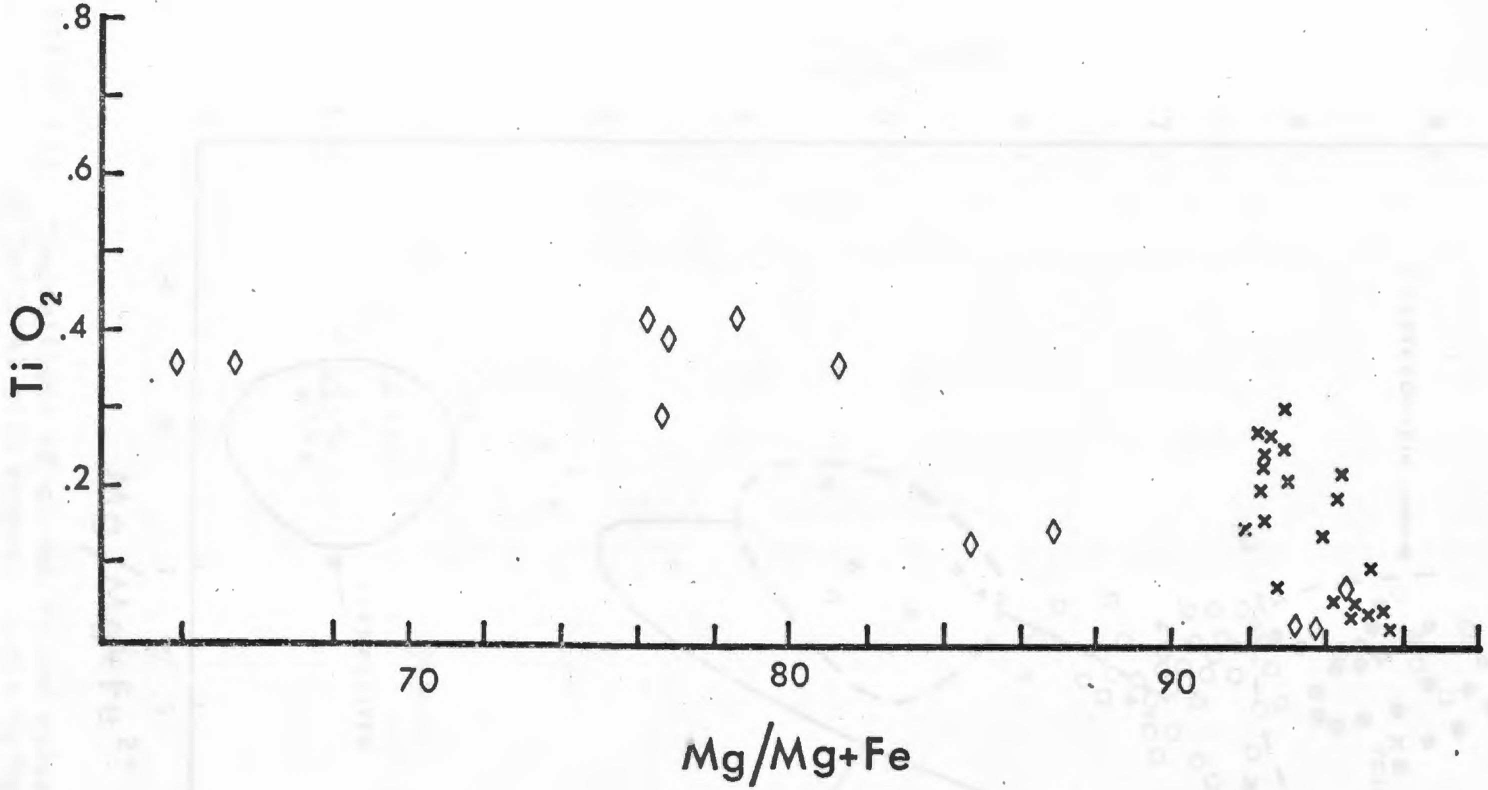

Fig. VII-11. Variation of TiO_2(wt%) with respect to Mg/Mg +Fe ratio, for clinopyroxenes from the Koffiefontein concentrate (✖) and clinopyroxene inclusions in diamonds from Koffiefontein (◊).

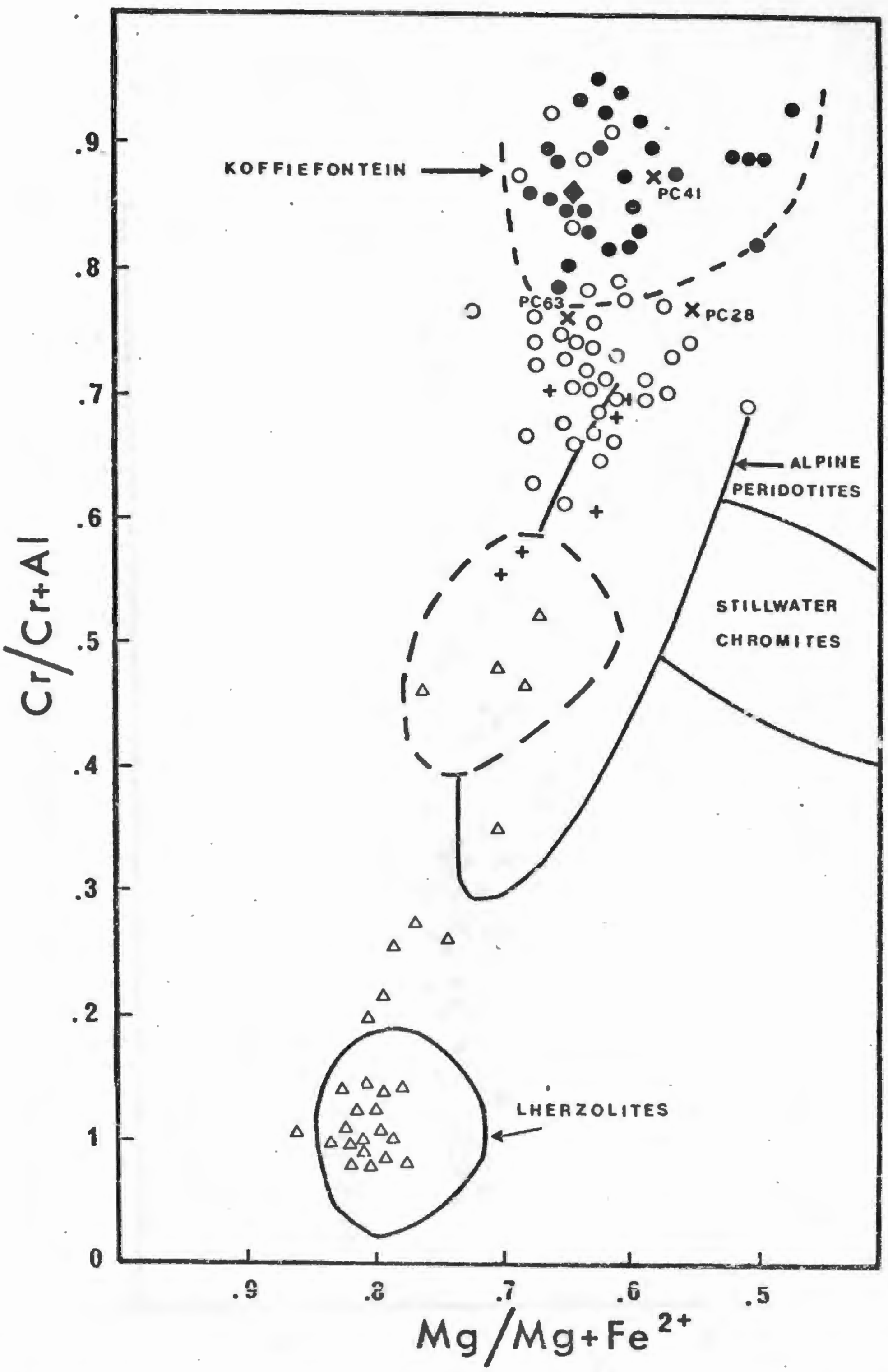

Fig. VII-12 (a). Compositions of chromites and spinels, in terms of the variation of Cr/Cr+Al with respect to the $Mg/Mg+Fe^{2+}$ ratio. Projections after Irvine(1965). Symbols: ● Koffiefontein concentrate; × Koffiefontein xenoliths; ◆ Koffief. diamond inclusion; ○ and + euhedral and symplectite chromites,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

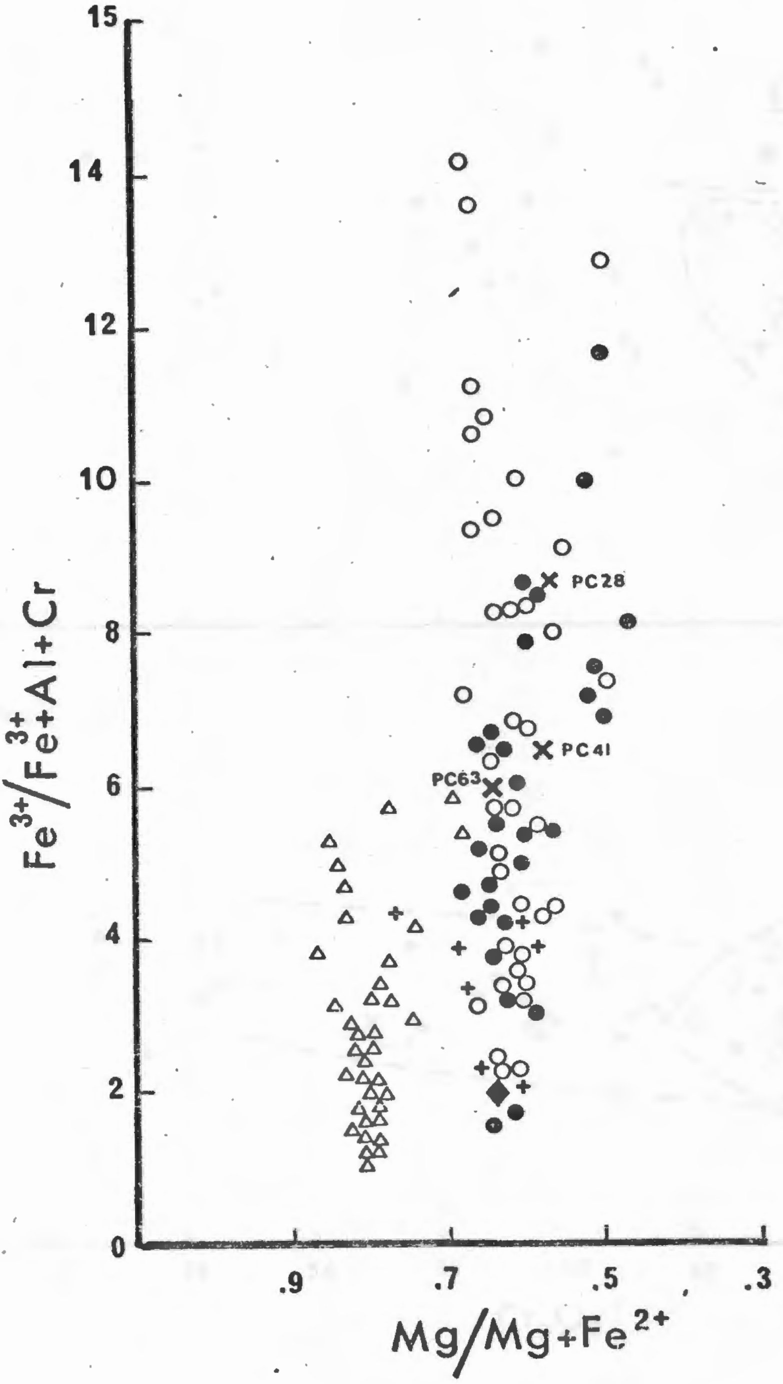

Fig. VII-12 (b). Compositions of chromites and spinels in terms of the variation of $Fe^{3+}/Fe^{3+}+Al+Cr$ ratio with respect to the $Mg/Mg+Fe^{2+}$ ratio. Projection after Irvine(1965). Symbols as for Fig.VII-12 (a). (after Sigurdson, 1977).

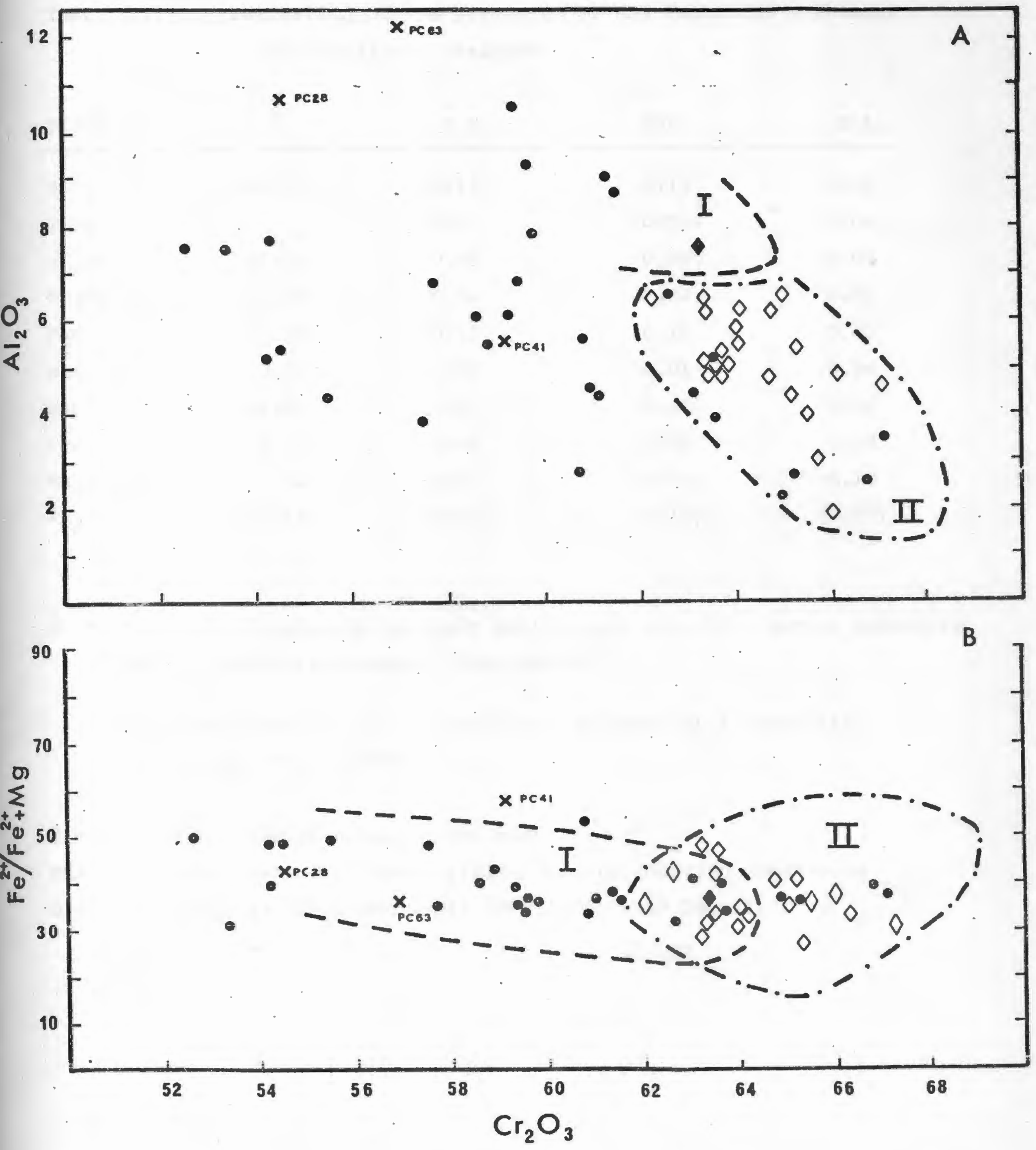

Fig. VII-13. Variation in Al_2O_3 content and Fe^{2+}/Fe^{2+} + Mg ratio with respect to Cr_2O_3 (wt%) in all analysed chromites from Koffiefontein. Symbols: Koffiefontein concentrate; Koffiefontein xenoliths; Koffiefontein diamond inclusion; diamond inclusions, U.S.S.R.(Sobolev,1977) Fields I and II 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_2O_3	21,60	0,09	0,08	0,04
Cr_2O_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_2O	0,12	0,01	0,02	0,10
$^*K_2O$	(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).

*K_2O estimates are for 10 replicate analyses of a pargasitic 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_2O_3	15.0	0.080	0.079	0.022
Cr_2O_3	0.5	0.008	0.012	0.007
Fe_2O_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_2O	2.5	0.032	0.067	0.080
K_2O	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 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE I PYROXENITES

	1	2	3	4	5	6	7	8	9
SIO2	55.13	56.22	40.01	54.53	56.54	39.90	54.20	57.59	41.37
TIO2	.05	.03	.04	.03	.02	.03	.16	.07	.06
AL2O3	1.09	.44	21.09	.66	.39	21.02	2.13	.69	22.03
CR2O3	.78	.15	3.21	.47	.13	2.68	1.26	.16	2.62
FEO	3.25	9.87	14.31	2.87	9.25	13.89	2.21	5.74	10.08
MNO	.13	.22	.78	.08	.20	.79	.06	.11	.50
MGO	16.60	33.13	14.80	17.42	33.52	14.74	16.07	35.54	18.60
CAO	22.66	.31	5.84	23.46	.28	6.08	21.44	.23	5.07
NA2O	.90	.03	ND	.51	ND	ND	1.73	.04	.03
K2O	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	6	6	12	6	6	12	6	6	12
SI	1.991	1.965	2.961	1.984	1.971	2.974	1.978	1.976	2.974
TI	.001	.001	.002	.001	.001	.002	.004	.002	.003
AL	.044	.018	1.840	.028	.016	1.847	.092	.028	1.867
CR	.022	.004	.188	.014	.004	.158	.036	.004	.149
FE2+	.098	.289	.886	.087	.270	.866	.067	.165	.606
MN	.004	.007	.049	.002	.006	.050	.002	.003	.030
MG	.904	1.726	1.652	.945	1.741	1.634	.874	1.818	1.993
CA	.877	.012	.463	.915	.010	.486	.838	.008	.391
NA	.063	.002	-	.036	-	-	.122	.003	.004
K	-	-	-	-	-	-	-	-	-
SUM	4.006	4.024	8.024	4.012	4.019	8.023	4.015	4.007	8.018
	WO 46.66 EN 48.12 FS 5.22	WO .57 EN 85.19 FS 14.24	CA 15.53 MG 54.76 FE 29.71	WO 46.99 EN 48.53 FS 4.49	WO .52 EN 86.14 FS 13.34	CA 16.25 MG 54.78 FE 28.97	WO 47.10 EN 49.11 FS 3.79	WO .42 EN 91.30 FS 8.27	CA 13.06 MG 66.66 FE 20.27
	M: 90.21 C: 49.23	M: 85.69 C: .67	M: 64.83	M: 91.54 C: 49.19	M: 86.59 C: .60	M: 65.41	M: 92.84 C: 48.96	M: 91.69 C: .46	M: 76.68

* * * SAMPLE DIRECTORY * * *

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

ANALYSIS NO.	DESCRIPTION
6	PC25,GT(3)
7	PC33,CPX(5)
8	PC33,OPX(5)
9	PC33,GT(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        .03        .05        .12        .06        .09        .08        .06        .08
AL2O3          2.40        .60      23.24       1.97        .56      22.29        .96        .39      20.08
CR2O3           .66        .06       1.22        .83        .09       1.71        .75        .12       2.68
FEO            2.69       6.78      11.74       3.55       8.76      13.69       2.38       8.21      12.81
MNO             .05        .10        .36        .06        .13        .48        .08        .15        .63
MGO           16.50      35.27      18.36      15.98      33.84      16.08      17.25      33.00      17.41
CAO           21.01        .20       4.73      21.61        .27       4.96      22.91        .19       5.61
NA2O           1.82        .04         ND       1.75         ND         ND        .74         ND         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      1.751
CR             .019       .002       .069       .024       .002       .099       .022       .003       .157
FE2+           .082       .196       .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             .821       .007       .365       .834       .010       .389       .894       .007       .445
NA             .129       .003         -        .122         -          -        .052         -          -
K                -          -          -          -          -          -          -          -          -

SUM           4.029      4.023      8.044      4.019      4.007      8.013      4.008      3.996      8.077

          WO 45.62   WO   .37   CA 12.00   WO 46.37   WO   .50   CA 13.05   WO 46.99   WO   .36   CA 14.09
          EN 49.83   EN 89.93   MG 64.76   EN 47.69   EN 86.88   MG 58.84   EN 49.21   EN 87.43   MG 60.81
          FS  4.56   FS  9.70   FE 23.24   FS  5.95   FS 12.62   FE 28.11   FS  3.81   FS 12.21   FE 25.11

          M: 91.62   M: 90.26   M: 73.59   M: 88.92   M: 97.32   M: 67.67   M: 92.81   M: 87.75   M: 70.78
          C: 47.79   C:   .41              C: 49.30   C:   .57              C: 48.85   C:   .41

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

     ANALYSIS NO.     DESCRIPITION                                ANALYSIS NO.     DESCRIPTION
     ------------     ------------                                ------------     -----------
          1           PC35,CPX(2)                                      6           PC54,GT(3)
          2           PC35,OPX(2)                                      7           PC55,CPX(5)
          3           PC35,GT(3)                                       8           PC55,OPX(2)
          4           PC54,CPX(2)                                      9           PC55,GT(2)
          5           PC54,OPX(2)

** ND = NOT DETECTED **
```

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TABLE IV-2(CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE I PYROXENITES
             1          2          3          4          5

SIO2      54.61      57.59      41.69      55.40      42.15
TIO2        .07        .03        ND         .12        .09
AL2O3      3.06        .64      23.40       4.87      24.06
CR2O3      1.25        .12       1.32        .45        .43
FEO        1.64       5.03       8.84       2.24       8.84
MNO         .04        .08        .33        .05        .28
MGO       16.56      37.25      20.32      15.28      20.60
CAO       20.86        .16       4.30      19.18       4.12
NA2O       2.44        .04        ND        2.88        .04
K2O         .02        ND         ND         ND         ND
TOTAL    100.55     101.06     100.20     100.48     100.62

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

OXYGEN       6          6         12          6         12

SI        1.962      1.957      2.962      1.977      2.970
TI         .002       .001        -         .003       .005
AL         .130       .026      1.960       .205      1.999
CR         .036       .003       .074       .013       .024
FE2+       .049       .143       .523       .067       .521
MN         .001       .002       .020       .002       .017
MG         .887      1.886      2.152       .813      2.164
CA         .803       .006       .327       .733       .311
NA         .167       .003        -         .199       .005
K          .001        -          -          -          -

SUM       4.038      4.030      8.021      4.011      8.017

       WO 46.18   WO    .29  CA 10.91   WO 45.47   CA 10.39
       EN 50.99   EN  92.69  MG 71.68   EN 50.38   MG 72.22
       FS  2.83   FS   7.02  FE 17.42   FS  4.14   FE 17.39

       M: 94.74   M:  92.96  M: 80.45   M: 92.40   M: 80.59
       C: 47.52   C:    .31             C: 47.44

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

   ANALYSIS NO.    DESCRIPTION                      ANALYSIS NO.    DESCRIPTION
   ------------    -----------                      ------------    -----------
        1          PC58,CPX(2)                           4          PC34,CPX(5)
        2          PC58,OPX(3)                           5          PC34,GT(4)
        3          PC58,GT(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
$NaTi(AlSi)_2O_6$	0.10	0.10	0.10	0.39	0.29	0.30	0.20	0.19	0.29
$NaCrSi_2O_6$	2.28	2.19	1.38	3.55	1.85	2.37	2.19	3.47	1.27
$NaAlSi_2O_6$	3.17	3.98	2.08	8.09	9.75	7.98	2.78	12.34	19.21
$NaFe^{3+}Si_2O_6$	-	-	-	-	0.68	1.38	-	0.19	-
$CaAl(AlSi)_2O_6$	0.45	0.15	0.30	0.30	-	-	0.55	-	0.29
$Ca_2Si_2O_6$	43.55	43.55	45.06	41.17	40.01	41.10	44.15	38.72	35.77
$Mg_2Si_2O_6$	45.68	44.96	46.69	43.10	43.71	42.24	46.51	42.77	39.83
$(Fe,Mn)_2Si_2O_6$	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) Wood and Banno (1973)	(2) Wells (1977)	(3) Davis and Boyd (1960)	(4) Boyd and Nixon (1973)	(5) Akella and Boyd (1974)	(6) Ellis and Green (1979) (P=col.(8))	(7) Mysen (1976)	(8) Wood (1974) (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 BULK ROCK XRF ANALYSES OF TYPE I PYROXENITES

               1           2           3           4           5           6           7           8

SIO2       54.71       54.45       54.11       54.01       54.65       54.30       52.80       53.20
TIO2         .31         .31         .28         .28         .05         .05         .13         .23
AL2O3       1.87        1.80        1.41        1.35        1.45        1.44        4.20        4.26
CR2O3        .59         .58         .46         .46         .42         .43        1.11         .65
FEO         6.45        6.36        7.64        7.74        5.66        5.52        4.17        6.76
MNO          .16         .16         .18         .18         .19         .18         .13         .14
MGO        24.55       24.24       27.58       27.60       21.61       22.19       21.51       22.56
CAO        11.13       11.12        7.50        7.53       15.07       15.02       13.75       11.31
NA2O         .54         .55         .49         .51         .52         .50         .95         .84
K2O           -          .42         .18         .19         .25         .24         .06         .05
NIO          .06         .00         .11         .12         .09         .08         .07         .00
TOTAL     100.57       99.99       99.94       99.96       99.96       99.95       98.88      100.00

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

OXYGEN         6           6           6           6           6           6           6           6

SI         1.948       1.950       1.932       1.930       1.970       1.958       1.909       1.907
TI          .008        .008        .008        .008        .001        .001        .004        .006
AL          .078        .076        .059        .057        .062        .061        .179        .180
CR          .017        .016        .013        .013        .012        .012        .032        .018
FE2+        .192        .190        .228        .231        .171        .169        .126        .203
MN          .005        .005        .005        .005        .006        .005        .004        .004
MG         1.303       1.294       1.468       1.470       1.161       1.193       1.159       1.205
CA          .425        .427        .287        .288        .582        .580        .533        .434
NA          .037        .038        .034        .035        .036        .035        .067        .058
K             -         .019        .008        .008        .011        .011        .003        .002
NI          .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

        WO 22.12    WO 22.33    WO 14.47    WO 14.49    WO 30.42    WO 29.93    WO 29.30    WO 23.58
        EN 67.87    EN 67.70    EN 74.02    EN 73.68    EN 60.67    EN 61.49    EN 63.76    EN 65.42
        FS 10.01    FS  9.97    FS 11.51    FS 11.63    FS  8.92    FS  8.58    FS  6.94    FS 11.00

        M: 87.15    M: 87.17    M: 86.55    M: 86.40    M: 87.19    M: 87.75    M: 90.19    M: 85.61
        C: 24.58    C: 24.80    C: 16.35    C: 16.40    C: 33.39    C: 32.74    C: 31.49    C: 26.49

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

    ANALYSIS NO.      DESCRIPTION                          ANALYSIS NO.     DESCRIPTION
    ------------      -----------                          ------------     -----------
         1            PC 21-A                                   5            PC25A
         2            PC 21-B                                   6            PC25B
         3            PC22A                                     7            PC33A
         4            PC22B                                     8            PC 54-A
```

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

                1           2           3           4           5           6

SIO2        51.36       51.69       49.36       48.97       50.76       50.53
TIO2          .07         .06         .07         .07         .13         .13
AL2O3        2.33        2.36       11.25       11.60       10.20       10.20
CR2O3        1.08        1.09        1.11        1.13         .46         .47
FEO          7.31        7.29        5.53        5.60        4.70        4.82
MNO           .17         .17         .22         .22         .15         .16
MGO         25.90       25.64       22.95       23.11       17.94       18.15
CAO         10.98       10.94        8.29        8.09       13.54       13.42
NA2O          .55         .55        1.10        1.11        1.68        1.69
K2O           .07         .07         .08         .07         .25         .26
NIO           .14         .14         .04         .04         .05         .05
TOTAL       99.97      100.00      100.00      100.01       99.86       99.87

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

OXYGEN          6           6           6           6           6           6

SI          1.861       1.871       1.752       1.738       1.819       1.812
TI           .002        .002        .002        .002        .004        .004
AL           .100        .101        .471        .485        .431        .431
CR           .031        .031        .031        .032        .013        .013
FE2+         .222        .221        .164        .166        .141        .145
MN           .005        .005        .007        .007        .005        .005
MG          1.390       1.383       1.214       1.223        .958        .970
CA           .426        .424        .315        .308        .520        .516
NA           .039        .039        .076        .076        .117        .117
K            .003        .003        .004        .003        .011        .012
NI           .004        .004        .001        .001        .001        .001

SUM         4.092       4.083       4.035       4.041       4.020       4.026

         WO 20.83    WO 20.92    WO 18.62    WO 18.14    WO 32.12    WO 31.63
         EN 68.34    EN 68.20    EN 71.69    EN 72.06    EN 59.18    EN 59.50
         FS 10.82    FS 10.88    FS  9.69    FS  9.80    FS  8.70    FS  8.87

         M: 86.33    M: 86.24    M: 88.09    M: 88.03    M: 87.18    M: 87.03
         C: 23.36    C: 23.49    C: 20.62    C: 20.11    C: 35.19    C: 34.71

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

     ANALYSIS NO.     DESCRIPTION                          ANALYSIS NO.     DESCRIPTION
     ------------     -----------                          ------------     -----------
          1             PC55A                                    4             PC58B
          2             PC55B                                    5             PC34A
          3             PC58A                                    6             PC34B
```

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
$NaTi(AlSi)_2O_6$	0.8	0.8	0.1	0.4	0.6	0.2	0.2	0.4
$NaCrSi_2O_6$	1.7	1.3	1.2	3.1	1.8	2.8	3.1	1.3
$NaAlSi_2O_6$	1.3	2.1	3.5	3.7	3.5	0.9	4.4	11
$MgAl(AlSi)_2O_6$	2.8	1.45	1.4	6.7	6.8	4.1	20.7	15.4
$Ca_2Si_2O_6$	21.0	13.9	29.9	26.1	21.3	19.6	15.0	25.3
$(Fe,Mn)Si_2O_6$	9.7	11.3	3.9	6.4	10.2	10.4	8.3	7.2
$Mg_2Si_2O_6$	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_2O_3	8.37	10.41	8.63	8.63
Cr_2O_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_2O	0.87	1.24	0.88	1.10
K_2O	0.02	0.11	0.06	-
	99.79	99.28	99.78	98.84

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

(2) "Eclogite", Salt Lake Crater, Ohau, Hawaii (Grenn, 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
SiO2	52.2	52.1	50.3	50.3	50.3
TiO_2	0.50	0.44	0.47	0.96	0.55
Al_2O_3	6.39	6.84	9.54	9.78	10.8
Cr_2O_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_2O	0.51	0.85	1.43	1.57	1.88
K_2O	0.01	0.02	0.03	0.03	0.01
	99.9	100.1	99.7	100.1	100.3

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	88.55	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
SIO2	58.31	41.71	41.67	58.91	41.84	36.92	57.83	41.93
TIO2	.04	.08	.22	.02	.03	.50	.02	ND
AL2O3	.75	20.49	13.31	.70	21.39	11.60	.69	20.72
CR2O3	.32	4.69	.80	.31	4.26	.61	.30	4.90
FEO	3.64	5.70	2.46	3.99	6.49	6.51	4.51	6.09
MNO	.08	.26	.02	.08	.29	.26	.07	.32
MGO	35.63	21.20	25.09	36.95	21.76	21.83	35.77	21.66
CAO	.46	4.97	.02	.33	4.52	2.50	.60	4.97
NA2O	.11	ND	.08	.06	.02	.45	.08	ND
K2O	ND	ND	10.10	.02	ND	2.23	ND	ND
TOTAL	99.35	99.12	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	2.993	5.947	1.982	2.961	5.862	1.981	2.972
TI	.001	.004	.024	.001	.002	.060	.001	-
AL	.030	1.733	2.239	.028	1.784	2.171	.028	1.731
CR	.009	.266	.090	.008	.238	.077	.008	.275
FE2+	.104	.342	.294	.112	.384	.864	.129	.361
MN	.002	.016	.002	.002	.017	.035	.002	.019
MG	1.818	2.267	5.336	1.853	2.295	5.166	1.826	2.288
CA	.017	.382	.003	.012	.343	.425	.022	.377
NA	.007	-	.022	.004	.003	.139	.005	-
K	-	-	1.839	.001	-	.452	-	-
SUM	3.966	8.005	15.796	4.002	8.029	15.250	4.003	8.026
	WO .87 EN 93.75 FS 5.37	CA 12.77 MG 75.79 FE 11.44		WO .60 EN 93.72 FS 5.68	CA 11.34 MG 75.95 FE 12.71		WO 1.11 EN 92.35 FS 6.53	CA 12.47 MG 75.60 FE 11.93
	M: 94.58 C: .92	M: 86.69		M: 94.29 C: .64	M: 85.66		M: 93.39 C: 1.19	M: 86.37

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 24A,OPX(5)	5	PC 24B,GT(2)
2	PC 24A,GT(2)	6	PC24B,MICA(1)
3	PC24A,PHLOGOPITE(2)	7	PC 71,OPX(3)
4	PC24B,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

SIO2        58.30      41.74      54.89      58.14      54.63      40.97        .06
TIO2          .06        .18        .10        ND         .02        ND          ND
AL2O3         .70      21.27       2.24        .58       5.53      21.14      10.76
CR2O3         .31       4.29       1.68        .17       2.44       3.71      54.53
FE2O3          -          -          -          -          -          -        7.02
FEO          4.79       7.09       2.23       5.08       2.37       8.82      15.24
MNO           .11        .35        .12        .11        .10        .44        .83
MGO         35.43      20.34      17.53      35.74      14.91      19.73      11.41
CAO           .57       4.75      19.55        .24      18.61       4.14        .03
NA2O          .14        ND        1.74        .03       5.66        ND         .02
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 * *

OXYGEN         6         12          6          6          6         12          4

SI          1.988      2.980      1.977      1.989      1.972      2.974       .002
TI           .002       .010       .003        -         .001        -          -
AL           .028      1.790       .095       .023       .150      1.809       .415
CR           .008       .242       .048       .005       .070       .213      1.410
FE3+          -          -          -          -          -          -         .173
FE2+         .137       .423       .067       .145       .072       .535       .417
MN           .003       .021       .004       .003       .003       .027       .023
MG          1.801      2.164       .941      1.822       .802      2.134       .556
CA           .021       .363       .754       .009       .720       .322       .001
NA           .009        -         .121       .002       .256        -         .001
K             -          -         .001        -          -          -         .001

SUM         3.997      7.996      4.010      3.998      4.046      8.016      3.000

         WO  1.06   CA 12.31   WO 42.80   WO   .45   WO 45.17   CA 10.76   CR    .77
         EN 91.94   MG 73.34   EN 53.38   EN 92.20   EN 50.34   MG 71.34   MG    .57
         FS  6.99   FE 14.35   FS  3.81   FS  7.35   FS  4.49   FE 17.90   FE    .09

         M: 92.95   M: 83.64   M: 93.34   M: 92.61   M: 91.81   M: 79.94
         C:  1.14              C: 44.50   C:   .48   C: 47.30

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

      ANALYSIS NO.      DESCRIPTION                         ANALYSIS NO.      DESCRIPTION
      ------------      -----------                         ------------      -----------
           1            PC27,OPX(3)                              5            PC28,CPX(2)
           2            PC27,GT(2)                               6            PC28,GT(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	.04	.05	.06	.12	.06	.17	.13	.05
AL2O3	22.03	21.87	.87	2.63	1.45	4.27	3.69	1.14
CR2O3	3.15	3.21	.28	1.83	.33	1.39	1.53	.37
FEO	7.63	7.69	4.16	1.03	4.07	.78	1.02	4.30
MNO	.35	.32	.07	.05	.07	.05	.04	.06
MGO	20.06	20.02	36.52	16.37	36.23	14.49	15.13	35.88
CAO	4.79	5.02	.14	21.27	.25	21.07	21.33	.14
NA2O	ND	ND	ND	2.08	.04	2.33	2.34	.03
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	.002	.003	.002	.003	.002	.005	.003	.001
AL	1.863	1.851	.035	.112	.058	.183	.155	.046
CR	.179	.182	.008	.052	.009	.040	.043	.010
FE2+	.458	.462	.118	.031	.116	.024	.030	.123
MN	.021	.019	.002	.002	.002	.002	.001	.002
MG	2.145	2.143	1.851	.884	1.842	.786	.802	1.835
CA	.368	.386	.005	.825	.009	.821	.813	.005
NA	-	-	-	.146	.003	.160	.161	.002
K	-	-	-	-	-	-	-	-
SUM	8.008	8.015	4.000	4.022	4.004	3.995	3.994	3.998
	CA 12.39	CA 12.92	WO .26	WO 47.43	WO .46	WO 50.37	WO 49.41	WO .26
	MG 72.20	MG 71.64	EN 93.75	EN 50.77	EN 93.63	EN 48.18	EN 48.75	EN 93.45
	FE 15.41	FE 15.44	FS 5.99	FS 1.79	FS 5.90	FS 1.46	FS 1.84	FS 6.28
	M: 82.41	M: 82.27	M: 93.99	M: 96.59	M: 94.07	M: 97.07	M: 96.35	M: 93.70
			C: .27	C: 48.30	C: .49	C: 51.11	C: 50.34	C: .28

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC20A,GT 1	5	PC20A,OPX 5
2	PC20A,GT 2	6	PC20A,CPX 6
3	PC20A,OPX 3,NEXT TO GT 2	7	PC 20A,CPX 7
4	PC20A,CPX 4	8	PC20A,OPX 8

** ND = NOT DETECTED **

```
TABLE IV-9(CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE II PYROXENITES
                1            2            3            4

SIO2         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
FEO           4.22         4.27         4.13         1.13
MNO            .05          .05          .04          .06
MGO          35.96        36.10        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

SI           1.982        1.984        1.980        1.966
TI            .001         .001         .001         .004
AL            .039         .039         .039         .146
CR            .012         .011         .011         .051
FE2+          .120         .121         .118         .034
MN            .001         .001         .001         .002
MG           1.828        1.824        1.834         .846
CA            .006         .005         .007         .800
NA            .004         .003         .003         .163
K             .001          -            -            -

SUM          3.994        3.991        3.995        4.013
          WO    .30    WO    .24    WO    .37    WO 47.63
          EN  93.54    EN  93.55    EN  93.61    EN 50.37
          FS   6.16    FS   6.21    FS   6.01    FS  2.00

          M:  93.82    M:  93.78    M:  93.96    M: 96.18
          C:    .32    C:    .26    C:    .40    C: 48.61

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

     ANALYSIS NO.      DESCRIPTION                             ANALYSIS NO.     DESCRIPTION
     ------------      -----------                             ------------     -----------
          1            PC20B,OPX 1                                  3           PC20B,OPX 3,NEXT TO CPX LAMELLAE
          2            PC20B,OPX 2                                  4           PC20B,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
$NaTi(AlSi)_2O_6$	0.09	0.1	0.1	0.1	0.2	-	0.1
$NaCrSi_2O_6$	0.09	0.4	0.6	0.4	0.7	0.2	0.4
$MgCr(AlSi)_2O_6$	0.9	0.8	0.3	0.4	0.1	0.3	0.5
$MgAl(AlSi)_2O_6$	1.69	1.50	1.32	1.25	1.25	1.00	1.10
$Ca_2Si_2O_6$	0.20	0.3	0.9	0.6	1.05	0.45	1.10
$(Fe,Mn)Si_2O_6$	5.9	6.51	5.38	5.68	7.02	7.41	5.96
$Mg_2Si_2O_6$	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.

	Temperature °C (1 to 7)								Pressure Kb (8 to 10)		
	(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)		Wood(1974)		
							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	39
PC28	~925	~940	838	702	991	1112	1222	1191	38	32	24
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       .06       .06       .05       .06       .05       .06       .17       .17
AL2O3     3.42      3.43      3.73      2.13      1.97      1.95      3.09      3.13
CR2O3     1.09      1.08      1.11       .57       .52       .52       .82       .85
FEO       4.57      4.52      4.51      3.90      4.11      4.10      5.17      5.17
MNO        .10       .10       .10       .10       .09       .09       .14       .14
MGO      32.63     32.56     32.16     35.24     35.34     35.20     33.27     33.34
CAO       2.21      2.22      2.43       .97       .94       .96      1.96      1.98
NA2O       .54       .54       .55       .11       .18       .18       .17       .17
K2O        .19       .18       .17       .07       .10       .12       .24       .23
NIO        .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

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

OXYGEN      6         6         6         6         6         6         6         6

SI       1.910     1.913     1.909     1.946     1.943     1.945     1.905     1.902
TI        .002      .002      .001      .002      .001      .002      .004      .004
AL        .140      .140      .152      .086      .080      .079      .126      .128
CR        .030      .030      .030      .015      .014      .014      .022      .023
FE2+      .132      .131      .131      .112      .118      .120      .150      .150
MN        .003      .003      .003      .003      .003      .003      .004      .004
MG       1.683     1.678     1.660     1.798     1.807     1.801     1.720     1.723
CA        .082      .082      .090      .036      .035      .035      .073      .074
NA        .036      .036      .037      .007      .012      .012      .011      .011
K         .008      .008      .008      .003      .004      .005      .011      .010
NI        .000      .000      .000      .000      .000      .000      .000      .000

SUM      4.026     4.023     4.021     4.007     4.017     4.016     4.027     4.029

      WO  4.32  WO  4.35  WO  4.79  WO  1.83  WO  1.76  WO  1.80  WO  3.75  WO  3.78
      EN 88.71  EN 88.74  EN 88.26  EN 92.43  EN 92.22  EN 92.05  EN 88.53  EN 88.52
      FS  6.97  FS  6.91  FS  6.95  FS  5.74  FS  6.02  FS  6.15  FS  7.72  FS  7.70

      M: 92.71  M: 92.77  M: 92.70  M: 94.15  M: 93.87  M: 93.74  M: 91.98  M: 91.99
      C:  4.64  C:  4.67  C:  5.15  C:  1.94  C:  1.88  C:  1.92  C:  4.06  C:  4.09

                         * * * 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 20B-B                                 7           PC 27-A
        4           PC 24A-A                                 8           PC 27-B
```

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

              1            2            3            4

SIO2        56.29        56.15        56.28        55.03
TIO2          .06          .06          .02          .03
AL2O3        1.61         1.63         2.29         4.16
CR2O3         .77          .78          .67          .06
FEO          4.95         5.05         4.29         4.40
MNO           .12          .13          .09          .10
MGO         33.33        33.33        34.57        36.66
CAO          2.19         2.19          .95         1.98
NA2O          .36          .37          .08          .19
K2O           .20          .20           -            -
NIO           .10          .11          .00          .10
TOTAL       99.98       100.00        99.24       102.71

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

OXYGEN         6            6            6            6

SI          1.949        1.946        1.944        1.852
TI           .002         .002         .001         .001
AL           .066         .067         .093         .165
CR           .021         .021         .018         .002
FE2+         .143         .146         .124         .124
MN           .004         .004         .003         .003
MG          1.720        1.722        1.780        1.838
CA           .081         .081         .035         .071
NA           .024         .025         .005         .012
K            .009         .009          -            -
NI           .003         .003         .000         .003

SUM         4.022        4.025        4.003        4.071

        WO   4.18    WO   4.17    WO   1.81    WO   3.51
        EN  88.45    EN  88.32    EN  91.79    EN  90.40
        FS   7.37    FS   7.51    FS   6.39    FS   6.09

        M:  92.31    M:  92.16    M:  93.49    M:  93.69
        C:   4.51    C:   4.51    C:   1.94    C:   3.74

                    * * * 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           U95(CARSWELL,1973)
```

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

	PC20A	PC20B	PC24A	PC24B	PC27	PC28
$NaTi(AlSi)_2O_6$	0.2	0.2	0.2	0.2	0.4	0.4
$NaCrSi_2O_6$	2.9	2.9	0.8	1.4	1.7	2.1
$NaAlSi_2O_6$	1.2	1.3	--	0.1	-	1.1
$MgCr(AlSi)_2O_6$	-	-	0.7	-	0.5	-
$MgAl(AlSi)_2O_6$	6.1	6.4	3.8	3.8	5.7	2.6
$CaSi_2O_6$	3.9	4.2	1.8	1.7	3.6	4.0
$(Fe,Mn)Si_2O_6$	6.6	6.6	5.7	6.0	7.5	7.3
$Mg_2Si_2O_6$	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.

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

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

	1	2	3	4	5	6	7	* 8	9
SIO2	57.68	55.60	41.97	57.81	54.64	57.67	54.55	42.15	41.69
TIO2	.02	.07	.05	.14	.24	.02	.07	.04	.19
AL2O3	.78	2.86	22.56	.75	1.79	.83	4.70	22.55	14.90
CR2O3	.21	1.31	2.21	.27	1.09	.27	2.77	2.80	.82
FEO	4.76	1.49	8.40	5.07	2.64	4.42	2.42	7.35	2.72
MNO	.09	.05	.36	.10	.11	.10	.09	.39	.04
MGO	35.78	16.30	19.70	34.33	18.07	35.72	13.87	21.40	25.51
CAO	.21	21.55	4.79	.66	19.44	.26	17.02	3.77	ND
NA2O	ND	2.02	.07	.12	1.57	.14	4.36	.07	.64
K2O	ND	ND	ND	ND	.03	ND	ND	ND	8.93
TOTAL	99.55	101.26	100.12	99.26	99.63	99.44	99.86	100.53	95.45

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

OXYGEN	6	6	12	6	6	6	6	12	22
SI	1.982	1.979	2.990	1.996	1.978	1.982	1.971	2.975	5.818
TI	.001	.002	.003	.004	.007	.001	.002	.002	.020
AL	.032	.120	1.895	.031	.076	.034	.200	1.876	2.451
CR	.006	.037	.125	.007	.031	.007	.079	.156	.090
FE2+	.137	.044	.501	.146	.080	.127	.073	.434	.317
MN	.003	.002	.022	.003	.003	.003	.003	.023	.005
MG	1.832	.865	2.092	1.766	.975	1.829	.747	2.251	5.306
CA	.008	.827	.366	.024	.754	.010	.659	.285	-
NA	-	.139	.010	.008	.112	.009	.305	.010	.173
K	-	-	-	-	.001	-	-	-	1.590
SUM	4.000	4.010	8.003	3.986	4.018	4.002	4.040	8.012	15.773
	WO .39 EN 92.69 FS 6.92	WO 47.48 EN 49.95 FS 2.56	CA 12.36 MG 70.72 FF 16.92	WO 1.26 EN 91.18 FS 7.56	WO 41.69 EN 53.89 FS 4.42	WO .49 EN 93.05 FS 6.46	WO 44.55 EN 50.50 FS 4.94	CA 9.60 MG 75.79 FF 14.61	
	M: 93.05 C: .42	M: 95.12 C: 48.73	M: 80.69	M: 92.35 C: 1.36	M: 92.42 C: 43.61	M: 93.51 C: .52	M: 91.08 C: 46.87	M: 83.84	

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

ANALYSIS NO.	DESCRIPTION
1	PC29,OPX(3)
2	PC29,CPX(3)
3	PC29,GT(2)
4	PC30,OPX(4)
5	PC30,CPX(2)

ANALYSIS NO.	DESCRIPTION
6	PC31,OPX(5)
7	PC31,CPX(3)
8	PC31,GT(5)
9	PC31,MICA(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

SIO2        58.08       54.75       41.84       57.33       57.31       54.62         .19       45.01
TIO2          .02         .10          ND         .11         .11         .16        2.31         .06
AL2O3         .76        3.82       23.24         .51         .49        1.14        5.59        1.73
CR2O3         .22        2.14        2.19         .46        1.31        2.11       59.07         .10
FEO          4.37        2.05        7.41        5.42        6.18        2.55       20.14       17.10
MNO           .08         .06         .30         .13         .15         .12         .91         .07
MGO         36.83       14.91       21.97       35.07       34.02       17.86       12.33       20.52
CAO           .23       16.95        3.84         .66         .67       19.54          ND        1.49
NA2O          .09        5.46          ND         .12         .16        1.45           -         .05
K2O            ND          ND          ND          ND         .02         .05           -         .17
TOTAL      100.69      100.25      100.82       99.82      100.42       99.60      100.55       86.30

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

OXYGEN          6           6          12           6           6           6           4           9

SI          1.972       1.972       2.941       1.977       1.975       1.983        .006       2.894
TI           .001        .003           -        .003        .003        .004        .058        .003
AL           .030        .162       1.926        .021        .020        .049        .220        .131
CR           .006        .061        .122        .013        .036        .061       1.559        .005
FE2+         .124        .062        .436        .156        .178        .077        .562        .919
MN           .002        .002        .018        .004        .004        .004        .026        .004
MG          1.863        .800       2.302       1.802       1.747        .967        .614       1.966
CA           .008        .731        .289        .024        .025        .760           -        .103
NA           .006        .242           -        .008        .011        .102           -        .006
K               -           -           -           -        .001        .002           -        .014

SUM         4.013       4.035       8.036       4.008       4.000       4.010       3.046       6.045

        WO    .42   WO 45.90    CA  9.56   WO  1.23   WO  1.27   WO 42.14
        EN  93.36   EN 50.23    MG 76.05   EN 90.89   EN 89.60   EN 53.57
        FS   6.22   FS  3.88    FE 14.39   FS  7.88   FS  9.13   FS  4.29

        M:  93.76   M: 92.84    M: 84.09   M: 92.02   M: 90.75   M: 92.58
        C:    .45   C: 47.75               C:  1.34   C:  1.40   C: 44.03

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

     ANALYSIS NO.      DESCRIPTION                           ANALYSIS NO.      DESCRIPTION
     ------------      -----------                           ------------      -----------
          1            PC39,OPX(5)                                5            PC41,OPX CENTRE IN CHROMITE
          2            PC39,CPX(2)                                6            PC41,CPX(4)
          3            PC39,GT(2)                                 7            PC41,CHROMITES(2)
          4            PC41,OPX(4)                                8            PC41,SERPENTINITE(1)

** ND = NOT DETECTED **
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TABLE IV-14(CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE III PYROXENITES

                1           2           3

SIO2        55.84       53.50       39.60
TIO2          .05         .13         .67
AL2O3         .59        1.22       15.89
CR2O3         .50        2.01       12.30
FEO          5.72        2.68        8.10
MNO           .12         .09         .36
MGO         35.71       18.28       16.94
CAO           .61       19.37        6.67
NA2O          .13        1.52         .03
K2O           ND          .04         ND
TOTAL       99.28       98.84      100.57

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

OXYGEN          6           6          12

SI          1.945       1.963       2.951
TI           .001        .004        .038
AL           .024        .053       1.220
CR           .014        .058        .725
FE2+         .167        .082        .505
MN           .004        .003        .023
MG          1.853        .999       1.882
CA           .023        .761        .692
NA           .009        .108        .004
K             -          .002         -

SUM         4.040       4.033       8.041

         WO  1.11    WO 41.31    CA 22.49
         EN 90.73    EN 54.23    MG 61.11
         FS  8.16    FS  4.46    FE 16.40

         M: 91.75    M: 92.40    M: 78.84
         C:  1.21    C: 43.24

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

     ANALYSIS NO.     DESCRIPTION                    ANALYSIS NO.    DESCRIPTION
     ------------     -----------                    ------------    -----------
          1           PC50,OPX(5)                         3          PC50,GT(3)
          2           PC50,CPX(2)

** ND = NOT DETECTED **
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TABLE IV-15. Estimates of temperatures and pressure of equilibration for Type III pyroxenites.

	Temperature °C (1 to 7)							
	(1) Wood and Banno(1973)	(2) Davis and Boyd(1966)	(3) Boyd and Nixon(1973)	(4) Wells (1977)	(5) Mysen (1976)	(6) Akella and Boyd(1974)	(7) Ellis and Green(1979)	(8) Wood (1974) T(col.1)
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

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

	orthopyroxene	clinopyroxene	phlogopite	amphibole	% porphyroclasts
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 MICROPROBE ANALYSES 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	.76	.79	.06	ND	.06	.05	.02	.02	ND
AL2O3	15.19	14.73	2.21	1.76	1.24	1.29	1.06	1.10	1.12
CR2O3	.60	.50	.43	.19	.08	.10	.02	.04	.05
FEO	2.56	2.43	2.95	9.71	2.83	2.94	8.57	8.79	9.04
MNO	ND	ND	.12	.18	.12	.11	.16	.17	.16
MGO	26.50	26.15	16.14	31.45	16.99	17.02	32.17	31.89	32.11
CAO	ND	ND	24.65	.42	24.85	24.79	.43	.51	.40
NA2O	.19	.33	.62	ND	.35	.36	ND	ND	ND
K2O	10.19	10.52	ND	ND	ND	ND	ND	ND	ND
TOTAL	98.65	97.88	100.62	99.32	100.21	100.51	98.08	98.43	98.72

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

OXYGEN	22	22	6	6	6	6	6	6	6
SI	5.779	5.809	1.943	1.960	1.958	1.958	1.976	1.980	1.974
TI	.077	.081	.002	-	.002	.001	.001	.001	-
AL	2.427	2.377	.095	.073	.053	.055	.044	.046	.047
CR	.064	.054	.012	.005	.002	.003	.001	.001	.001
FE2+	.290	.278	.090	.286	.086	.089	.255	.260	.267
MN	-	-	.004	.005	.004	.003	.005	.005	.005
MG	5.352	5.334	.875	1.653	.924	.922	1.703	1.683	1.692
CA	-	-	.960	.016	.971	.966	.016	.019	.015
NA	.050	.088	.044	-	.025	.025	-	-	-
K	1.762	1.834	-	-	-	-	-	-	-
SUM	15.804	15.856	4.024	4.001	4.025	4.025	4.001	3.997	4.003
			WO 49.90	WO .81	WO 49.02	WO 48.84	WO .83	WO .99	WO .77
			EN 45.44	EN 84.54	EN 46.62	EN 46.64	EN 86.27	EN 85.75	EN 85.69
			FS 4.66	FS 14.65	FS 4.36	FS 4.52	FS 12.90	FS 13.26	FS 13.54
			M: 90.70	M: 85.23	M: 91.45	M: 91.16	M: 86.99	M: 86.60	M: 86.36
			C: 52.34	C: .95	C: 51.26	C: 51.15	C: .95	C: 1.14	C: .89

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC 23,PHLOGOPITE 2	6	PC23,CPX6,EDGE,NEXT TO OPX 8
2	PC 23,PHLOGOPITE 3	7	PC23,OPX8,EDGE
3	PC23,CPX4,ADJAC. TO OPX 4,5	8	PC23,OPX8,CENTRE
4	PC23,OPTIC. HOMOG. GRAIN	9	PC23,OPX10(RECRYST. GRAIN)
5	PC23,CPX6,CENTRE(WITH EXSOL.)		

** 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
SIO2	56.01	56.37	56.82	55.93	55.52	55.85	55.62	52.40	53.43	52.59
TIO2	.06	.07	.06	.02	.06	.05	.11	.21	.13	.24
AL2O3	2.59	2.48	2.51	2.42	2.47	2.45	2.53	3.77	3.22	3.79
CR2O3	.29	.30	.31	.30	.28	.30	.32	.65	.58	.66
FEO	7.65	7.82	7.92	6.97	7.60	7.67	7.19	3.75	5.56	3.80
MNO	.09	.11	.11	.07	.12	.11	.09	.07	.09	.08
MGO	32.89	33.14	33.24	34.46	32.91	33.41	31.81	14.85	22.85	15.01
CAO	.28	.26	.18	.33	.32	.31	2.16	23.07	12.13	23.06
NA2O	ND	ND	.02	ND	ND	ND	.06	1.20	.68	1.20
K2O	ND	ND	ND	ND	ND	.02	ND	ND	ND	.02
TOTAL	99.89	100.57	101.18	100.52	99.30	100.18	99.90	99.98	98.68	100.45

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

	1	2	3	4	5	6	7	8	9	10
OXYGEN	6	6	6	6	6	6	6	6	6	6
SI	1.944	1.945	1.948	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+	.222	.226	.227	.201	.222	.222	.210	.115	.168	.116
MN	.003	.003	.003	.002	.004	.003	.003	.002	.003	.002
MG	1.702	1.704	1.698	1.770	1.714	1.726	1.652	.811	1.232	.816
CA	.010	.010	.007	.012	.012	.012	.081	.906	.470	.901
NA	-	-	.001	-	-	-	.004	.085	.048	.085
K	-	-	-	-	-	.001	-	-	-	.001
SUM	3.999	3.999	3.996	4.020	4.004	4.010	4.004	4.026	4.011	4.027
WO	.54	.50	.34	.61	.62	.59	4.15	49.45	25.14	49.17
EN	87.98	87.87	87.90	89.25	87.98	88.07	85.06	44.27	65.87	44.51
FS	11.49	11.64	11.75	10.13	11.40	11.35	10.79	6.27	8.99	6.32
M:	88.45	88.31	88.21	89.81	88.53	88.59	88.74	87.59	87.99	87.56
C:	.61	.56	.39	.68	.69	.66	4.65	52.76	27.62	52.48

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION
1	PC26,OPX1A(OPTIC. HOMOG.)
2	PC26,OPX1B(OPTIC. HOMOG.)
3	PC26,OPX1C(OPTIC. HOMOG.)
4	PC 26,OPX 2
5	PC26,OPX 3 TRAVERSE,,A
6	PC26,DITTO,B
7	PC26,DITTO,C
8	PC 26,CPX 4 TRAVERSE,A
9	PC 26,CPX 4 TRAVERSE,B
10	PC 26,CPX 4 TRAVERSE,C

** ND = NOT DETECTED **

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TABLE IV-17(CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV  PYROXENTIES
            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      3.29        3.99        2.49        3.82       13.67       13.87
CR2O3       .57         .70         .30         .68        1.22        1.19
FEO        6.11        3.68        7.69        3.63        6.13        5.63
MNO         .03         .07         .09         .06         .04         .04
MGO       23.21       15.22       34.00       15.48       17.53       17.43
CAO       12.09       23.20         .49       23.05       12.32       12.40
NA2O        .54        1.28          ND        1.28        2.86        2.69
K2O          ND          ND          ND          ND        1.19        1.14
TOTAL     99.21      100.50      100.81      100.11       99.59       99.47

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

OXYGEN        6           6           6           6          23          23

SI        1.904       1.903       1.921       1.902       6.108       6.195
TI         .004        .005        .002        .005        .116        .113
AL         .140        .172        .101        .165       2.283       2.311
CR         .016        .020        .008        .020        .137        .133
FE2+       .185        .112        .222        .111        .726        .669
MN         .002        .002        .003        .002        .005        .005
MG        1.252        .829       1.748        .845       3.701       3.673
CA         .492        .907        .018        .905       1.870       1.879
NA         .038        .091          -         .091        .766        .737
K            -           -           -           -          .215        .206

SUM       4.039       4.041       4.024       4.046      16.006      15.941
       WO 25.59    WO 49.11    WO   .91    WO 48.61
       EN 64.91    EN 44.81    EN 87.93    EN 45.41
       FS  9.59    FS  6.08    FS 11.16    FS  5.98

       M: 87.13    M: 88.05    M: 88.74    M: 88.37
       C: 28.20    C: 52.29    C:  1.03    C: 51.70

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

     ANALYSIS NO.    DESCRIPTION                          ANALYSIS NO.    DESCRIPTION
     -----------     -----------                          -----------     -----------
          11         PC 26,CPX 4 TRAVERSE,D                    14         PC 26,CPX 7
          12         PC 26,CPX 5                               15         PC 26,AMPHIBOLE 8
          13         PC 26,OPX 6                               16         PC 26,AMPHIBOLE 9
** ND = NOT DETECTED **
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TABLE IV-17(CONTINUED)MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7	8	9	10
SIO2	55.35	55.51	55.31	54.19	52.50	55.44	55.50	54.76	54.93	55.11
TIO2	.02	.03	.06	.15	.29	.02	.06	.10	.05	.02
AL2O3	2.68	2.89	2.70	1.58	3.35	2.47	2.81	2.79	2.73	2.76
CR2O3	.12	.12	.13	.29	.24	.16	.17	.17	.14	.14
FEO	9.07	9.17	8.90	4.58	2.94	9.30	9.13	8.90	8.84	9.23
MNO	.13	.12	.11	.05	.06	.14	.12	.11	.14	.13
MGO	31.92	32.36	32.39	25.70	15.84	31.49	31.94	28.70	31.43	31.45
CAO	.20	.18	.20	10.40	23.20	.70	.63	2.18	.53	.56
NA2O	ND	ND	ND	.06	.76	.02	ND	.11	.02	.02
K2O	ND	ND	ND	.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 OXYGEN'S * *

	1	2	3	4	5	6	7	8	9	10
OXYGEN	6	6	6	6	6	6	6	6	6	6
SI	1.941	1.931	1.933	1.969	1.928	1.936	1.933	1.961	1.940	1.938
TI	.001	.001	.002	.004	.008	.001	.002	.003	.001	.001
AL	.111	.118	.111	.068	.145	.118	.115	.118	.114	.114
CR	.003	.003	.004	.008	.007	.005	.005	.005	.004	.004
FE2+	.266	.267	.260	.139	.090	.272	.266	.267	.261	.271
MN	.004	.004	.003	.002	.002	.004	.004	.003	.004	.004
MG	1.668	1.677	1.687	1.392	.867	1.659	1.658	1.532	1.654	1.648
CA	.008	.007	.007	.405	.913	.026	.024	.084	.020	.021
NA	-	-	-	.004	.054	.001	-	.008	.001	.001
K	-	-	-	.002	-	-	-	-	-	-
SUM	4.002	4.008	4.009	3.992	4.015	4.003	4.006	3.979	4.001	4.003
WO	.39	.34	.38	20.92	48.62	1.35	1.21	4.44	1.04	1.09
EN	85.91	85.98	86.31	71.89	46.56	84.62	85.14	81.39	85.47	84.93
FS	13.70	13.67	13.31	7.19	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,CPX LAMELLA	10	PC43,OPX4,TRAVERSE

** ND = NOT DETECTED **

TABLE IV-1/(CONTINUED)MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	11	12	13	14	15	16	17	18	19	20
SIO2	54.94	54.62	54.47	54.59	55.00	54.96	55.02	54.86	55.06	54.23
TIO2	.04	.05	.18	.05	.04	.03	.04	.04	.04	.04
AL2O3	2.76	2.69	2.70	2.75	2.76	2.72	2.72	2.61	2.65	2.63
CR2O3	.14	.13	.11	.15	.12	.14	.17	.13	.14	.14
FEO	9.30	8.93	9.33	8.73	9.43	9.21	9.41	8.68	9.20	8.81
MNO	.13	.12	.14	.12	.12	.12	.13	.12	.13	.13
MGO	31.52	30.68	31.53	30.40	31.29	31.69	31.36	30.97	31.64	30.81
CAO	.55	1.55	.50	2.11	.40	.67	.60	1.40	.34	2.98
NA2O	.02	.04	ND	.05	.02	ND	.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	99.85

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

	11	12	13	14	15	16	17	18	19	20
OXYGEN	6	6	6	6	6	6	6	6	6	6
SI	1.934	1.937	1.934	1.934	1.939	1.932	1.936	1.941	1.939	1.914
TI	.001	.001	.005	.001	.001	.001	.001	.001	.001	.001
AL	.115	.112	.112	.115	.115	.113	.113	.109	.110	.109
CR	.004	.004	.003	.004	.003	.004	.005	.004	.004	.004
FE2+	.274	.265	.274	.259	.278	.271	.277	.257	.271	.260
MN	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
MG	1.653	1.621	1.653	1.605	1.644	1.660	1.645	1.633	1.661	1.621
CA	.021	.059	.019	.080	.015	.025	.023	.053	.013	.113
NA	.001	.003	-	.003	.001	-	.001	.003	-	.005
K	-	-	-	-	-	-	-	-	-	-
SUM	4.007.	4.006	4.005	4.007	4.001	4.010	4.005	4.004	4.003	4.031
WO	1.06	3.03	.97	4.12	.78	1.29	1.16	2.73	.66	5.65
EN	84.88	83.36	84.93	82.57	84.87	84.87	84.59	84.05	85.40	81.30
FS	14.05	13.62	14.10	13.31	14.35	13.84	14.24	13.22	13.94	13.05
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

* * * SAMPLE DIRECTORY * * *

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

ANALYSIS NO.	DESCRIPTION
16	PC43,OPX4,TRAVERSE
17	PC43,OPX4,TRAVERSE
18	PC43,OPX4,CENTRE,DARK BAND
19	PC43,OPX4,CENTRE,LIGHT BAND
20	PC43,OPX4,CENTRE,DARK BAND

** ND = NOT DETECTED **

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TABLE IV-17(CONTINUED)MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES
             21         22         23         24         25         26         27         28         29         30

SIO2       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        .06        .07        .09        .08        .11        .10
AL2O3       2.52       2.64       2.43       2.70       2.70       2.78       2.74       2.69       2.67       2.67
CR2O3        .13        .13        .17        .13        .17        .12        .13        .12        .13        .15
FEO         9.12       9.14       8.63       9.08       9.10       9.13       9.25       9.17       8.88       8.24
MNO          .13        .12        .13        .13         -         .13        .14        .14        .13        .11
MGO        32.08      31.30      31.18      32.00      31.99      31.96      31.99      31.95      31.55      29.46
CAO          .33       3.07       2.12        .36        .51        .19        .34        .37        .83       3.44
NA2O          ND         ND        .06         ND         ND         ND         ND         ND         ND        .08
K2O           ND         ND         ND         ND         ND         ND         ND         ND         ND         ND
TOTAL      99.18     100.82     100.30     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

SI         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       .003       .004       .003       .004       .004
FE2+        .269       .268       .252       .262       .263       .265       .268       .265       .259       .242
MN          .004       .004       .004       .004        -         .004       .004       .004       .004       .003
MG         1.685      1.634      1.624      1.649      1.646      1.652      1.649      1.647      1.641      1.544
CA          .012       .115       .079       .013       .019       .007       .013       .014       .031       .130
NA            -          -        .004        -          -          -          -          -          -        .005
K             -          -          -          -          -          -          -          -          -          -

SUM        4.013      4.039      4.009      3.993      3.993      3.994      3.996      3.994      3.997      3.992
        WO   .63   WO  5.71   WO  4.06   WO   .69   WO   .98   WO   .37   WO   .65   WO   .71   WO  1.61   WO  6.77
        EN 85.69   EN 81.01   EN 83.04   EN 85.67   EN 85.39   EN 85.87   EN 85.48   EN 85.51   EN 84.97   EN 80.59
        FS 13.67   FS 13.28   FS 12.90   FS 13.64   FS 13.63   FS 13.77   FS 13.87   FS 13.77   FS 13.42   FS 12.65

        M: 86.24   M: 85.92   M: 86.56   M: 86.26   M: 86.23   M: 86.13   M: 86.04   M: 86.13   M: 86.36   M: 86.43
        C:   .73   C:  6.59   C:  4.66   C:   .80   C:  1.13   C:   .43   C:   .76   C:   .83   C:  1.86   C:  7.75

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

     ANALYSIS NO.     DESCRIPTION                                      ANALYSIS NO.     DESCRIPTION
     ------------     -----------                                      ------------     -----------
          21       PC43,OPX4,CENTRE,LIGHT BAND                              26       PC43,OPX3,TRAVERSE
          22       PC43,OPX4,DARK BAND                                      27       PC43,OPX3,TRAVERSE
          23       PC43,OPX4,EDGE,NEXT TO CPX                               28       PC43,OPX3,TRAVERSE
          24       PC43,OPX3,TRAVERSE                                       29       PC43,OPX3,TRAVERSE
          25       PC43,OPX3,TRAVERSE                                       30       PC43,OPX3,TRAVERSE

** ND = NOT DETECTED **
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TABLE IV-17(CONTINUED)MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	31	32	33	34	35	36	37	38	39	40
SIO2	56.04	56.07	55.65	55.35	53.04	53.07	53.30	52.85	52.77	54.48
TIO2	.08	.04	.09	.06	.22	.19	.15	.21	.22	.07
AL2O3	2.76	2.79	2.84	3.01	3.58	3.61	3.60	3.64	3.63	3.15
CR2O3	.13	.13	.14	.18	.05	.21	.22	.22	.25	.20
FEO	9.09	9.22	8.65	9.23	3.78	4.11	5.64	3.95	3.60	10.33
MNO	.14	.15	.13	.13	.09	.09	.11	.08	.08	.13
MGO	31.74	32.01	30.41	31.34	15.66	16.41	19.96	15.76	15.43	27.56
CAO	.43	.42	2.92	.17	23.52	22.16	16.28	23.38	23.80	4.39
NA2O	ND	ND	.07	ND	.72	.61	.53	.71	.76	.68
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.42	100.65	101.11	99.49	100.66	100.46	99.80	100.81	100.55	101.00

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

OXYGEN	6	6	6	6	6	6	6	6	6	6
SI	1.947	1.941	1.934	1.941	1.926	1.926	1.927	1.918	1.920	1.922
TI	.002	.001	.002	.002	.006	.005	.004	.006	.006	.002
AL	.113	.114	.116	.124	.153	.154	.153	.156	.156	.131
CR	.004	.004	.004	.005	.001	.006	.006	.006	.007	.006
FE2+	.264	.267	.257	.271	.115	.125	.171	.120	.110	.305
MN	.004	.004	.004	.004	.002	.002	.003	.002	.002	.004
MG	1.643	1.652	1.575	1.638	.847	.887	1.075	.852	.837	1.449
CA	.016	.016	.109	.006	.915	.862	.631	.909	.928	.166
NA	-	-	.005	-	.051	.043	.037	.050	.054	.047
K	-	-	-	-	-	-	-	-	-	-
SUM	3.994	4.000	4.006	3.993	4.017	4.011	4.008	4.020	4.020	4.031
WO	.83	.81	5.60	.33	48.74	45.98	33.61	48.32	49.51	8.64
EN	85.45	85.39	81.15	85.53	45.14	47.36	57.31	45.31	44.64	75.48
FS	13.72	13.80	13.25	14.14	6.11	6.66	9.09	6.37	5.85	15.88
M:	86.17	86.09	85.96	85.82	88.07	87.68	86.31	87.67	88.42	92.62
C:	.96	.93	6.46	.39	51.92	49.26	36.96	51.61	52.58	10.28

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

ANALYSIS NO.	DESCRIPTION
31	PC43,OPX3,TRAVERSE
32	PC43,OPX3,TRAVERSE
33	PC43,OPX3,TRAVERSE
34	PC43,OPX3,NEXT TO CPX
35	PC43,CPX5,TRAVERSE,ADJ. TO OPX

ANALYSIS NO.	DESCRIPTION
36	PC43,CPX5,TRAVERSE
37	PC43,CPX5,TRAVERSE
38	PC43,CPX5,TRAVERSE
39	PC43,CPX5,TRAVERSE
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
SIO2	52.39	54.05	52.46	53.01	55.12	55.20	55.19	52.24	52.79	52.64
TIO2	.22	.07	.21	.28	.05	.12	.08	.31	.33	.24
AL2O3	3.66	3.43	3.72	3.45	2.65	2.72	2.70	4.01	3.71	3.60
CR2O3	.22	.17	.25	.24	.14	.14	.13	.22	.24	.25
FEO	3.85	9.25	3.96	3.27	8.92	8.76	8.64	3.35	3.03	3.37
MNO	.08	.14	.07	.06	.15	.14	.14	.08	.08	.08
MGO	15.63	26.94	15.76	15.66	31.94	31.80	31.66	15.59	15.83	15.74
CAO	23.23	5.93	23.35	24.05	.14	.42	.75	23.32	23.45	23.31
NA2O	.76	.73	.75	.76	ND	.02	ND	.84	.49	.67
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.05	100.72	100.54	100.79	99.13	99.33	99.31	99.97	99.96	99.92

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

OXYGEN	6	6	6	6	6	6	6	6	6	6
SI	1.916	1.913	1.911	1.922	1.939	1.938	1.939	1.909	1.923	1.922
TI	.006	.002	.006	.008	.001	.003	.002	.009	.009	.007
AL	.158	.143	.160	.147	.110	.113	.112	.173	.159	.155
CR	.006	.005	.007	.007	.004	.004	.004	.006	.007	.007
FE2+	.118	.274	.121	.099	.262	.257	.254	.102	.092	.103
MN	.002	.004	.002	.002	.004	.004	.004	.002	.002	.002
MG	.852	1.421	.856	.846	1.675	1.664	1.658	.849	.859	.857
CA	.910	.225	.911	.934	.005	.016	.028	.913	.915	.912
NA	.054	.050	.053	.053	-	.001	-	.060	.035	.047
K	-	-	-	-	-	-	-	-	-	-
SUM	4.023	4.037	4.027	4.020	4.003	4.001	4.002	4.023	4.003	4.014
WO	48.42	11.71	48.28	49.71	.27	.82	1.46	48.97	49.03	48.73
EN	45.31	74.02	45.33	45.02	86.22	85.90	85.46	45.54	46.03	45.77
FS	6.26	14.26	6.39	5.28	13.51	13.28	13.09	5.49	4.94	5.50
M:	87.86	83.84	87.64	89.51	86.45	86.61	86.72	89.24	90.30	89.27
C:	51.66	13.66	51.58	52.48	.31	.94	1.67	51.82	51.58	51.57

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION
41	PC43,CPX5,TRAVERSE
42	PC43,CPX5,TRAVERSE
43	PC43,CENTRE SMALL INTERST. CPX6
44	PC43,CPX6,EDGE
45	PC43,OPX8

ANALYSIS NO.	DESCRIPTION
46	PC43,OPX9,EDGE
47	PC43,OPX9,CENTRE
48	PC43,SMALL CPX10
49	PC43,SMALL CPX11,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
SIO2	54.61	53.87	50.84	50.40	53.96	53.66	54.10	41.61	42.49	43.18
TIO2	.05	.04	.30	.31	.02	.04	.12	.59	ND	ND
AL2O3	3.06	3.97	4.96	4.77	3.61	3.92	.39	11.61	.77	1.28
CR2O3	.32	.35	.67	.72	.41	.40	1.31	.21	ND	.04
FEO	8.69	8.78	3.55	3.92	8.81	8.69	2.24	3.28	16.24	17.82
MNO	.13	.11	.05	.07	.12	.14	.07	.02	.15	.08
MGO	31.01	31.88	14.83	15.41	31.71	31.60	17.64	26.60	26.05	22.58
CAO	1.20	.46	23.29	22.41	.40	.77	22.93	ND	.98	1.59
NA2O	.02	ND	.56	.60	ND	.02	.18	.13	.18	.34
K2O	ND	ND	ND	ND	ND	ND	.03	10.62	.18	.37
TOTAL	99.76	99.44	99.06	98.62	99.06	99.25	99.06	94.87	87.64	87.99

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

OXYGEN	6	6	6	6	6	6	6	22	9	9
SI	1.915	1.894	1.879	1.873	1.905	1.893	1.984	5.931	2.718	2.773
TI	.001	.001	.008	.009	.001	.001	.003	.063	-	-
AI	.151	.165	.216	.209	.150	.163	.017	1.951	.058	.097
CR	.011	.010	.020	.021	.011	.011	.038	.024	-	.002
FE2+	.255	.258	.110	.122	.269	.256	.069	.391	.869	.957
MN	.004	.003	.002	.002	.004	.004	.002	.002	.008	.004
MG	1.620	1.669	.817	.853	1.668	1.661	.964	5.650	2.483	2.161
CA	.045	.017	.922	.892	.015	.029	.901	-	.067	.109
NA	.001	-	.040	.043	-	.001	.013	.036	.022	.042
K	-	-	-	-	-	-	.001	1.931	.015	.030
SUM	4.004	4.018	4.015	4.025	4.015	4.020	3.993	16.002	6.271	6.213
	WO 2.35 EN 84.40 FS 13.26	WO .69 EN 85.83 FS 13.28	WO 49.88 EN 44.18 FS 5.93	WO 47.78 EN 45.70 FS 6.52	WO .78 EN 85.84 FS 13.38	WO 1.50 EN 85.34 FS 13.17	WO 46.59 EN 49.85 FS 3.55			
	M: 86.42 C: 2.71	M: 86.60 C: 1.03	M: 88.16 C: 53.03	M: 87.51 C: 51.11	M: 86.51 C: .90	M: 86.63 C: 1.72	M: 93.35 C: 48.31			

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	PC53,OPX1,CENTRE	6	PC53,OPX5,CENTRE
2	PC53,OPX1,EDGE,ADJ. TO CPX4	7	PC57,CPX(3)
3	PC 53,CPX 3	8	PC57,PHLOGOPITE(4)
4	PC 53,CPX 4	9	PC57,SERPENTINITE
5	PC53,OPX5,EDGE	10	PC57,SERPENTINITE

** ND = NOT DETECTED **

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     TABLE IV-17(CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV  PYROXENITES
                 1            2            3            4            5            6            7

SIO2         54.07        40.59        56.06        54.86        55.38        54.53        40.34
TIO2            ND         1.08           ND           ND           ND           ND         1.26
AL2O3         3.34        13.24         3.14         2.92         3.13         2.78        13.67
CR2O3          .40          .48          .43          .40          .40          .36          .41
FEO           7.41         1.59         7.17         7.20         7.01         7.10         1.66
MNO            .13           ND          .13          .14          .13          .13          .02
MGO          34.12        26.55        35.04        34.74        34.47        34.26        26.27
CAO            .44           ND          .51          .36          .68          .13           ND
NA2O            ND          .53           ND           ND           ND           ND          .40
K2O             ND        10.34           ND           ND           ND           ND        12.26
TOTAL       100.21        94.61       102.80       100.90       101.51        99.59        96.67

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

OXYGEN           6           22            6            6            6            6           20

SI           1.882        5.760        1.897        1.893        1.898        1.903        5.162
TI               -         .115            -            -            -            -         .121
AL            .139        2.216         .125         .119         .126         .114        2.062
CR            .011         .054         .012         .011         .011         .010         .041
FE2+          .216         .149         .203         .208         .201         .207         .178
MN            .004            -         .004         .004         .004         .004         .002
MG           1.770        5.619        1.767        1.786        1.760        1.782        5.010
CA            .016            -         .018         .013         .025         .005            -
NA               -         .091            -            -            -            -         .099
K                -        1.873            -            -            -            -        2.001

SUM          4.044       15.969        4.035        4.043        4.034        4.035       14.716

          WO   .82              WO   .93  WO   .66  WO  1.26  WO   .24
          EN 88.41              EN 88.87  EN 88.99  EN 88.63  EN 89.36
          FS 10.77              FS 10.20  FS 10.35  FS 10.11  FS 10.39

          M: 89.14              M: 89.70  M: 89.58  M: 89.76  M: 89.58
          C:   .92              C:  1.04  C:   .74  C:  1.40  C:   .27

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

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

** ND = NOT DETECTED **
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TABLE IV-17(CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV PYROXENITES

	1	2	3	4	5	6	7	8	9
SIO2	57.01	55.74	57.58	56.34	54.52	51.28	54.67	54.46	52.28
TIO2	ND	ND	ND	ND	ND	ND	ND	ND	ND
AL2O3	1.10	1.19	1.19	1.10	3.00	3.52	2.87	2.87	3.19
CR2O3	.04	.04	.06	.04	.35	.55	.32	.34	.52
FEO	6.46	6.56	6.39	6.37	7.81	2.85	7.93	8.10	2.97
MNO	.05	.05	.04	.05	.15	.07	.15	.16	.08
MGO	35.03	34.83	34.83	34.47	34.11	16.65	33.93	33.76	17.22
CAO	.56	.51	.48	.52	.66	24.02	.50	.49	23.59
NA2O	.02	.03	.03	ND	ND	.49	ND	ND	.54
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.29	98.97	100.62	98.92	100.77	99.54	100.54	100.36	100.49

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

OXYGEN	6	6	6	6	6	6	6	6	6
SI	1.962	1.948	1.972	1.965	1.890	1.889	1.898	1.896	1.902
TI	-	-	-	-	-	-	-	-	-
AL	.045	.049	.048	.045	.123	.153	.117	.118	.137
CR	.001	.001	.002	.001	.010	.016	.009	.009	.015
FE2+	.186	.192	.183	.186	.226	.088	.230	.236	.090
MN	.001	.001	.001	.001	.004	.002	.004	.005	.002
MG	1.797	1.814	1.778	1.792	1.762	.913	1.756	1.752	.934
CA	.021	.019	.018	.019	.025	.947	.019	.018	.920
NA	.001	.002	.002	-	-	.035	-	-	.038
K	-	-	-	-	-	-	-	-	-
SUM	4.015	4.028	4.004	4.012	4.044	4.045	4.039	4.040	4.041
WO	1.03	.94	.89	.97	1.22	48.62	.93	.91	47.31
EN	89.69	89.59	89.86	89.72	87.54	46.88	87.58	87.33	48.04
FS	9.28	9.47	9.25	9.30	11.25	4.50	11.49	11.76	4.65
M:	90.62	90.44	90.67	90.60	88.61	91.24	88.41	88.13	91.18
C:	1.14	1.04	.98	1.07	1.37	50.91	1.05	1.03	49.62

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION
1	PC 65,OPX 1
2	PC 65,OPX 2
3	PC 65,OPX 3
4	PC 65,OPX 4
5	PC 66,OPX 1

ANALYSIS NO.	DESCRIPTION
6	PC 66,CPX 2
7	PC 66,OPX 3,ADJACENT TO CPX 2
8	PC 66,OPX 6,ADJACENT TO CPX 7
9	PC 66,CPX 7

** ND = NOT DETECTED **

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      TABLE IV-17(CONTINUED) MICROPROBE ANALYSES OF INDIVIDUAL MINERALS FROM TYPE IV  PYROXENITES
                  1             2             3             4             5

SIO2          54.40         52.49         52.51         55.83         54.45
TIO2            .03           .22           .21           .03           .06
AL2O3          2.13          2.69          2.85          2.18          2.13
CR2O3           .28           .63           .57           .33           .30
FEO           10.82          4.21          5.29         10.72         10.75
MNO             .17           .07           .10           .15           .17
MGO           32.55         16.56         18.13         32.55         32.29
CAO             .28         22.37         19.91           .37           .41
NA2O             ND           .81           .64            ND            ND
K2O              ND            ND            ND            ND            ND
TOTAL        100.69        100.38        100.34        102.39        100.77

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

OXYGEN            6             6             6             6             6

SI            1.912         1.917         1.914         1.924         1.911
TI             .001          .006          .006          .001          .002
AL             .089          .124          .122          .089          .088
CR             .008          .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          .045           -             -
K               -             -             -             -             -

SUM           4.040         4.035         4.034         4.027         4.040

         WO     .52   WO 45.94      WO 40.42      WO     .69    WO     .76
         EN   83.76   EN 47.31      EN 51.20      EN   83.82    EN   83.62
         FS   15.72   FS  6.75      FS  8.38      FS   15.49    FS   15.62

         M:   84.20   M: 87.51      M: 85.93      M:   84.40    M:   84.26
         C:     .62   C: 49.27      C: 44.12      C:     .81    C:     .90

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

         ANALYSIS NO.      DESCRIPTION                               ANALYSIS NO.     DESCRIPTION
         ------------      -----------                               ------------     -----------
              1            PC 68,OPX 1                                    4           PC 68,OPX 4
              2            PC68,CPX 2,EDGE                                5           PC 68,OPX 5
              3            PC68,CPX2,CENTRE

** ND = NOT DETECTED **
```

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_2O_3	12.26	13.14	11.71	10.87	11.10
Cr_2O_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_2O	3.29	2.48	4.31	3.64	3.79
K_2O	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 MICROPROVE ANALYSES OF INDIVIDUAL MINERALS FOM OLIVINE-BEARING PYROXENITE(TYPE V)

	1	2	3	4	5	6	7	8	9	10
SIO2	40.34	40.68	40.78	40.80	40.90	40.79	40.98	40.61	39.72	39.76
TIO2	.10	.09	.17	.09	.08	.08	.09	.08	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	.05	ND
FE2O3	-	-	-	-	-	-	-	-	-	-
FEO	12.91	12.21	13.02	13.26	12.46	13.27	13.14	13.01	13.66	13.49
MNO	.62	.67	.65	.62	.64	.63	.61	.69	.12	.12
MGO	15.34	15.38	15.51	15.56	15.31	15.59	15.81	15.52	45.77	45.93
CAO	6.21	6.10	6.23	6.14	6.30	6.18	6.02	6.06	.03	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
SI	2.973	2.991	2.975	2.972	2.993	2.969	2.972	2.977	.997	.998
TI	.006	.005	.009	.005	.004	.004	.005	.004	-	-
AL	1.828	1.854	1.835	1.841	1.822	1.835	1.853	1.828	-	-
CR	.194	.178	.180	.180	.205	.187	.170	.188	.001	-
FE3+	-	-	-	-	-	-	-	-	-	-
FE2+	.796	.751	.794	.808	.763	.808	.797	.798	.287	.283
MN	.039	.042	.040	.038	.040	.039	.037	.043	.003	.003
MG	1.685	1.685	1.686	1.689	1.670	1.691	1.709	1.696	1.713	1.717
CA	.490	.481	.487	.479	.494	.482	.468	.476	.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 MG 56.71 FE 26.78	CA 16.48 MG 57.78 FE 25.74	CA 16.41 MG 56.82 FE 26.77	CA 16.10 MG 56.76 FE 27.14	CA 16.88 MG 57.05 FE 26.06	CA 16.17 MG 56.73 FE 27.10	CA 15.73 MG 57.47 FE 26.80	CA 16.03 MG 57.11 FE 26.86	FO 85.65 FA 14.35	FO 85.85 FA 14.15
	M: 67.92	M: 69.18	M: 67.98	M: 67.65	M: 68.65	M: 67.67	M: 68.19	M: 68.01		

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

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

** ND = NOT DETECTED **

```
   TABLE IV-19 MICROPROVE ANALYSES OF INDIVIDUAL MINERALS  FOM 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         .02         .36
TIO2          ND         .03         .03         .02         .03         .04         .02         .06        1.27        1.18
AL2O3         ND          ND         .52         .51         .51        1.04         .52         .99       11.21       11.00
CR2O3        .02         .03         .16         .15         .15         .83         .24         .74       50.98       49.35
FE2O3          -           -           -           -           -           -           -           -        6.13        6.37
FEO        13.62       13.63        8.23        8.26        8.28        2.28        7.87        2.44       22.45       22.02
MNO          .12         .12         .16         .12         .14         .09         .15         .08         .70         .67
MGO        46.06       45.94       34.85       34.81       34.62       17.50       34.62       17.43        7.80        7.97
CAO          .06         .03         .22         .23         .22       23.64         .23       23.61         .02         .02
NA2O          ND          ND         .02          ND          ND         .87          ND         .76           -           -
K2O           ND          ND          ND          ND          ND          ND          ND          ND           -           -
TOTAL      99.84       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       1.964       1.962       1.968       1.962       1.986        .001        .012
TI             -        .001        .001        .001        .001        .001        .001        .002        .032        .030
AL             -           -        .021        .021        .021        .044        .021        .042        .440        .438
CR          .000        .001        .004        .004        .004        .024        .007        .021       1.342       1.317
FE3+           -           -           -           -           -           -           -           -        .154        .162
FE2+        .285        .285        .237        .237        .240        .069        .229        .073        .625        .621
MN          .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        .387        .401
CA          .002        .001        .008        .008        .008        .915        .009        .903        .001        .001
NA             -           -        .001           -           -        .061           -        .053           -           -
K              -           -           -           -           -           -           -           -           -           -

SUM        3.003       3.001       4.028       4.024       4.026       4.028       4.025       4.008       3.000       3.000

        FO 85.77    FO 85.73    WO   .40    WO   .42    WO   .40    WO 47.51    WO   .42    WO 47.45    CR   .75    CR   .75
        FA 14.23    FA 14.27    EN 87.95    EN 87.88    EN 87.81    EN 48.92    EN 88.31    EN 48.72    MG   .38    MG   .39
                                FS 11.65    FS 11.70    FS 11.79    FS  3.58    FS 11.27    FS  3.83    FE   .08    FE   .08

                                M: 88.30    M: 88.25    M: 88.17    M: 93.19    M: 88.69    M: 92.72
                                C:   .45    C:   .47    C:   .45    C: 49.27    C:   .48    C: 49.34

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

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

** ND = NOT DETECTED **
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TABLE IV-20. Visual estimates of modal proportions (vol.%) of minerals in peridotites.

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

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TABLE IV-21 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS IN PRIDOTITES
                1          2          3          4          5          6          7          8

SIO2        40.67      57.80      54.38      40.74      41.74      58.25      39.43      39.61
TIO2          -          ND         ND         .40        ND         ND         ND         ND
AL2O3         -          .65       2.56      22.00        ND         .74      13.39      14.14
CR2O3        .02         .22       1.82       2.45        ND         .27        .95       1.07
FEO         7.64        4.93       1.50       8.60       6.44       4.01       2.31       2.33
MNO          .07         .10        .05        .46        .06        .08        ND         .02
MGO        50.53       36.79      16.66      19.36      51.86      36.44      27.06      25.67
CAO           -          .19      21.25       4.83        ND         .18        ND         ND
NA2O          -          .07       2.00        -          ND         .08        .79        .77
K2O           -          ND         ND         -          ND         ND        8.48       9.02
NIO          .44         .00        .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

SI          .995      1.967      1.962      2.954      1.002      1.983      5.696      5.716
TI            -          -          -        .022        -          -          -          -
AL            -        .026       .109      1.880        -        .030      2.278      2.405
CR          .000       .006       .052       .140        -        .007       .108       .122
FE2+        .156       .140       .045       .522       .129       .114       .279       .281
MN          .001       .003       .002       .028       .001       .002        -         .002
MG         1.843      1.866       .896      2.092      1.855      1.849      5.825      5.521
CA            -        .007       .822       .375        -        .007        -          -
NA            -        .005       .140        -          -        .005       .221       .215
K             -          -          -          -          -          -       1.563      1.661
NI          .009       .000       .000       .000       .009       .003       .028       .030

SUM        3.005      4.020      4.028      8.014      2.998      4.001     16.002     15.957

        FO 92.18   WO   .34   WO 46.61   CA 12.56   FO 93.49   WO   .33
        FA  7.42   EN 92.69   EN 50.82   MG 70.00   FA  6.51   EN 93.87
                   FS  6.97   FS  2.57   FE 17.45              FS  5.80

                   M: 93.01   M: 95.19   M: 80.05              M: 94.18
                   C:   .37   C: 47.84                         C:   .35

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

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

** ND = NOT DETECTED **
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    TABLE IV-21 MICROPROBE ANALYSES OF INDIVIDUAL MINERALS IN PRIDOTITES
                 1          2          3          4          5          6

SIO2         58.16      41.62      41.59        .02      40.68      55.57
TIO2           ND         ND         ND         .03        ND         ND
AL2O3         .81         ND         ND       12.29        ND        2.43
CR2O3         .31        .02        .08       56.85        .03        .83
FE2O3          -          -          -         4.97         -          -
FEO          4.06       6.47       6.47       13.35       6.68       4.19
MNO           .09        .07        .08         .73        .08        .09
MGO         36.99      52.59      52.73       15.33      51.31      36.43
CAO           .22        ND         .02         .02        ND         .74
NA2O          .11         -          -           -         ND         ND
K2O            ND         -          -           -         ND         ND
NIO           .00        .00        .00         .00        .39        .00
TOTAL      100.77     100.80     100.99      101.59      99.22     100.31

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

OXYGEN          6          4          4          4          4          6

SI          1.971       .996       .994        .001       .993      1.904
TI             -          -          -         .001         -          -
AL           .032         -          -         .458         -         .098
CR           .008       .000       .002       1.421       .001       .022
FE3+           -          -          -         .118         -          -
FE2+         .115       .129       .129        .353       .136       .120
MN           .003       .001       .002        .020       .002       .003
MG          1.868      1.876      1.878        .628      1.866      1.860
CA           .008         -        .001        .001         -         .027
NA           .007         -          -           -          -          -
K              -          -          -           -          -          -
NI           .000       .000       .000        .000       .008       .000

SUM         4.013      3.004      3.005       3.000      3.007      4.036

       WO     .40   FO 93.54   FO 93.56   CR    .76   FO 93.19   WO  1.35
       EN   93.82   FA  6.46   FA  6.44   MG    .64   FA  6.81   EN 92.67
       FS    5.78                         FE    .06              FS  5.98

       M:   94.20                                                M: 93.94
       C:     .43                                                C:  1.44

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

    ANALYSIS NO.       DESCRIPITION                           ANALYSIS NO.     DESCRIPTION
    ------------       ------------                           ------------     -----------
         1             PC63,OPX(2)                                 4           PC63,CHROMITE(2)
         2             PC63,OLIVINE(2)                             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.

No. of inclusions	Sulphides	Peridotitic inclusions	Eclogitic inclusions	Graphite	Clouds	Ec/Ec+Per %
938	397	277	22	66	176	7

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

observed abundances				calculated proportions			
gt	cpx	colourless (opx+ol)	ratio (++) opx/ol	gt	cpx	opx	ol
47	5	222	10:12	17.2	1.8	36.8	44.2

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 (PERIDOTITIC SUITE) FROM KOFFIEFONTEIN (GROUP A)

	1	2	3	4	5	6	7	8
SIO2	42.40	42.60	41.80	42.30	43.50	42.30	42.50	42.30
TIO2	ND	.03	ND	.04	-	ND	.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	3.89	5.07	3.46	6.50
FEO	4.94	5.06	5.66	5.62	3.78	4.97	5.26	5.20
MNO	.26	.23	.26	.28	.19	.25	.21	.25
MGO	25.10	23.60	24.40	23.60	26.50	23.60	23.50	23.90
CAO	.59	2.67	.91	2.52	.56	2.20	2.46	1.84
NA2O	-	ND	ND	-	ND	-	-	-
K2O	-	-	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 * *

OXYGEN	12	12	12	12	12	12	12	12
SI	2.992	2.994	2.970	2.941	3.010	3.001	2.998	3.004
TI	-	.002	-	.002	-	-	.002	.002
AL	1.705	1.790	1.700	1.645	1.770	1.731	1.821	1.632
CR	.311	.226	.335	.366	.213	.284	.193	.365
FE2+	.292	.297	.336	.331	.219	.295	.310	.309
MN	.016	.014	.016	.017	.011	.015	.013	.015
MG	2.640	2.472	2.584	2.479	2.733	2.496	2.471	2.529
CA	.045	.201	.069	.190	.042	.167	.186	.140
NA	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-
SUM	8.000	7.997	8.013	8.011	7.990	7.990	7.993	7.996
	CA 1.50	CA 6.77	CA 2.32	CA 6.34	CA 1.39	CA 5.65	CA 6.27	CA 4.70
	MG 88.70	MG 83.22	MG 86.43	MG 82.62	MG 91.30	MG 84.37	MG 83.27	MG 84.93
	FE 9.80	FE 10.01	FE 11.25	FE 11.04	FE 7.31	FE 9.97	FE 10.46	FE 10.37
	M: 90.05	M: 89.26	M: 88.48	M: 88.21	M: 92.59	M: 89.43	M: 88.84	M: 89.12

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	GT K1	5	GT K12
2	GT K4	6	GT K45
3	GT K10	7	GT K47
4	GT K11	8	GT K48

** ND = NOT DETECTED **

TABLE V-28 GARNET DIAMOND INCLUSIONS (PERIDOTITIC SUITE) FROM KOFFIEFFONTEIN (GROUP B)

	1	2	3	4	5	6
SIO2	42.00	42.10	41.70	42.00	41.60	41.20
TIO2	ND	.03	.05	ND	.03	.05
AL2O3	20.80	20.30	21.10	20.70	20.50	17.50
CR2O3	5.16	4.52	3.84	4.56	4.63	8.74
FEO	5.65	5.72	6.96	5.36	6.27	5.44
MNO	.25	.18	.25	.21	.29	.31
MGO	22.00	22.50	20.50	21.70	20.60	20.80
CAO	3.85	3.74	5.23	4.60	5.19	5.09
NA2O	ND	.05	ND	.10	-	-
K2O	-	-	-	-	-	-
TOTAL	99.73	99.14	99.64	99.24	99.11	99.13

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

OXYGEN	12	12	12	12	12	12
SI	2.986	3.007	2.987	2.990	2.994	2.996
TI	-	.002	.003	-	.002	.003
AL	1.743	1.709	1.781	1.742	1.739	1.500
CR	.290	.255	.217	.257	.263	.502
FE2+	.336	.342	.417	.320	.377	.331
MN	.015	.011	.015	.013	.018	.019
MG	2.331	2.395	2.188	2.309	2.210	2.254
CA	.293	.286	.401	.352	.400	.397
NA	-	.007	-	.014	-	-
K	-	-	-	-	-	-
SUM	7.997	8.013	8.012	8.007	8.003	8.001
	CA 9.91 MG 78.74 FE 11.35	CA 9.47 MG 79.23 FE 11.30	CA 13.35 MG 72.78 FE 13.87	CA 11.81 MG 77.46 FE 10.74	CA 13.40 MG 73.97 FE 12.63	CA 13.30 MG 75.60 FE 11.10
	M: 87.40	M: 87.51	M: 84.00	M: 87.83	M: 85.41	M: 87.20

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

ANALYSIS NO.	DESCRIPTION
1	GT K2
2	GT K3
3	GT K5

ANALYSIS NO.	DESCRIPTION
4	GT K9
5	GT K44
6	GT K46

** ND = NOT DETECTED **

TABLE V-3 OLIVINE DIAMOND INCLUSIONS FROM KOFFIEFONTEIN

	1	2	3	4	5	6	7	8	9	10
SIO2	41.10	41.40	41.30	40.90	41.40	41.40	40.90	39.80	40.00	41.40
TIO2	ND	ND	-	-	-	-	-	ND	-	-
AL2O3	.04	.03	-	ND	-	-	.06	.06	.04	ND
CR2O3	.04	.05	.07	.08	.05	.06	.05	.10	ND	.05
FEO	5.40	6.53	7.18	7.60	4.70	6.42	7.10	7.76	7.95	7.15
MNO	.12	.07	.19	.20	.10	.14	.16	.08	.09	.16
MGO	52.80	51.90	51.00	50.50	52.80	52.40	51.30	50.00	48.70	51.30
CAO	.07	.03	.11	.13	.03	.03	.07	.16	.10	.04
NA2O	ND	-	.07	-	ND	ND	.06	-	ND	.06
K2O	-	-	-	-	-	-	-	-	-	-
TOTAL	99.59	100.02	99.92	99.42	99.09	100.46	99.70	97.97	96.90	100.17

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

OXYGEN	4	4	4	4	4	4	4	4	4	4
SI	.992	.999	1.001	.999	1.000	.995	.994	.988	1.003	1.000
TI	-	-	-	-	-	-	-	-	-	-
AL	.001	.001	-	-	-	-	.002	.002	.001	-
CR	.001	.001	.001	.002	.001	.001	.001	.002	-	.001
FE2+	.109	.132	.146	.155	.095	.129	.144	.161	.167	.144
MN	.002	.001	.004	.004	.002	.003	.003	.002	.002	.003
MG	1.899	1.866	1.842	1.837	1.901	1.876	1.858	1.850	1.820	1.847
CA	.002	.001	.003	.003	.001	.001	.002	.004	.003	.001
NA	-	-	.003	-	-	-	.003	-	-	.003
K	-	-	-	-	-	-	-	-	-	-
SUM	3.007	3.000	3.000	3.001	3.000	3.005	3.006	3.010	2.996	3.000
	FO 94.57 FA 5.43	FO 93.41 FA 6.59	FO 92.68 FA 7.32	FO 92.21 FA 7.79	FO 95.24 FA 4.76	FO 93.57 FA 6.43	FO 92.79 FA 7.21	FO 91.99 FA 8.01	FO 91.61 FA 8.39	FO 92.75 FA 7.25

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	OL K10	6	OL K24
2	OL K11	7	OL K25
3	OL K18	8	OL K26
4	OL K20	9	OL K27
5	OL K22	10	OL K31

** ND = NOT DETECTED **

```
      TABLE V-3 OLIVINE DIAMOND INCLUSIONS FROM KOFFIEFONTEIN

            11          12          13          14          15

SIO2      41.40       41.10       41.40       41.10       40.90
TIO2        -           ND          -           -           ND
AL2O3       -           ND         .03          ND          ND
CR2O3      .04         .06         .15         .05         .04
FEO       5.76        5.93        8.16        7.82        8.20
MNO        .05         .06          -          .09          -
MGO      52.20       51.80       50.60       50.70       50.40
CAO         ND         .03         .08         .12         .09
NA2O       .06          -           -           ND          ND
K2O         -           -           -           -           -
TOTAL    99.52       99.00      100.42       99.90       99.65

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

OXYGEN      4           4           4           4           4

SI       1.000        .999       1.002        .999        .998
TI          -           -           -           -           -
AL          -           -          .001         -           -
CR        .001        .001        .003        .001        .001
FE2+      .116        .121        .165        .159        .167
MN        .001        .001          -         .002          -
MG       1.879       1.877       1.824       1.836       1.833
CA          -         .001        .002        .003        .002
NA        .003          -           -           -           -
K           -           -           -           -           -

SUM      3.001       3.000       2.997       3.001       3.002

       FO 94.17    FO 93.96    FO 91.70    FO 92.03    FO 91.63
       FA  5.83    FA  6.04    FA  8.30    FA  7.97    FA  8.37

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

     ANALYSIS NO.      DESCRIPTION                         ANALYSIS NO.      DESCRIPTION
     ------------      -----------                         ------------      -----------
         11         OL K52                                     14         OL K256A
         12         OL K49                                     15         OL K258A
         13         OL K254A

** ND = NOT DETECTED **
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TABLE V-4  CLINOPYROXENE DIAMOND INCLUSIONS (PERIDOTITIC SUITE) FROM KOFFIEFONTEIN

                1            2            3            4            5

SIO2        55.00        54.70        55.10        54.30        54.80
TIO2          .07          .03          ND           ND           .03
AL2O3        2.14         1.55         1.37          .68          .72
CR2O3        3.66          .89          .75         2.44         2.34
FEO          1.75         2.40         2.69         1.91         2.28
MNO           .08          .09          .09          .08          .11
MGO         16.60        18.50        18.30        17.50        19.11
CAO         18.30        20.10        19.20        20.30        17.90
NA2O         2.35          .45         1.22          .33          .30
K2O           .04          .79          .31         1.57         1.69
TOTAL       99.99        99.50        99.04        99.12        99.27

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

OXYGEN          6            6            6            6            6

SI          1.983        1.985        2.003        1.992        1.996
TI           .002         .001          -            -           .001
AL           .091         .066         .059         .029         .031
CR           .104         .026         .022         .071         .067
FE2+         .053         .073         .082         .059         .069
MN           .002         .003         .003         .002         .003
MG           .892        1.000         .991         .957        1.037
CA           .707         .781         .748         .798         .699
NA           .164         .032         .086         .023         .021
K            .002         .037         .014         .073         .078

SUM         4.001        4.003        4.007        4.006        4.003

          WO 42.80     WO 42.13     WO 41.07     WO 44.01     WO 38.70
          EN 54.00     EN 53.94     EN 54.44     EN 52.76     EN 57.46
          FS  3.19     FS  3.93     FS  4.49     FS  3.23     FS  3.85

          M: 94.41     M: 93.21     M: 92.38     M: 94.23     M: 93.72
          C: 44.22     C: 43.86     C: 43.00     C: 45.47     C: 40.24

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

      ANALYSIS NO.    DESCRIPTION                          ANALYSIS NO.     DESCRIPTION
      -----------     -----------                          -----------      -----------
           1          CPX K13                                   4          CPX K18
           2          CPX K14                                   5          CPX K18-A2
           3          CPX K15

** ND = NOT DETECTED **
```

TABLE V-5 ORTHOPYROXENE DIAMOND INCLUSIONS FROM KOFFIEFONTEIN

	1	2	3	4	5	6	7	8	9	10
SIO2	57.90	58.00	59.30	59.80	58.10	58.80	59.00	57.60	57.30	57.30
TIO2	ND	ND	-	-	-	-	-	-	ND	ND
AL2O3	.59	.76	.60	.56	.90	.30	.73	.76	.74	.55
CR2O3	.21	.26	.28	.31	.18	.10	.41	.57	.39	.15
FEO	4.22	4.01	3.83	3.90	5.03	3.58	4.14	2.79	3.91	3.56
MNO	.11	.09	.12	.09	.10	.05	.10	.05	.08	.07
MGO	36.20	36.70	37.20	36.20	35.20	36.80	36.10	36.10	36.40	36.70
CAO	.56	.61	.27	.48	.76	.13	.48	.21	.58	.44
NA2O	ND	.06	ND	ND	.15	ND	.16	-	.06	.09
K2O	-	ND	ND	.03	.10	ND	.09	-	.04	-
TOTAL	99.81	100.51	101.62	101.38	100.52	99.78	101.21	98.08	99.51	98.87

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

	1	2	3	4	5	6	7	8	9	10
OXYGEN	6	6	6	6	6	6	6	6	6	6
SI	1.982	1.972	1.987	2.007	1.983	2.001	1.990	1.991	1.968	1.975
TI	-	-	-	-	-	-	-	-	-	-
AL	.024	.030	.024	.022	.036	.012	.029	.031	.030	.022
CR	.006	.007	.007	.008	.005	.003	.011	.016	.011	.004
FE2+	.121	.114	.107	.109	.144	.102	.117	.081	.112	.103
MN	.003	.003	.003	.003	.003	.001	.003	.001	.002	.002
MG	1.847	1.859	1.858	1.811	1.791	1.867	1.815	1.859	1.863	1.885
CA	.021	.022	.010	.017	.028	.005	.017	.008	.021	.016
NA	-	.004	-	-	.010	-	.010	-	.004	.006
K	-	-	-	.001	.004	-	.004	-	.002	-
SUM	4.003	4.012	3.998	3.979	4.003	3.992	3.997	3.986	4.014	4.014
WO	1.03	1.11	.49	.89	1.42	.24	.89	.40	1.07	.81
EN	92.89	93.17	94.07	93.46	91.26	94.60	93.12	95.46	93.31	94.07
FS	6.08	5.71	5.44	5.65	7.32	5.16	5.99	4.14	5.62	5.12
M:	93.86	94.22	94.54	94.30	92.59	94.82	93.95	95.84	94.31	94.84
C:	1.10	1.19	.52	.94	1.53	.25	.95	.42	1.13	.85

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

ANALYSIS NO.	DESCRIPTION
1	OPX K2
2	OPX K9
3	OPX K21
4	OPX K23
5	OPX K27

ANALYSIS NO.	DESCRIPTION
6	OPX K29
7	OPX K29
8	OPX K36
9	OPX K46
10	OPX K47

** ND = NOT DETECTED **

```
TABLE V-5 ORTHOPYROXENE DIAMOND INCLUSIONS FROM KOFFIEFONTEIN

              11            12

SIO2        57.70         57.10
TIO2          -             .03
AL2O3         .53          1.16
CR2O3         -             .36
FEO          3.86          3.33
MNO           .08           .11
MGO         37.00         36.90
CAO           .27           .12
NA2O          ND            -
K2O           -             -
TOTAL       99.45         99.11

                  * * ATOMIC PROPORTIONS BASED ON SELECTED NO. 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

        WO    .49     WO    .22
        EN  94.00     EN  94.97
        FS   5.50     FS   4.81

        M:  94.47     M:  95.18
        C:    .52     C:    .23

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

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

** ND = NOT DETECTED **
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TABLE V-6 CHROMITE DIAMOND INCLUSION FROM KOFFIEFONTEIN

            1

SIO2        .13
TIO2        .11
AL2O3      7.72
CR2O3     63.30
FE2O3      1.61
FEO       13.05
MNO         .72
MGO       12.80
CAO          -
NA2O         -
K2O          -
TOTAL     99.44

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

OXYGEN        4

SI         .004
TI         .003
AL         .299
CR        1.647
FE3+       .040
FE2+       .359
MN         .020
MG         .628
CA           -
NA           -
K            -

SUM       3.000
      CR    .85
      MG    .64
      FE    .02


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

    ANALYSIS NO.    DESCRIPTION                                    ANALYSIS NO.    DESCRIPTION
    ------------    -----------                                    ------------    -----------
         1        CHR K22-8A
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TABLE V-7 GARNET DIAMOND INCLUSIONS (ECLOGITIC SUITE) FROM KOFFIEFONTEIN

	1	2	3	4	5	6	7	8	9	10
SIO2	40.60	40.80	40.10	38.30	38.70	39.20	40.70	38.00	39.80	38.40
TIO2	.54	.53	.65	.10	.07	.07	.38	.13	.62	.60
AL2O3	22.00	22.10	22.00	22.00	22.40	22.40	22.40	21.60	21.10	21.10
CR2O3	.70	.84	.23	-	ND	-	.20	.04	.20	.11
FEO	14.50	13.30	14.40	22.70	24.00	21.30	16.20	22.90	22.00	22.30
MNO	.28	.28	.31	.63	.61	.38	.25	.42	.40	.41
MGO	15.10	15.20	13.50	7.29	9.63	10.60	15.40	7.36	11.90	10.60
CAO	5.83	6.21	8.29	7.68	4.13	5.45	4.05	8.00	3.26	4.35
NA2O	.07	.16	.14	.11	.08	.20	.18	.07	.17	.14
K2O	-	-	-	.04	-	-	-	-	-	.03
TOTAL	99.62	99.42	99.62	98.85	99.63	99.60	99.76	98.52	99.45	98.04

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

OXYGEN	12	12	12	12	12	12	12	12	12	12
SI	2.990	2.998	2.974	2.977	2.966	2.976	2.996	2.970	3.019	2.978
TI	.030	.029	.036	.006	.004	.004	.021	.008	.035	.035
AL	1.910	1.914	1.923	2.016	2.024	2.004	1.943	1.990	1.886	1.929
CR	.041	.049	.013	-	-	-	.012	.002	.012	.007
FE2+	.893	.817	.893	1.476	1.538	1.352	.997	1.497	1.396	1.446
MN	.017	.017	.019	.041	.040	.024	.016	.028	.026	.027
MG	1.658	1.665	1.492	.844	1.100	1.199	1.689	.857	1.345	1.225
CA	.460	.489	.659	.640	.339	.443	.319	.670	.265	.361
NA	.010	.023	.020	.017	.012	.029	.026	.011	.025	.021
K	-	-	-	.004	-	-	-	-	-	.003
SUM	8.009	8.002	8.031	8.020	8.023	8.033	8.019	8.032	8.009	8.032
CA	15.28	16.46	21.64	21.61	11.39	14.80	10.63	22.15	8.81	11.92
MG	55.05	56.03	49.02	28.53	36.94	40.04	56.20	28.35	44.75	40.39
FE	29.67	27.51	29.34	49.86	51.67	45.15	33.18	49.50	46.43	47.69
M:	64.98	67.07	62.56	36.40	41.69	47.00	62.88	36.42	49.08	45.86

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

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION.
1	GT K9	6	GT K19A1
2	GT K7	7	GT K37
3	GT K8	8	GT K37D
4	GT K16	9	GT K41A
5	GT K19A2	10	GT K42

** ND = NOT DETECTED **

```
    TABLE V-7 GARNET DIAMOND INCLUSIONS (ECLOGITIC SUITE) FROM KOFFIEFONTEIN
              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          .23         .38         .51         .61         .60         .22         .76         .50
AL2O3       22.70       22.80       21.80       22.30       22.50       23.10       22.30       21.10
CR2O3         .16         .08         .18         .07         .65          ND         .06         .74
FEO         16.50       15.10       21.30       19.80       17.10       15.30       15.50       13.50
MNO           .41         .29         .39         .29         .43         .23         .31         .33
MGO         15.90       16.60       11.80       10.10       14.80       15.60       10.30       16.20
CAO          3.31        2.89        3.99        6.70        4.05        4.57       11.00        7.05
NA2O          .08         .09         .14         .34         .07         .15         .16         .17
K2O            -           -           -           -           -           -           -           -
TOTAL       99.79       99.33       99.51       99.71      100.70      100.18      100.29      100.19

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

OXYGEN        12          12          12          12          12          12          12          12

SI          2.979       3.008       2.984       2.985       2.973       2.991       2.975       2.979
TI           .013        .021        .029        .035        .033        .012        .043        .028
AL          1.968       1.967       1.946       1.986       1.939       1.967       1.960       1.825
CR           .009        .005        .011        .004        .049         -          .004        .043
FE2+        1.015        .924       1.349       1.251       1.050        .930        .966        .828
MN           .026        .018        .025        .019        .027        .014        .020        .021
MG          1.743       1.810       1.332       1.137       1.619       1.696       1.144       1.771
CA           .261        .227        .324        .543        .319        .357        .879        .554
NA           .011        .013        .021        .050        .010        .021        .023        .024
K              -           -           -           -           -           -           -           -

SUM         8.025       7.992       8.019       8.010       8.009       8.013       8.013       8.072

         CA  8.64    CA  7.65    CA 10.78    CA 18.51    CA 10.66    CA 11.96    CA 29.39    CA 17.57
         MG 57.74    MG 61.14    MG 44.32    MG 38.80    MG 54.20    MG 56.79    MG 38.28    MG 56.16
         FE 33.62    FE 31.21    FE 44.90    FE 42.69    FE 35.14    FE 31.25    FE 32.33    FE 26.26

         M: 63.20    M: 66.20    M: 49.68    M: 47.62    M: 60.67    M: 64.50    M: 54.22    M: 68.14

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

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

** ND = NOT DETECTED **
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TABLE V-8 CLINOPYROXENE DIAMOND INCLUSIONS (ECLOGITIC SUITE) FROM KOFFIEFONTEIN

	1	2	3	4	5	6	7	8	9
SIO2	55.50	54.60	56.30	55.00	54.60	53.30	53.60	54.50	54.80
TIO2	.15	.41	.36	.42	.39	.35	.35	.29	.13
AL2O3	3.18	6.26	7.95	7.59	4.76	4.16	4.15	7.23	2.71
CR2O3	.10	.13	.21	.17	.29	.11	.05	.15	.25
FEO	4.05	7.90	5.45	6.36	8.52	14.00	12.90	7.00	5.03
MNO	-	.13	.08	.10	.19	.17	.18	.10	.09
MGO	15.20	14.10	13.30	13.00	15.50	14.80	12.80	12.90	15.90
CAO	20.00	12.20	12.90	12.10	12.50	10.00	13.20	12.30	18.90
NA2O	2.13	3.78	4.17	4.16	2.92	2.56	2.62	4.61	1.69
K2O	.07	.19	.16	.20	.23	.03	.05	.14	.04
TOTAL	100.38	99.70	100.88	99.10	99.65	99.48	99.90	99.22	99.54

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

OXYGEN	6	6	6	6	6	6	6	6	6
SI	1.999	1.978	1.989	1.986	1.984	1.977	1.987	1.978	1.995
TI	.004	.011	.010	.011	.011	.010	.010	.008	.004
AL	.135	.267	.331	.323	.204	.182	.181	.309	.116
CR	.003	.004	.006	.005	.008	.003	.001	.004	.007
FE2+	.122	.239	.161	.192	.253	.434	.400	.212	.153
MN	-	.004	.002	.003	.004	.005	.006	.003	.003
MG	.816	.761	.700	.700	.840	.818	.707	.698	.863
CA	.772	.474	.488	.468	.487	.397	.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	3.980	3.989	4.007	4.013	4.007	4.023	4.000
WO	45.14	32.12	36.18	34.43	30.82	24.09	32.14	34.45	42.06
EN	47.72	51.64	51.69	51.45	53.16	49.59	43.35	50.25	49.21
FS	7.14	16.24	11.93	14.12	16.01	26.32	24.51	15.30	8.74
M:	86.99	76.08	81.30	78.46	76.85	65.32	63.88	76.66	84.92
C:	48.61	38.35	41.08	40.09	36.70	32.70	42.58	40.67	46.08

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

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
1	CPX K8	6	CPX K41
2	CPX K10	7	CPX K42
3	CPX K17	8	CPX K43
4	CPX K37	9	CPX K56
5	CPX K39		

```
TABLE V-4 >OOD> DIAMOND INCLUSIONS FROM KOFFIEFONTEIN

                1            2            3            4

SIO2           .08          .09          .13          .03
TIO2            -            -            -            -
AL2O3          ND           .07          .07           -
CR2O3          .49          .52          .60           -
FEO          21.60        20.50        20.30        18.90
MNO            .15          .16          .17           -
MGO          77.30        76.60        76.90        76.00
CAO             -           .05          .03           -
NA2O           .29          .25          .20           -
K2O            ND           .06          ND            -
TOTAL        99.93        98.30        98.41        94.93

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

OXYGEN          4            4            4

SI            .002         .003         .004           -
TI              -            -            -            -
AL              -          .002         .002           -
CR            .012         .012         .014           -
FE2+          .537         .517         .510           -
MN            .004         .004         .004           -
MG           3.428        3.441        3.445           -
CA              -          .002         .001           -
NA            .017         .015         .012           -
K               -          .002          -             -

SUM          4.000        3.998        3.994         .000

        FO 86.44     FO 86.94     FO 87.10
        FA 13.56     FA 13.06     FA 12.90


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

     ANALYSIS NO.     DESCRIPTION                               ANALYSIS NO.     DESCRIPTION
     ------------     -----------                               ------------     -----------
          1           OOD K30                                         3          OOD K34
          2           OOD K35                                         4          PER K262-A

** ND = NOT DETECTED **
```

Table V-10.

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

	T°C		P Kb	
cpx-gt pairs	(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°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        .78        .81        .85        .90       1.05       1.08        .95       1.00        .75        .81
AL2O3     21.70      21.67      21.97      21.78      21.76      21.53      21.79      21.58      21.90      21.93
CR2O3      1.00       1.01        .90        .85        .78        .76        .71        .73       1.09       1.06
FEO        9.66       9.29       9.79       9.94      11.62      11.57      10.85      11.02       9.20       9.12
MNO         .18        .19        .19        .21        .25        .24        .29        .29        .26        .25
MGO       20.59      20.07      20.63      20.49      19.47      19.39      19.71      19.54      20.88      21.04
CAO        4.11       4.09       4.33       4.32       4.58       4.44       4.26       4.42       4.45       4.16
NA2O        .22        .23        .12        .11        .13        .13        .13        .12        .12        .13
K2O         .05        .11        .02        .02        .02        .02         ND         ND         ND         ND
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        2.991      3.003      2.983      2.996      2.973      2.982      2.987      2.989      2.992      2.980
TI         .042       .044       .045       .048       .056       .058       .051       .054       .040       .043
AL        1.826      1.839      1.837      1.822      1.827      1.818      1.839      1.824      1.826      1.836
CR         .056       .058       .050       .048       .044       .043       .040       .041       .061       .060
FE2+       .577       .559       .581       .590       .692       .693       .650       .661       .544       .542
MN         .011       .012       .011       .013       .015       .015       .018       .018       .016       .015
MG        2.191      2.154      2.181      2.167      2.067      2.070      2.103      2.088      2.201      2.227
CA         .314       .316       .329       .329       .350       .341       .327       .340       .337       .317
NA         .030       .032       .017       .015       .018       .018       .018       .017       .016       .018
K          .005       .010       .002       .002       .002       .002        -          -          -          -

SUM       8.043      8.026      8.037      8.030      8.045      8.039      8.032      8.033      8.033      8.038

       CA 10.20   CA 10.42   CA 10.65   CA 10.65   CA 11.24   CA 10.98   CA 10.61   CA 11.00   CA 10.94   CA 10.26
       MG 71.08   MG 71.11   MG 70.56   MG 70.23   MG 66.49   MG 66.69   MG 68.29   MG 67.61   MG 71.40   MG 72.18
       FE 18.71   FE 18.47   FE 18.79   FE 19.12   FE 22.27   FE 22.33   FE 21.10   FE 21.40   FE 17.66   FE 17.56

       M: 79.16   M: 79.38   M: 78.97   M: 78.60   M: 74.91   M: 74.91   M: 76.40   M: 75.96   M: 80.18   M: 80.43

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

     ANALYSIS NO.        DESCRIPTION                           ANALYSIS NO.        DESCRIPTION
     ------------        -----------                           ------------        -----------
          1           GT KF69(CENTRE)                               6           GT KF71(EDGE)
          2           GT KF69(EDGE)                                 7           GT KF72(CENTRE)
          3           GT KF70(CENTRE)                               8           GT KF72(EDGE)
          4           GT KF70(EDGE)                                 9           GT KF73(CENTRE)
          5           GT KF71(CENTRE)                              10           GT KF73(EDGE)

** ND = NOT DETECTED **
```

TABLE VI-1 ANALYSES OF GARNET MEGACRYSTS FROM KOFFIEFONTEIN

	11	12	13	14	15	16	17	18	19	20
SIO2	41.48	41.48	41.75	41.60	42.03	41.82	41.55	41.56	41.94	41.85
TIO2	1.04	1.03	.94	1.06	.80	.76	.94	.96	.94	.81
AL2O3	21.36	21.23	21.64	21.40	21.64	21.71	21.68	21.57	21.39	21.98
CR2O3	1.07	1.03	.60	.81	1.09	1.05	.78	.78	1.14	.97
FEO	10.39	10.38	11.03	11.11	9.62	9.43	10.18	10.39	8.80	9.82
MNO	.27	.25	.28	.27	.24	.24	.26	.26	.17	.21
MGO	19.65	19.65	19.51	19.42	20.28	20.34	20.23	19.90	21.07	20.72
CAO	4.51	4.42	4.40	4.38	4.30	4.23	4.16	4.22	4.30	4.27
NA2O	.10	.11	.14	.10	.11	.12	.11	.10	.21	.11
K2O	ND	ND	ND	ND	ND	ND	.02	ND	.04	ND
TOTAL	99.87	99.59	100.50	100.16	100.12	99.71	99.91	99.74	100.00	100.75

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

OXYGEN	12	12	12	12	12	12	12	12	12	12
SI	2.986	2.993	2.991	2.992	3.002	2.997	2.982	2.990	2.992	2.974
TI	.054	.056	.051	.057	.043	.041	.051	.052	.050	.043
AL	1.812	1.806	1.827	1.814	1.822	1.834	1.834	1.829	1.799	1.841
CR	.061	.059	.045	.046	.062	.059	.044	.044	.064	.054
FE2+	.625	.626	.661	.668	.575	.565	.611	.625	.525	.584
MN	.016	.015	.017	.016	.015	.015	.016	.016	.010	.013
MG	2.108	2.113	2.043	2.082	2.159	2.172	2.163	2.134	2.240	2.194
CA	.348	.342	.338	.338	.329	.325	.320	.325	.329	.325
NA	.014	.015	.019	.014	.015	.017	.015	.014	.029	.015
K	-	-	-	-	-	-	.002	-	.004	-
SUM	8.029	8.027	8.033	8.028	8.021	8.025	8.037	8.029	8.042	8.044
	CA 11.29 MG 68.43 FE 20.28	CA 11.09 MG 68.58 FE 20.33	CA 10.96 MG 67.59 FE 21.44	CA 10.93 MG 67.42 FE 21.65	CA 10.75 MG 70.49 FE 18.76	CA 10.61 MG 70.94 FE 18.46	CA 10.34 MG 69.92 FE 19.74	CA 10.55 MG 69.20 FE 20.25	CA 10.62 MG 72.41 FE 16.97	CA 10.48 MG 70.72 FE 18.81
	M: 77.13	M: 77.13	M: 75.92	M: 75.70	M: 78.98	M: 79.35	M: 77.98	M: 77.36	M: 81.01	M: 78.99

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION	ANALYSIS NO.	DESCRIPTION
11	GT KF74(CENTRE)	16	GT KF77(EDGE)
12	GT KF74(EDGE)	17	GT KF78(CENTRE)
13	GT KF75(CENTRE)	18	GT KF78(EDGE)
14	GT KF75(EDGE)	19	GT KF79
15	GT KF77(CENTRE)	20	GT KF80

** ND = NOT DETECTED **

TABLE VI-2 ANALYSES OF ORTHOPYROXENE MEGACRYSTS FROM KOFFIEFONTEIN

	1	2	3	4	5	6	7
SIO2	57.20	55.93	40.45	57.80	56.76	57.09	57.44
TIO2	.10	.10	1.84	.17	.14	.13	.13
AL2O3	.71	.71	12.64	.45	.52	.51	.50
CR2O3	.15	.15	.29	.23	.25	.31	.32
FEO	7.78	7.80	5.22	5.63	5.50	5.73	5.79
MNO	.13	.12	.02	.07	.09	.08	.10
MGO	34.09	34.27	23.81	35.42	35.14	34.99	35.13
CAO	.49	.47	ND	.53	.54	.75	.77
NA2O	.23	.23	.12	.19	.20	.26	.20
K2O	ND	ND	9.73	ND	ND	ND	.03
TOTAL	100.89	99.79	94.13	100.49	99.15	99.86	100.41

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

OXYGEN	6	6	20	6	6	6	6
SI	1.971	1.952	5.303	1.979	1.971	1.972	1.973
TI	.003	.003	.181	.004	.004	.003	.003
AL	.029	.029	1.953	.018	.021	.021	.020
CR	.004	.004	.030	.006	.007	.008	.009
FE2+	.224	.228	.572	.161	.160	.166	.166
MN	.004	.004	.002	.002	.003	.002	.003
MG	1.750	1.783	4.652	1.807	1.819	1.801	1.799
CA	.018	.018	-	.019	.020	.028	.028
NA	.015	.016	.031	.012	.013	.017	.013
K	-	-	1.627	-	-	-	.001
SUM	4.018	4.036	14.353	4.010	4.018	4.019	4.016
	WO .91 EN 87.84 FS 11.25	WO .67 EN 87.91 FS 11.23		WO .98 EN 90.91 FS 8.11	WO 1.01 EN 91.00 FS 7.99	WO 1.39 EN 90.31 FS 8.30	WO 1.42 EN 90.23 FS 8.35
	M: 88.65 C: 1.02	M: 88.67 C: .98		M: 91.81 C: 1.06	M: 91.93 C: 1.09	M: 91.58 C: 1.52	M: 91.53 C: 1.55

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION
1	PC 62(CENTRE)
2	PC 62(EDGE)
3	PC 62, MICA(?)
4	PC 70(CENTRE)
5	PC 70(EDGE)
6	PC 72(CENTRE)
7	PC 72(EDGE)

** ND = NOT DETECTED **

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TABLE VI-3 ANALYSES OF CLINOPYROXENE MEGACRYSTS FROM KOFFIEFONTEIN

                 1             2             3             4

SIO2         53.76         54.13         39.10         54.49
TIO2           .21           .22           .12           .28
AL2O3         2.68          2.55          1.01          1.63
CR2O3          .34           .34            ND           .33
FEO           5.42          5.46          7.43          5.52
MNO            .11           .10           .08           .11
MGO          21.76         21.54         35.65         19.82
CAO          13.00         12.97           .15         15.69
NA2O          1.93          1.91           .04           .91
K2O            .04           .03           .10           .87
TOTAL        99.25         99.25         83.69         99.65

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

OXYGEN           6             6             9             6

SI           1.945         1.956         2.516         1.979
TI            .006          .006          .006          .008
AL            .114          .109          .077          .070
CR            .010          .010            -           .009
FE2+          .164          .165          .400          .168
MN            .003          .003          .004          .003
MG           1.173         1.160         3.419         1.073
CA            .504          .502          .010          .611
NA            .135          .134          .005          .064
K             .002          .001          .008          .040

SUM          4.056         4.046         6.446         4.026

          WO 27.37      WO 27.48                    WO 32.99
          EN 63.72      EN 63.49                    EN 57.96
          FS  8.91      FS  9.03                    FS  9.06

          M: 87.74      M: 87.55                    M: 86.48
          C: 30.05      C: 30.21                    C: 36.27

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

      ANALYSIS NO.     DESCRIPTION                              ANALYSIS NO.     DESCRIPTION
      -----------      -----------                              -----------      -----------
           1         PC 56(CENTRE)                                   3         PC 56,ALTERATION 3,SERPENTINITE ????
           2         PC 56(EDGE)                                     4         PC 69(?)

** ND = NOT DETECTED **
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TABLE VII-1. Relative abundance of individual minerals from the Koffiefontein concentrate.

Size fraction (mm)	Garnet	Ortho-pyroxene	Clino-pyroxene	Opaques (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.

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TABLE VII-2 ANALYSES OF PURPLE GARNETS FROM THE KOFFIEFONTEIN CONCENTRATE.
              1          2          3          4          5          6          7          8          9         10

SIO2        42.53      41.70      36.56      36.93      37.83      42.17      41.44      41.62      42.26      42.06
TIO2          .06        .05        .05        .05        .07        .06        .10        .11        .06        .05
AL2O3       24.47      24.12      21.81      21.84      21.95      23.23      22.13      22.42      23.10      22.92
CR2O3         .36        .45        .11        .10        .17       1.86       2.81       2.57       1.88       1.84
FEO          7.39       8.68      35.85      34.46      32.51       8.24       9.18       8.77       6.92       8.23
MNO           .21        .19        .34        .66        .88        .35        .47        .45        .27        .34
MGO         21.15      20.53       4.36       5.37       5.84      20.39      19.12      19.59      20.77      19.99
CAO          4.06       4.05        .91        .52       1.47       4.61       4.91       5.04       5.17       5.00
NA2O          .03         ND        .05        .11        .04         ND        .03        .03         ND        .02
K2O            ND         ND        .02        .03        .03         ND         ND         ND         ND         ND
TOTAL      100.87      99.75     100.06     100.07     101.22     100.93     100.20     100.61     100.45     100.46

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

OXYGEN         12         12         12         12         12         12         12         12         12         12

SI          2.972      2.961      2.931      2.940      2.956      2.973      2.971      2.965      2.979      2.982
TI           .003       .003       .003       .003       .004       .003       .005       .006       .003       .003
AL          2.015      2.019      2.061      2.049      2.022      1.939      1.870      1.883      1.920      1.915
CR           .020       .025       .007       .006       .011       .104       .159       .145       .105       .103
FE2+         .432       .513      2.404      2.294      2.124       .486       .550       .523       .408       .488
MN           .012       .011       .023       .045       .058       .021       .029       .027       .016       .020
MG          2.202      2.173       .521       .637       .680      2.142      2.043      2.080      2.182      2.112
CA           .349       .309       .078       .044       .165       .348       .377       .385       .391       .380
NA           .004         -        .008       .017       .006         -        .004       .004         -        .003
K              -          -        .002       .003       .003         -          -          -          -          -

SUM         8.010      8.015      8.037      8.039      8.029      8.009      8.011      8.018      8.006      8.008

         CA 11.70   CA 10.29   CA  2.60   CA  1.49   CA  5.55   CA 11.70   CA 12.70   CA 12.88   CA 13.10   CA 12.75
         MG 73.83   MG 72.57   MG 17.35   MG 21.41   MG 22.90   MG 71.98   MG 68.77   MG 69.63   MG 73.21   MG 70.88
         FE 14.48   FE 17.14   FE 80.05   FE 77.10   FE 71.54   FE 16.32   FE 18.53   FE 17.49   FE 13.69   FE 16.38

         M: 83.61   M: 80.90   M: 17.81   M: 21.73   M: 24.25   M: 81.51   M: 78.78   M: 79.92   M: 84.25   M: 81.23

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

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

	11	12	13	14	15	16	17	18	19	20
SIO2	42.16	42.28	41.93	42.15	42.20	41.83	41.95	41.69	42.50	42.20
TIO2	.03	.03	.06	.05	.07	.13	.12	.13	.10	.05
AL2O3	23.09	23.04	22.76	23.12	22.63	21.41	21.33	20.34	22.24	23.11
CR2O3	1.79	1.96	2.28	2.08	2.65	3.92	4.02	5.30	2.96	1.80
FEO	6.99	6.39	8.75	7.74	6.61	6.90	6.90	6.81	5.98	7.35
MNO	.29	.27	.39	.34	.26	.36	.34	.39	.28	.29
MGO	20.70	21.00	20.05	20.79	20.99	20.95	20.76	20.39	22.02	20.50
CAO	5.12	5.26	4.61	4.70	5.11	4.90	4.91	5.48	4.53	4.99
NA2O	.02	ND	.02	ND	ND	.05	.04	.05	.09	.04
K2O	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.19	100.21	100.86	100.99	100.74	100.46	100.38	100.59	100.71	100.34

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

OXYGEN	12	12	12	12	12	12	12	12	12	12
SI	2.980	2.982	2.970	2.966	2.973	2.971	2.981	2.975	2.983	2.982
TI	.002	.002	.003	.003	.004	.007	.006	.007	.005	.003
AL	1.924	1.912	1.901	1.918	1.879	1.792	1.787	1.711	1.840	1.925
CR	.100	.109	.128	.116	.148	.220	.226	.299	.164	.101
FE2+	.413	.377	.518	.456	.401	.410	.410	.406	.351	.434
MN	.017	.016	.023	.020	.016	.022	.020	.024	.017	.017
MG	2.181	2.208	2.117	2.180	2.204	2.217	2.199	2.168	2.303	2.159
CA	.388	.398	.350	.354	.386	.373	.374	.419	.341	.378
NA	.003	-	.003	-	-	.007	.006	.007	.012	.005
K	-	-	-	-	-	-	-	-	-	-
SUM	8.008	8.006	8.014	8.015	8.011	8.020	8.009	8.017	8.017	8.006
CA	13.01	13.33	11.72	11.85	12.90	12.43	12.54	14.00	11.37	12.72
MG	73.14	74.03	70.91	72.92	73.69	73.91	73.72	72.43	76.90	72.66
FE	13.86	12.64	17.37	15.23	13.42	13.66	13.75	13.57	11.72	14.62
M:	84.07	85.41	80.33	82.72	84.60	84.40	84.28	84.22	86.78	83.25

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

ANALYSIS NO.	DESCRIPTION
11	GT KF53
12	GT KF54
13	GT KF55
14	GT KF56
15	GT KF57

ANALYSIS NO.	DESCRIPTION
16	GT KF58
17	GT KF59
18	GT KF60
19	GT KF61
20	GT KF62

** ND = NOT DETECTED **

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     TABLE VII-2 ANALYSES OF PURPLE GARNETS FROM THE KOFFIEFONTEIN CONCENTRATE.
               21          22          23          24          25          26

SIO2         41.84       41.44       41.54       41.78       41.41       41.32
TIO2           .05         .14         .08         .12         .06         .36
AL2O3        22.53       21.43       21.09       19.87       19.39       18.27
CR2O3         2.57        3.80        4.37        6.03        5.82        7.94
FEO           8.82        8.07        8.57        7.29        7.01        6.41
MNO            .45         .51         .54         .49         .41         .42
MGO          19.78       19.75       18.79       20.35       18.93       20.26
CAO           4.59        4.93        5.63        4.83        6.24        5.66
NA2O           .04         .09         .10         .10         .02         .05
K2O            ND          ND          .02         .02         ND          ND
TOTAL       100.68      100.17      100.73      100.88       99.21      100.70

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

OXYGEN        12          12          12          12          12          12

SI           2.974       2.969       2.977       2.982       3.010       2.970
TI            .003        .008        .004        .006        .003        .019
AL           1.887       1.810       1.782       1.671       1.654       1.548
CR            .144        .215        .248        .340        .335        .451
FE2+          .524        .484        .514        .435        .426        .385
MN            .027        .031        .033        .030        .025        .026
MG           2.095       2.109       2.007       2.164       2.051       2.171
CA            .350        .378        .432        .369        .486        .436
NA            .006        .013        .014        .014        .003        .007
K              -           -          .002        .002         -           -

SUM          8.011       8.017       8.012       8.014       7.994       8.014

          CA 11.77    CA 12.74    CA 14.64    CA 12.44    CA 16.40    CA 14.57
          MG 70.57    MG 70.98    MG 67.96    MG 72.90    MG 69.21    MG 72.55
          FE 17.66    FE 16.28    FE 17.40    FE 14.66    FE 14.38    FE 12.88

          M: 79.90    M: 81.35    M: 79.62    M: 83.26    M: 82.79    M: 84.92

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

        ANALYSIS NO.     DESCRIPTION                               ANALYSIS NO.     DESCRIPTION
        ------------     -----------                               ------------     -----------
             21       GT KF63                                           24       GT KF66
             22       GT KF64                                           25       GT KF67
             23       GT KF65                                           26       GT KF68
** ND = NOT DETECTED **
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TABLE VII-3 ANALYSES OF ORANGE GARNETS FROM THE KOFFIEFONTEIN CONCENTRATE.
             1          2          3          4          5          6          7          8          9          10

SIO2       41.47      41.23      41.10      41.28      41.82      42.02      41.41      41.68      41.36      40.29
TIO2         .12        .07        .14        .13        .15        .11        .12        .31        .13        .15
AL2O3      23.92      23.76      23.85      23.73      23.70      23.58      23.41      23.35      23.76      23.06
CR2O3        .08        .21        .16        .58        .42        .11        .38        .30        .20        .16
FEO        11.60      12.60      10.14      11.08       9.71       9.07      13.11      10.26       9.87      17.85
MNO          .25        .23        .23        .29        .27        .29        .35        .36        .28        .39
MGO        17.55      17.35      19.71      19.61      20.00      20.35      18.21      19.39      16.96      15.12
CAO         5.37       4.72       3.51       3.00       4.00       4.12       3.37       4.08       7.34       3.01
NA2O         .05        .08        .08        .11        .04        .08        .08        .08        .05        .08
K2O           ND         ND         ND        .05         ND         ND         ND         ND         ND         ND
TOTAL     100.42     100.26      98.93      99.66     100.12      99.74     100.45      99.78      99.96     100.12

                     * * ATOMIC PROPORTIONS BASED ON SELECTED NO. 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
TI          .006       .004       .009       .007       .008       .006       .006       .017       .007       .008
AL         2.021      2.018      2.024      2.007      1.986      1.977      1.984      1.970      2.014      2.003
CR          .005       .012       .009       .022       .024       .006       .022       .017       .011       .009
FE2+        .696       .759       .611       .665       .577       .540       .788       .614       .594      1.100
MN          .015       .014       .014       .018       .016       .017       .021       .022       .017       .024
MG         1.875      1.863      2.115      2.097      2.120      2.158      1.951      2.069      1.818      1.660
CA          .413       .364       .271       .231       .305       .314       .260       .313       .566       .238
NA          .007       .011       .011       .015       .006       .011       .011       .011       .007       .011
K             -          -          -        .005         -          -          -          -          -          -

SUM        8.012      8.017      8.023      8.027      8.016      8.019      8.020      8.015      8.009      8.023

        CA 13.83   CA 12.20   CA  9.04   CA  7.71   CA 10.15   CA 10.43   CA  8.66   CA 10.45   CA 19.00   CA  7.93
        MG 62.86   MG 62.38   MG 70.58   MG 70.07   MG 70.61   MG 71.65   MG 65.06   MG 69.05   MG 61.06   MG 55.38
        FE 23.31   FE 25.42   FE 20.38   FE 22.22   FE 19.24   FE 17.92   FE 26.28   FE 20.50   FE 19.94   FE 36.69

        M: 72.94   M: 71.05   M: 77.60   M: 75.93   M: 78.59   M: 79.99   M: 71.22   M: 77.10   M: 75.38   M: 60.15

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

    ANALYSIS NO.     DESCRIPTION                                      ANALYSIS NO.     DESCRIPTION
    ------------     -----------                                      ------------     -----------
         1          GT KF3                                                 6          GT KF9
         2          GT KF4                                                 7          GT KF10
         3          GT KF6                                                 8          GT KF11
         4          GT KF7                                                 9          GT KF12
         5          GT KF8                                                10          GT KF13
** ND = NOT DETECTED **
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TABLE VII-3 ANALYSES OF ORANGE GARNETS FROM THE KOFFIEFONTEIN CONCENTRATE.

	11	12	13	14	15	16	17	18
SIO2	40.96	41.26	41.38	41.76	41.62	41.32	41.09	41.47
TIO2	.12	.10	.41	.17	.16	.91	.88	.40
AL2O3	23.78	23.30	23.11	23.36	23.79	21.61	21.70	23.04
CR2O3	.10	.53	.26	.67	.11	.99	.84	1.11
FEO	12.30	12.97	11.83	10.14	11.21	9.39	10.33	8.10
MNO	.34	.38	.24	.35	.34	.22	.22	.27
MGO	18.25	18.08	19.05	19.48	18.60	20.44	19.93	20.82
CAO	3.94	3.53	3.36	4.03	3.97	4.34	4.11	4.18
NA2O	.04	.06	.12	.05	.05	.20	.11	.07
K2O	ND	ND	ND	ND	ND	.02	ND	.02
TOTAL	99.84	100.22	99.77	100.02	100.10	99.44	99.22	99.48

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

OXYGEN	12	12	12	12	12	12	12	12
SI	2.956	2.974	2.978	2.982	2.978	2.974	2.972	2.959
TI	.007	.005	.022	.009	.009	.049	.048	.021
AL	2.023	1.980	1.960	1.966	2.007	1.833	1.850	1.938
CR	.006	.030	.015	.038	.006	.056	.048	.063
FE2+	.742	.782	.712	.606	.671	.565	.625	.483
MN	.021	.023	.015	.021	.023	.013	.013	.016
MG	1.963	1.943	2.043	2.073	2.005	2.192	2.148	2.214
CA	.305	.273	.259	.308	.304	.335	.319	.320
NA	.006	.008	.017	.007	.007	.028	.015	.010
K	-	-	-	-	-	.002	-	.002
SUM	8.027	8.020	8.021	8.011	8.011	8.047	8.039	8.025
	CA 10.12 MG 65.21 FE 24.66	CA 9.10 MG 64.81 FE 26.09	CA 8.60 MG 67.78 FE 23.62	CA 10.32 MG 69.40 FE 20.27	CA 10.21 MG 67.27 FE 22.51	CA 10.82 MG 70.90 FE 18.28	CA 10.30 MG 69.49 FE 20.21	CA 10.59 MG 73.39 FE 16.02
	M: 72.56	M: 71.30	M: 74.16	M: 77.39	M: 74.93	M: 79.50	M: 77.47	M: 82.08

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

ANALYSIS NO.	DESCRIPTION
11	GT KF14
12	GT KF15
13	GT KF16
14	GT KF17

ANALYSIS NO.	DESCRIPTION
15	GT KF18
16	GT KF19
17	GT KF20
18	GT KF21

** ND = NOT DETECTED **

```
TABLE VII-4 ANALYSES OF RED GARNETS FROM THE KOFFIEFONTEIN CONCENTRATE.
                1          2          3          4          5          6          7          8          9         10

SIO2         41.87      41.85      41.05      41.07      41.04      41.80      41.66      40.89      41.28      40.99
TIO2           .91        .60        .92        .94        .98        .70        .68        .72        .85       1.03
AL2O3        21.34      21.64      21.49      21.49      21.65      21.69      21.78      21.53      21.66      21.35
CR2O3         1.10       1.07       1.29        .98        .73       1.85       1.62       2.00       1.07       1.12
FEO           9.49       8.52       9.70      10.16      10.13       8.81       8.77       8.59       9.04      10.19
MNO            .22        .19        .22        .24        .23        .29        .29        .27        .20        .22
MGO          20.64      20.79      20.16      20.00      20.01      19.97      20.16      19.99      20.90      19.99
CAO           4.37       4.26       4.37       4.47       4.26       5.00       5.03       5.00       4.22       4.40
NA2O           .10        .11        .14        .09        .20        .09        .09        .05        .08        .07
K2O             ND         ND        .04         ND         ND         ND         ND         ND         ND         ND
TOTAL       100.05      99.04      99.38      99.49      99.24     100.21     100.09      99.05      99.31      99.37

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

OXYGEN          12         12         12         12         12         12         12         12         12         12

SI           2.994      3.006      2.964      2.966      2.969      2.985      2.978      2.957      2.968      2.965
TI            .049       .032       .050       .053       .053       .038       .037       .039       .046       .056
AL           1.749      1.832      1.829      1.829      1.845      1.826      1.835      1.835      1.836      1.820
CR            .062       .061       .074       .056       .042       .104       .092       .114       .061       .064
FE2+          .569       .512       .586       .614       .613       .526       .524       .520       .544       .616
MN            .013       .012       .013       .015       .014       .018       .018       .017       .012       .013
MG           2.200      2.225      2.169      2.153      2.156      2.126      2.148      2.155      2.240      2.155
CA            .335       .328       .338       .346       .330       .383       .385       .387       .325       .341
NA            .014       .015       .020       .013       .028       .012       .012       .007       .011       .010
K               -          -        .004         -          -          -          -          -          -          -

SUM          8.034      8.024      8.046      8.045      8.050      8.019      8.029      8.033      8.044      8.042

          CA 10.79   CA 10.70   CA 10.93   CA 11.11   CA 10.65   CA 12.01   CA 12.60   CA 12.66   CA 10.46   CA 10.96
          MG 70.91   MG 72.61   MG 70.13   MG 69.17   MG 69.58   MG 70.05   MG 70.25   MG 70.37   MG 72.05   MG 69.24
          FE 18.30   FE 16.70   FE 18.94   FE 19.72   FE 19.77   FE 17.94   FE 17.15   FE 16.97   FE 17.49   FE 19.81

          M: 79.49   M: 81.30   M: 78.74   M: 77.82   M: 77.89   M: 80.16   M: 80.38   M: 80.57   M: 80.47   M: 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 KF22                                              6        GT KF27
          2        GT KF23                                              7        GT KF28
          3        GT KF24                                              8        GT KF29
          4        GT KF25                                              9        GT KF30
          5        GT KF26                                             10        GT KF31

** ND = NOT DETECTED **
```

TABLE VII-5 ANALYSES OF REDDISH-BROWN GARNETS FROM THE KOFFIEFONTEIN CONCENTRATE

	1	2	3	4	5	6	7	8	9
SIO2	41.55	41.19	41.78	41.64	41.36	41.90	41.68	41.53	40.99
TIO2	.41	.33	1.12	.78	.97	.78	.08	.97	1.20
AL2O3	21.73	22.29	21.57	21.69	21.24	21.60	22.53	21.13	21.01
CR2O3	.59	.59	.96	1.73	1.01	1.05	1.93	1.17	.70
FEO	11.43	11.91	10.49	7.74	9.75	6.50	8.30	10.06	11.85
MNO	.29	.35	.28	.29	.26	.22	.36	.28	.31
MGO	19.38	18.28	20.11	20.32	19.96	20.87	20.25	20.18	18.65
CAO	4.30	4.48	4.53	4.83	4.51	4.19	4.06	4.35	4.39
NA2O	.02	.09	.13	.08	.09	.08	.03	.11	.13
K2O	ND	ND	.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 NO. OF OXYGENS * *

OXYGEN	12	12	12	12	12	12	12	12	12
SI	3.001	2.969	2.976	2.990	2.990	3.004	2.988	2.988	2.989
TI	.022	.018	.060	.042	.053	.042	.004	.052	.066
AL	1.850	1.906	1.811	1.836	1.810	1.825	1.903	1.792	1.806
CR	.034	.034	.054	.098	.058	.060	.109	.067	.040
FE2+	.690	.723	.625	.465	.590	.510	.498	.605	.723
MN	.018	.022	.017	.018	.016	.013	.022	.017	.019
MG	2.086	1.977	2.134	2.175	2.151	2.230	2.163	2.164	2.027
CA	.333	.348	.346	.372	.349	.322	.312	.335	.343
NA	.003	.013	.018	.011	.013	.011	.004	.015	.018
K	-	-	.002	-	-	-	-	-	-
SUM	8.037	8.030	8.042	8.007	8.030	8.018	8.004	8.038	8.032
	CA 10.70 MG 67.09 FE 22.21	CA 11.43 MG 64.86 FE 23.71	CA 11.13 MG 68.74 FE 20.12	CA 12.34 MG 72.22 FE 15.44	CA 11.31 MG 69.61 FE 19.08	CA 10.51 MG 72.84 FE 16.65	CA 10.49 MG 72.77 FE 16.74	CA 10.80 MG 69.70 FE 19.50	CA 11.09 MG 65.54 FE 23.37
	M: 75.13	M: 73.23	M: 77.36	M: 82.39	M: 78.49	M: 81.40	M: 81.30	M: 78.14	M: 73.72

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPTION
1	GT KF32
2	GT KF33
3	GT KF34
4	GT KF35
5	GT KF36

ANALYSIS NO.	DESCRIPTION
6	GT KF37
7	GT KF38
8	GT KF39
9	GT KF40

** ND = NOT DETECTED **

```
TABLE VII-6A ANALYSES OF GREEN ORTHOPYROXENES (GLASSY) FROM THE KOFFIEFONTEIN CONCENTRATE

            1          2          3          4          5          6          7          8          9

SIO2      57.97      58.08      55.95      57.43      56.77      57.55      57.64      56.77      56.74
TIO2        .12        .06        .04        .09        .05        .15        .11        .09        .11
AL2O3       .30        .53       2.83        .74       2.01        .71        .77        .75        .76
CR2O3       .38        .32        .69        .29        .64        .29        .34        .33        .32
FEO        3.98       3.61       4.23       5.10       4.44       5.36       5.49       5.51       5.49
MNO         .11        .09        .10        .12        .12        .13        .12        .12        .12
MGO       37.34      37.52      35.32      35.24      34.51      35.19      34.79      35.12      35.09
CAO         .46        .28        .97        .66       1.29        .67        .83        .84        .85
NA2O        .12        .09        .02        .10        .18        .15        .19        .13        .15
K2O          ND         ND         ND         ND         ND         ND        .02         ND         ND
TOTAL    100.79     100.59     100.36      99.78     100.02     100.21     100.30      99.67      99.60

                 * * 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      1.976      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
FE2+       .113       .102       .121       .147       .128       .154       .158       .159       .159
MN         .003       .003       .003       .003       .003       .004       .003       .004       .004
MG        1.839      1.896      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       .013       .009       .010
K           -          -          -          -          -          -         .001        -          -

SUM       4.023      4.018      4.016      4.006      4.006      4.008      4.006      4.019      4.019

       WO    .83  WO    .51  WO   1.82  WO   1.23  WO   2.45  WO   1.25  WO   1.55  WO   1.56  WO   1.58
       EN  93.57  EN  94.40  EN  92.00  EN  91.35  EN  90.99  EN  90.98  EN  90.44  EN  90.48  EN  90.48
       FS   5.60  FS   5.10  FS   6.18  FS   7.42  FS   6.57  FS   7.78  FS   8.01  FS   7.97  FS   7.94

       M:  94.36  M:  94.88  M:  93.70  M:  92.49  M:  93.27  M:  92.13  M:  91.86  M:  91.91  M:  91.93
       C:    .88  C:    .53  C:   1.94  C:   1.33  C:   2.62  C:   1.35  C:   1.69  C:   1.69  C:   1.71

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

     ANALYSIS NO.      DESCRIPTION                             ANALYSIS NO.      DESCRIPTION
     ------------      -----------                             ------------      -----------
          1            OPX KF3                                      6            OPX KF8
          2            OPX KF4                                      7            OPX KF9
          3            OPX KF5                                      8            OPX KF10
          4            OPX KF6                                      9            OPX KF11
          5            OPX KF7

** ND = NOT DETECTED **
```

TABLE VII-6B ANALYSES OF GREEN ORTHOPYROXENES (WITH CLEAVAGE) FROM THE KOFFIEFONTEIN CONCENTRATE

	1	2	3	4	5	6	7	8	9
SIO2	56.39	56.23	56.24	57.67	57.49	58.14	57.60	57.37	57.67
TIO2	.04	.03	.04	.05	.08	.07	.05	.09	.04
AL2O3	5.25	3.07	3.53	.80	.52	.26	.75	.37	.69
CR2O3	.75	.85	.87	.37	.36	.29	.40	.26	.40
FEO	4.40	4.56	4.30	3.81	4.36	3.77	3.82	4.75	3.43
MNO	.11	.13	.11	.09	.11	.12	.11	.11	.08
MGO	34.82	34.65	34.78	36.99	36.53	37.24	36.13	36.21	37.18
CAO	1.04	.82	.89	.23	.43	.32	.30	.37	.26
NA2O	.07	.06	.04	.07	.12	.15	.16	.10	.10
K2O	ND	.06	ND	ND	ND	ND	ND	ND	ND
TOTAL	100.90	100.46	100.61	100.09	100.01	100.37	99.33	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
FE2+	.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	.008	.016	.012	.011	.014	.010
NA	.005	.004	.003	.005	.008	.010	.011	.007	.007
K	-	.003	-	-	-	-	-	-	-
SUM	4.008	4.007	4.004	4.014	4.018	4.017	4.005	4.016	4.015
WO	1.97	1.56	1.69	.42	.79	.58	.56	.68	.48
EN	91.54	91.67	91.93	94.14	92.99	94.07	93.87	92.51	94.63
FS	6.49	6.77	6.38	5.44	6.23	5.34	5.57	6.81	4.90
M:	93.39	93.12	93.51	94.54	93.72	94.62	94.40	93.14	95.08
C:	2.10	1.67	1.81	.45	.84	.61	.59	.73	.50

* * * SAMPLE DIRECTORY * * *

ANALYSIS NO.	DESCRIPITON
1	OPX KF23
2	OPX KF24
3	OPX KF25
4	OPX KF26
5	OPX KF27

ANALYSIS NO.	DESCRIPTION
6	OPX KF28
7	OPX KF30
8	OPX KF31
9	OPX KF32

** ND = NOT DETECTED **

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TABLE VII-6C ANALYSES OF BROWN ORTHOPYROXENES (GLASSY) FROM THE KOFFIFFONTEIN CONCENTRATE
              1          2          3          4          5          6          7          8          9         10

SIO2        57.09      57.22      56.60      57.34      56.85      56.79      56.24      56.51      56.86      55.77
TIO2          .09        .13        .14        .11        .26        .24        ND         .23        .25        .23
AL2O3         .75        .80        .76        .58        .75        .86        .83        .96        .84        .91
CR2O3         .30        .17        .22        .34        .25        .05        .14        ND         .05        ND
FEO          5.36       5.77       7.04       5.41       6.28       8.14       7.38       9.41       7.94       9.20
MNO           .14        .13        .13        .12        .10        .15        .13        .15        .16        .14
MGO         34.47      34.33      34.08      35.75      34.71      32.92      32.96      32.09      33.13      32.08
CAO           .89        .88        .76        .48        .80        .88        .86        .92        .87        .91
NA2O          .14        .14        .11        .12        .16        .24        .62        .30        .24        .26
K2O           .02        ND         ND         ND         ND         ND         .12        ND         ND         .02
TOTAL       99.25      99.58      99.85     100.26     100.17     100.28      99.29     100.59     100.35      99.53

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

OXYGEN        6          6          6          6          6          6          6          6          6          6

SI          1.979      1.980      1.966      1.968      1.963      1.973      1.972      1.969      1.972      1.964
TI           .002       .003       .004       .003       .007       .006        -         .006       .007       .006
AL           .031       .033       .031       .023       .031       .035       .034       .039       .034       .038
CR           .008       .005       .006       .009       .007       .001       .004        -         .001        -
FE2+         .155       .167       .205       .155       .181       .237       .216       .274       .230       .271
MN           .004       .004       .004       .003       .003       .004       .004       .004       .005       .004
MG          1.781      1.770      1.764      1.829      1.786      1.705      1.722      1.667      1.713      1.684
CA           .033       .033       .028       .018       .030       .033       .032       .034       .032       .034
NA           .009       .009       .007       .008       .011       .016       .042       .020       .016       .018
K            .001        -          -          -          -          -         .005        -          -         .001

SUM         4.004      4.003      4.016      4.017      4.018      4.011      4.033      4.015      4.011      4.020

        WO  1.68   WO  1.66   WO  1.42   WO   .88   WO  1.48   WO  1.66   WO  1.64   WO  1.74   WO  1.64   WO  1.73
        EN 90.43   EN 89.87   EN 88.34   EN 91.36   EN 89.44   EN 86.36   EN 87.38   EN 84.38   EN 86.70   EN 84.65
        FS  7.89   FS  8.48   FS 10.24   FS  7.76   FS  9.08   FS 11.98   FS 10.98   FS 13.88   FS 11.66   FS 13.62

        M: 91.97   M: 91.38   M: 89.61   M: 92.17   M: 90.78   M: 87.81   M: 88.84   M: 85.87   M: 88.15   M: 86.14
        C:  1.82   C:  1.81   C:  1.58   C:   .96   C:  1.63   C:  1.89   C:  1.84   C:  2.02   C:  1.85   C:  2.00

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

      ANALYSIS NO.      DESCRIPTION                                  ANALYSIS NO.      DESCRIPTION
      ------------      -----------                                  ------------      -----------
           1            OPX KF12                                          6            OPX KF17
           2            OPX KF13                                          7            OPX KF18
           3            OPX KF14                                          8            OPX KF19
           4            OPX KF15                                          9            OPX KF20
           5            OPX KF16                                         10            OPX KF21

** ND = NOT DETECTED **
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TABLE VII-6C ANALYSES OF BROWN ORTHOPYROXENES (GLASSY) FROM THE KOFFIEFONTEIN CONCENTRATE

                11

SIO2         56.01
TIO2           .23
AL2O3          .85
CR2O3          .05
FEO           8.17
MNO            .12
MGO          33.18
CAO            .86
NA2O           .20
K2O             ND
TOTAL        99.69

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

OXYGEN           6

SI           1.960
TI            .006
AL            .035
CR            .001
FE2+          .239
MN            .004
MG           1.731
CA            .032
NA            .014
K               -

SUM          4.022

          WO  1.61
          EN 86.44
          FS 11.94

          M: 87.86
          C:  1.83

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

         ANALYSIS NO.    DESCRIPTION                                   ANALYSIS NO.    DESCRIPTION
         ------------    -----------                                   ------------    -----------
              11         OPX KF22

** ND = NOT DETECTED **
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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	.12	.04	.22	.03	.20	.25	.24
AL2O3	.62	.79	.74	.73	.56	.88	1.03	1.08
CR2O3	.33	.25	.22	.31	.08	.02	.08	.11
FEO	4.55	5.72	6.22	5.43	6.48	9.42	8.33	8.31
MNO	.10	.11	.13	.11	.14	.14	.12	.13
MGO	36.25	35.11	34.58	35.02	34.42	31.87	32.38	32.18
CAO	.36	.65	.82	.84	.50	.94	1.14	1.23
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	1.979	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	.032	.030	.030	.023	.036	.043	.045
CR	.009	.007	.006	.008	.002	.001	.002	.003
FE2+	.130	.164	.179	.157	.187	.276	.244	.244
MN	.003	.003	.004	.003	.004	.004	.004	.004
MG	1.840	1.789	1.774	1.802	1.775	1.663	1.690	1.684
CA	.013	.024	.030	.031	.019	.035	.043	.046
NA	.007	.010	.011	.010	.012	.015	.020	.019
K	-	.001	-	-	-	-	-	-
SUM	4.006	4.008	4.011	4.014	4.008	4.010	4.017	4.016
WO	.66	1.20	1.52	1.56	.94	1.79	2.16	2.34
EN	92.80	90.52	89.45	90.56	89.60	84.24	85.49	85.30
FS	6.54	8.28	9.03	7.88	9.47	13.97	12.34	12.36
M:	93.42	91.62	90.63	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

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

ANALYSIS NO.	DESCRIPTION
1	OPX KF33
2	OPX KF34
3	OPX KF35
4	OPX KF36

ANALYSIS NO.	DESCRIPTION
5	OPX KF37
6	OPX KF38
7	OPX KF51
8	OPX KF52

** ND = NOT DETECTED **

TABLE VII-7 ANALYSES OF CLINOPYROXENES FROM KOFFIEFONTEIN 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	.14	.03	.23	.15	.04	.06	.04	.05	.19	.30
AL2O3	2.59	2.39	1.01	1.49	3.32	1.05	3.20	2.96	2.75	1.66
CR2O3	1.45	1.07	1.59	1.33	1.10	1.55	1.18	1.17	3.59	2.72
FEO	1.85	1.33	2.65	2.87	1.45	2.00	1.58	1.56	1.63	2.20
MNO	.03	.04	.10	.11	.05	.08	.04	.04	.11	.09
MGO	15.93	16.56	17.85	18.29	15.56	18.31	15.80	16.07	15.02	16.31
CAO	20.93	22.09	20.48	19.54	20.96	20.51	20.82	21.04	19.08	19.35
NA2O	2.19	1.70	1.48	1.41	2.10	1.04	2.31	2.13	3.23	2.01
K2O	ND	ND	.04	.04	ND	.11	ND	.02	ND	.03
TOTAL	100.62	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	1.982	1.980	1.983	1.987	1.979	1.973	1.973	1.983
TI	.004	.001	.006	.004	.001	.002	.001	.001	.005	.008
AL	.110	.101	.043	.063	.142	.045	.136	.125	.117	.072
CR	.041	.030	.045	.038	.032	.044	.034	.033	.103	.079
FE2+	.056	.040	.080	.087	.044	.061	.048	.047	.049	.067
MN	.001	.001	.003	.003	.002	.002	.001	.001	.003	.003
MG	.857	.888	.961	.983	.840	.990	.850	.859	.809	.891
CA	.810	.852	.793	.755	.813	.797	.805	.832	.739	.760
NA	.153	.119	.104	.099	.147	.073	.162	.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
	WO 47.00	WO 47.85	WO 43.23	WO 41.38	WO 47.93	WO 43.14	WO 47.29	WO 47.87	WO 46.26	WO 44.23
	EN 49.76	EN 49.90	EN 52.40	EN 53.87	EN 49.49	EN 53.57	EN 49.91	EN 49.44	EN 50.65	EN 51.85
	FS 3.24	FS 2.25	FS 4.37	FS 4.74	FS 2.59	FS 3.28	FS 2.80	FS 2.69	FS 3.08	FS 3.92
	M: 93.84	M: 95.69	M: 92.31	M: 91.91	M: 95.03	M: 94.22	M: 94.69	M: 94.83	M: 94.26	M: 92.96
	C: 48.58	C: 48.96	C: 45.20	C: 43.44	C: 49.20	C: 44.61	C: 48.65	C: 49.19	C: 47.73	C: 46.03

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

ANALYSIS NO.	DESCRIPTION
1	CPX KF39
2	CPX KF40
3	CPX KF41
4	CPX KF42
5	CPX KF43

ANALYSIS NO.	DESCRIPTION
6	CPX KF44
7	CPX KF45
8	CPX KF46
9	CPX KF47
10	CPX KF48

** ND = NOT DETECTED **

TABLE VII-7 ANALYSES OF CLINOPYROXENES FROM KOFFIEFONTEIN CONCENTRATE

	11	12	13	14	15	16	17	18	19	20
SIO2	55.05	54.44	55.11	55.01	54.83	55.06	54.68	54.83	54.99	54.66
TIO2	.21	.16	.25	.05	.25	.24	.10	.20	.07	.22
AL2O3	2.16	3.33	2.97	2.34	1.82	.82	2.68	.91	2.94	2.11
CR2O3	2.37	2.81	.56	1.67	1.90	1.45	1.28	2.10	2.77	2.87
FEO	2.19	2.17	2.35	1.38	2.48	2.47	1.45	2.46	2.09	1.68
MNO	.10	.09	.08	.06	.10	.08	.05	.09	.09	.11
MGO	16.24	14.73	17.15	16.45	17.28	16.82	16.25	16.58	14.79	15.84
CAO	18.98	18.70	18.71	20.94	18.94	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	.03	ND	.04	.06	.03	.02	ND	ND	ND	ND
TOTAL	99.90	99.84	99.27	99.73	99.37	99.59	98.50	98.73	98.94	98.12

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

	11	12	13	14	15	16	17	18	19	20
OXYGEN	6	6	6	6	6	6	6	6	6	6
SI	1.990	1.973	1.990	1.987	1.989	2.003	1.993	2.008	2.002	2.003
TI	.006	.004	.007	.001	.007	.007	.003	.006	.002	.006
AL	.092	.142	.126	.100	.078	.035	.115	.039	.126	.091
CR	.068	.081	.016	.048	.054	.042	.037	.061	.080	.083
FE2+	.066	.066	.071	.042	.075	.075	.044	.075	.064	.051
MN	.003	.003	.002	.002	.003	.002	.002	.003	.003	.003
MG	.875	.796	.923	.885	.934	.912	.883	.905	.802	.865
CA	.735	.726	.724	.810	.736	.825	.788	.778	.705	.709
NA	.180	.239	.144	.124	.122	.103	.129	.122	.220	.182
K	.001	-	.002	.003	.001	.001	-	-	-	-
SUM	4.016	4.031	4.005	4.002	4.000	4.004	3.993	3.998	4.004	3.995
WO	43.86	45.74	42.14	46.64	42.17	45.53	45.94	44.25	44.87	43.62
EN	52.19	50.11	53.73	50.96	53.52	50.32	51.48	51.46	51.08	53.21
FS	3.95	4.14	4.13	2.40	4.31	4.15	2.58	4.28	4.05	3.17
M:	92.96	92.36	92.86	95.50	92.55	92.39	95.23	92.31	92.65	94.38
C:	45.66	47.72	43.96	47.79	44.07	47.50	47.16	46.23	46.76	45.05

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

ANALYSIS NO.	DESCRIPTION
11	CPX KF49
12	CPX KF50
13	CPX KF53
14	CPX KF54
15	CPX KF56

ANALYSIS NO.	DESCRIPTION
16	CPX KF57
17	CPX KF58
18	CPX KF59
19	CPX KF60
20	CPX KF61

** ND = NOT DETECTED **

```
TABLE VII-7 ANALYSES OF CLINOPYROXENES FROM KOFFIEFONTEIN CONCENTRATE

            21          22

SIO2      54.51       54.76
TIO2        .26         .27
AL2O3      1.30        1.51
CR2O3      1.88        1.97
FEO        2.48        2.53
MNO         .09         .09
MGO       17.05       16.57
CAO       19.15       19.48
NA2O       1.96        1.90
K2O         .03         .02
TOTAL     98.71       99.10

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

OXYGEN       6           6

SI         1.995       1.997
TI          .007        .007
AL          .056        .065
CR          .054        .057
FE2+        .076        .077
MN          .003        .003
MG          .930        .900
CA          .751        .761
NA          .139        .134
K           .001        .001

SUM        4.013       4.003

        WO 42.75    WO 43.77
        EN 52.93    EN 51.79
        FS  4.32    FS  4.44

        M: 92.45    M: 92.11
        C: 44.68    C: 45.81

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

     ANALYSIS NO.     DESCRIPTION                          ANALYSIS NO.     DESCRIPTION
     ------------     -----------                          ------------     -----------
          21          CPX KF62                                  22          CPX KF63
```

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TABLE VII-A ANALYSES OF CHROMITES FROM THE KOFFIEFONTEIN CONCENTRATE
              1          2          3          4          5          6          7          8          9         10

SIO2        .02        .04         ND        .07        .10        .28        .28        .28        .28        .30
TIO2       1.62       2.34        .77       1.59       2.60       2.25       1.36       2.42       1.19        .97
AL2O3      6.09       3.79       2.73       7.57       7.73       6.15       7.76       5.64       2.84       6.58
CR2O3     58.63      57.54      65.25      52.62      54.27      59.32      59.81      60.81      60.79      62.61
FE2O3      6.16       7.40       5.25       8.91       6.54       4.68       4.43       3.98       5.99       3.62
FEO       14.79      17.43      12.98      18.50      15.63      15.33      13.85      13.62      19.26      12.43
MNO         .77        .82          -          -          -          -          -          -          -          -
MGO       12.44      10.80      13.22      10.52      13.09      13.39      14.03      14.54       9.53      14.53
CAO           -          -          -          -          -          -          -          -          -          -
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 * *

OXYGEN        4          4          4          4          4          4          4          4          4          4

SI         .001       .001          -       .002       .003       .009       .009       .009       .010       .010
TI         .040       .060       .019       .040       .064       .055       .033       .059       .031       .024
AL         .237       .151       .107       .299       .298       .235       .293       .215       .115       .250
CR        1.529      1.539      1.721      1.392      1.405      1.522      1.516      1.553      1.650      1.596
FE3+       .153       .188       .132       .224       .161       .114       .107       .047       .155       .088
FE2+       .408       .493       .362       .518       .428       .416       .371       .368       .553       .335
MN         .022       .023          -          -          -          -          -          -          -          -
MG         .611       .544       .657       .525       .639       .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   CR   .91   CR   .94   CR   .82   CR   .82   CR   .87   CR   .84   CR   .88   CR   .93   CR   .86
       MG   .60   MG   .52   MG   .64   MG   .50   MG   .60   MG   .61   MG   .64   MG   .66   MG   .47   MG   .68
       FE   .09   FE   .10   FE   .07   FE   .12   FE   .09   FE   .06   FE   .06   FE   .05   FE   .08   FE   .05

                          * * * 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 6                                7          CHROMITE 13
           3          CHROMITE 7                                8          CHROMITE 14
           4          CHROMITE 9                                9          CHROMITE 15
           5          CHROMITE 10                              10          CHROMITE 16

** ND = NOT DETECTED **
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TABLE VII-8 ANALYSES OF CHROMITES FROM THE KOFFIEFONTEIN CONCENTRATE

             11          12          13          14          15          16          17          18          19          20

SIO2        .26         .26         .30         .29         .23         .25         .26         .06         .05         .04
TIO2        .65         .36        2.76        1.51         .23         .61        1.29        3.66        3.40        3.37
AL2O3      8.74        3.54        7.54        6.81       10.45        2.62        5.04        4.43        5.21        5.27
CR2O3     61.54       67.14       55.39       59.53       59.37       66.76       63.73       55.49       54.17       54.50
FE2O3      1.20        2.49        6.26        5.04        3.60        3.87        3.38        4.80        5.28        5.06
FEO       13.40       13.68       16.09       13.31       13.28       14.30       12.82       19.24       18.63       18.68
MNO          -           -           -           -           -           -           -           -           -           -
MGO       13.59       12.76       12.88       14.20       13.88       12.65       14.21       10.66       10.81       10.79
CAO          -           -           -           -           -           -           -           -           -           -
NA2O         -           -           -           -           -           -           -           -           -           -
K2O          -           -           -           -           -           -           -           -           -           -
TOTAL     99.48      100.43       99.22      100.70      101.04      101.06      100.73       98.34       97.55       97.72

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

OXYGEN       4           4           4           4           4           4           4           4           4           4

SI         .008        .009        .010        .009        .007        .008        .008        .002        .002        .001
TI         .016        .009        .069        .037        .006        .015        .032        .094        .088        .087
AL         .335        .130        .294        .260        .392        .103        .194        .179        .211        .213
CR        1.588       1.764       1.394       1.525       1.496       1.754       1.643       1.504       1.473       1.479
FE3+       .032        .062        .156        .123        .086        .097        .083        .124        .137        .131
FE2+       .365        .366        .445        .361        .354        .397        .350        .552        .536        .536
MN           -           -           -           -           -           -           -           -           -           -
MG         .650        .632        .634        .686        .659        .626        .691        .545        .554        .552
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   CR    .93   CR    .83   CR    .85   CR    .79   CR    .94   CR    .89   CR    .89   CR    .87   CR    .87
      MG  .64   MG    .62   MG    .59   MG    .66   MG    .65   MG    .61   MG    .66   MG    .50   MG    .51   MG    .51
      FE  .02   FE    .03   FE    .08   FE    .06   FE    .04   FE    .05   FE    .04   FE    .07   FE    .08   FE    .07

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

   ANALYSIS NO.     DESCRIPTION                         ANALYSIS NO.     DESCRIPTION
   ------------     -----------                         ------------     -----------
        11          CHROMITE 17                              16          CHROMITE 22
        12          CHROMITE 18                              17          CHROMITE 23
        13          CHROMITE 19                              18          CHROMITE 26
        14          CHROMITE 20                              19          CHROMITE 27
        15          CHROMITE 21                              20          CHROMITE 28
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TABLE VII-8 ANALYSES OF CHROMITES FROM THE KOFFIEFONTEIN CONCENTRATE

	21	22	23	24	25	26	27	28
SIO2	-	ND	.02	.05	ND	.02	.03	.04
TIO2	1.07	.17	.04	1.87	.42	2.43	.62	2.53
AL2O3	4.46	2.21	9.04	5.50	9.31	4.41	3.83	6.84
CR2O3	63.07	64.88	61.30	58.86	59.67	61.04	63.57	57.70
FE2O3	2.34	5.01	1.40	4.14	3.08	3.08	4.14	3.53
FEO	14.87	12.68	13.82	16.07	13.14	13.80	13.95	13.19
MNO	-	.74	-	-	.64	.75	.72	.63
MGO	11.82	12.00	12.50	11.77	12.99	13.02	11.85	13.75
CAO	-	-	-	-	-	-	-	-
NA2O	-	-	-	-	-	-	-	-
K2O	-	-	-	-	-	-	-	-
TOTAL	97.63	97.70	98.12	98.25	99.26	98.55	98.72	98.20

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

OXYGEN	4	4	4	4	4	4	4	4
SI	-	-	.001	.002	-	.001	.001	.001
TI	.028	.004	.001	.048	.010	.061	.016	.063
AL	.180	.090	.354	.220	.359	.175	.153	.268
CR	1.705	1.770	1.608	1.576	1.544	1.623	1.707	1.515
FE3+	.060	.130	.035	.105	.076	.078	.106	.088
FE2+	.425	.366	.384	.455	.359	.368	.396	.366
MN	-	.022	-	-	.018	.021	.021	.018
MG	.602	.617	.618	.594	.633	.653	.600	.681
CA	-	-	-	-	-	-	-	-
NA	-	-	-	-	-	-	-	-
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	.59	.63	.62	.57	.64	.63	.60	.65
FE	.03	.07	.02	.06	.04	.04	.05	.05

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

ANALYSIS NO.	DESCRIPTION
21	CHROMITE 29
22	CHROMITE 30
23	CHROMITE 31
24	CHROMITE 33

ANALYSIS NO.	DESCRIPTION
25	CHROMITE 34
26	CHROMITE 35
27	CHROMITE 36
28	CHROMITE 37

** ND = NOT DETECTED **

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TABLE VII-9 ANALYSES OF ILMENITES FROM THE KOFFIEFONTEIN CONCENTRATE

            1            2            3            4            5            6

SIO2        -           ND           ND           ND           ND           ND
TIO2      55.90        54.92        56.93        55.99        55.11        55.65
AL2O3       .14          .70          .22          .12          .09          .07
CR2O3      2.12          .68         2.71          .83         1.89         2.32
FE2O3      2.65         3.85         1.08         2.39         2.11         2.65
FEO       24.05        24.88        24.81        26.13        26.05        25.78
MNO         .32          .26          .27          .31          .33          .34
MGO       14.53        13.61        14.66        13.42        13.01        13.43
CAO         -            -            -            -            -            -
NA2O        -            -            -            -            -            -
K2O         -            -            -            -            -            -
TOTAL     99.72        98.92       100.69        99.20        98.60       100.25

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

OXYGEN      3            3            3            3            3            3

SI          -            -            -            -            -            -
TI        .956         .951         .964         .970         .963         .955
AL        .004         .019         .006         .003         .002         .002
CR        .039         .012         .048         .015         .035         .042
FE3+      .045         .067         .018         .041         .037         .045
FE2+      .458         .479         .467         .503         .506         .492
MN        .006         .005         .005         .006         .006         .007
MG        .493         .467         .492         .461         .450         .457
CA          -            -            -            -            -            -
NA          -            -            -            -            -            -
K           -            -            -            -            -            -

SUM       2.000        2.000        2.000        2.000        2.000        2.000

       IL 47.37     IL 49.17     IL 48.51     IL 51.41     IL 52.22     IL 50.96
       GK 50.31     GK 47.44     GK 50.55     GK 46.51     GK 45.90     GK 46.71
       HM  2.32     HM  3.39     HM   .94     HM  2.09     HM  1.88     HM  2.32

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

     ANALYSIS NO.     DESCRIPTION                              ANALYSIS NO.     DESCRIPTION
     ------------     -----------                              ------------     -----------
          1           ILMENITE 1                                    4           ILMENITE 8
          2           ILMENITE 3                                    5           ILMENITE 12
          3           ILMENITE 5                                    6           ILMENITE 32

** ND = NOT DETECTED **
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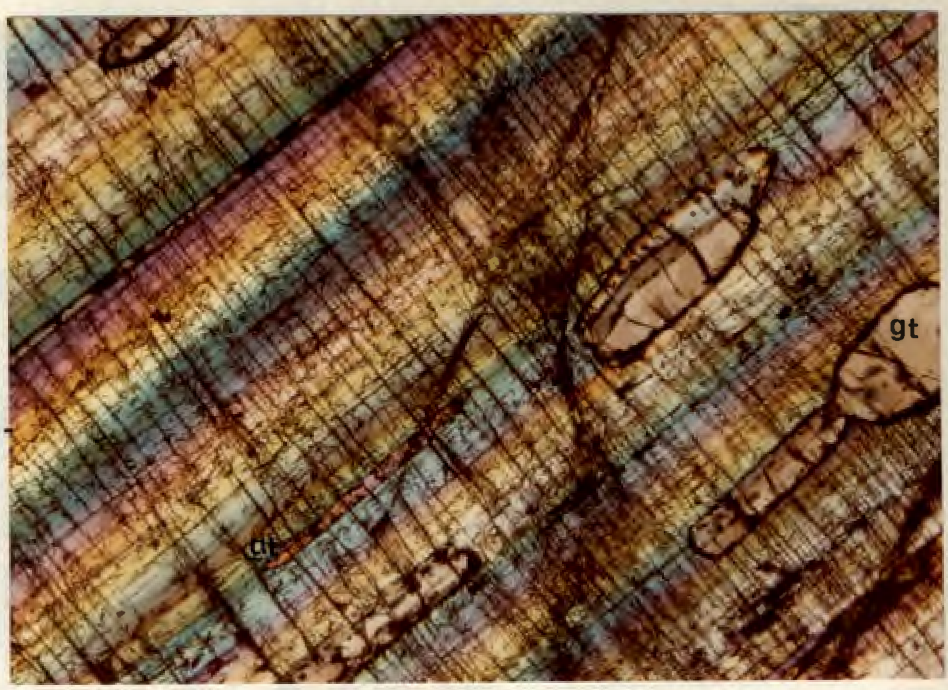

Plate 1. Illustration of clinopyroxene megacryst PC21, exsolving orthopyroxene and garnet. The orthopyroxene occurs as bands of variable width, recognised by its straight extinction,but there are no defined grain boundaries between the orthopyroxene and the clinopyroxene host. Garnet occurs as parallel 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)

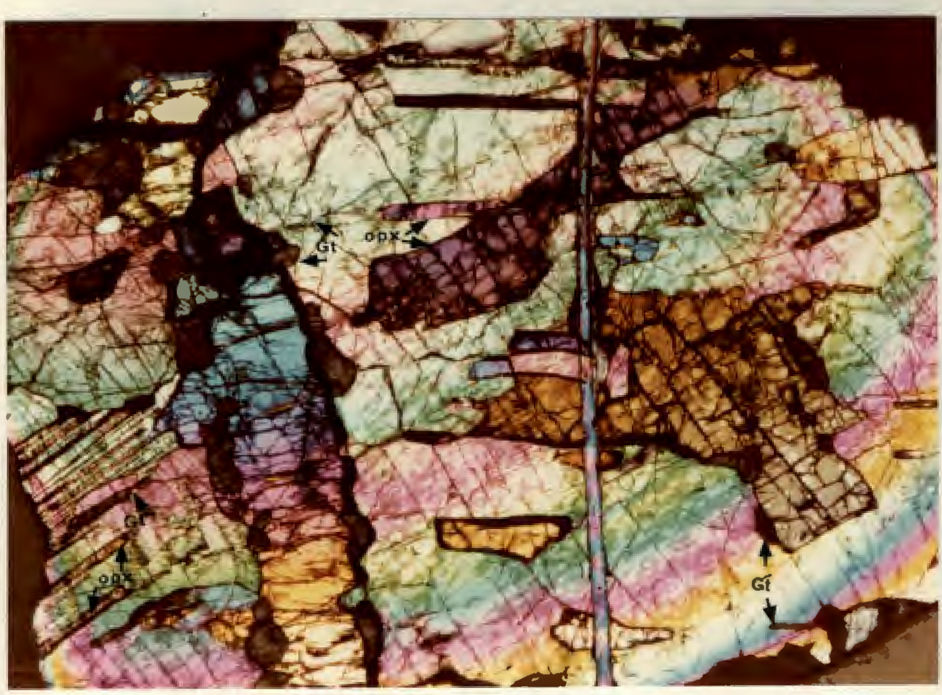

Plate 3. Clinopyroxene exsolving garnet and orthopyroxene (PC25). Note the variation in orthopyroxene size and shape, and the coalescence of lamellae and rod shaped grains with larger orthopyroxene inclusions; they all extinguish simultaneously. Garnet occurs as thin lamellae and as larger grains along orthopyroxene-clinopyroxene boundaries, and within large orthopyroxenes. A "finger" of orthopyroxene separates the two clinopyroxene crystals.

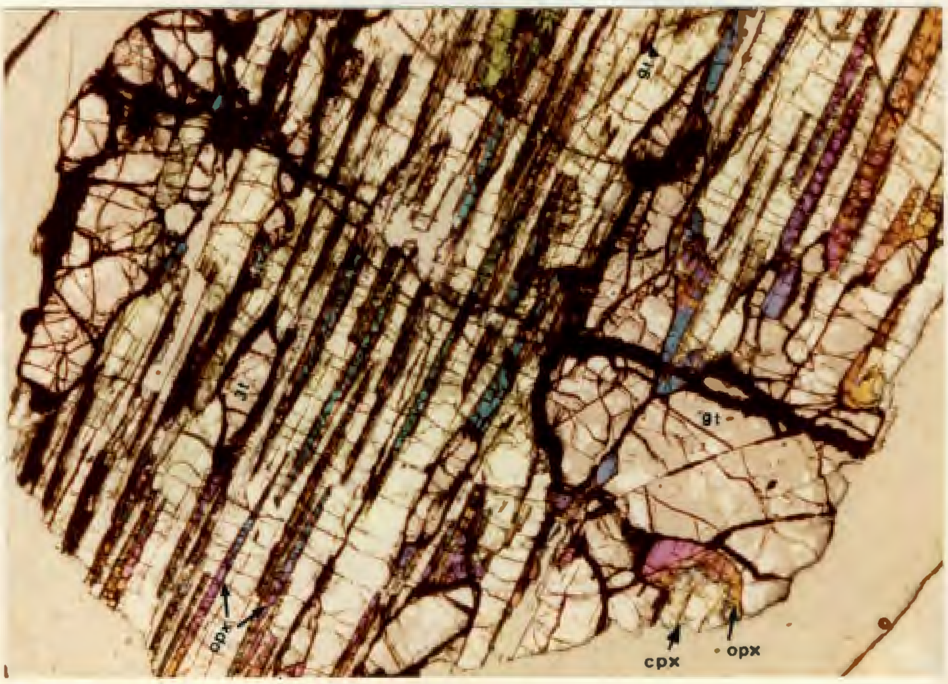

Plate 4. Xenolith PC33 . Clinopyroxene exsolving orhtopyroxene and garnet. The larger garnets may be primary, but the finger-like intergrowth of the largest garnet with the clinopyroxene host (bottom right hand side of plate) suggests exsolution followed by coarsening. Also note the grain with a centre of clinopyroxene surrounded by a rim of orthopyroxene, with no visible grain boundaries between the two (bottom right hand side).

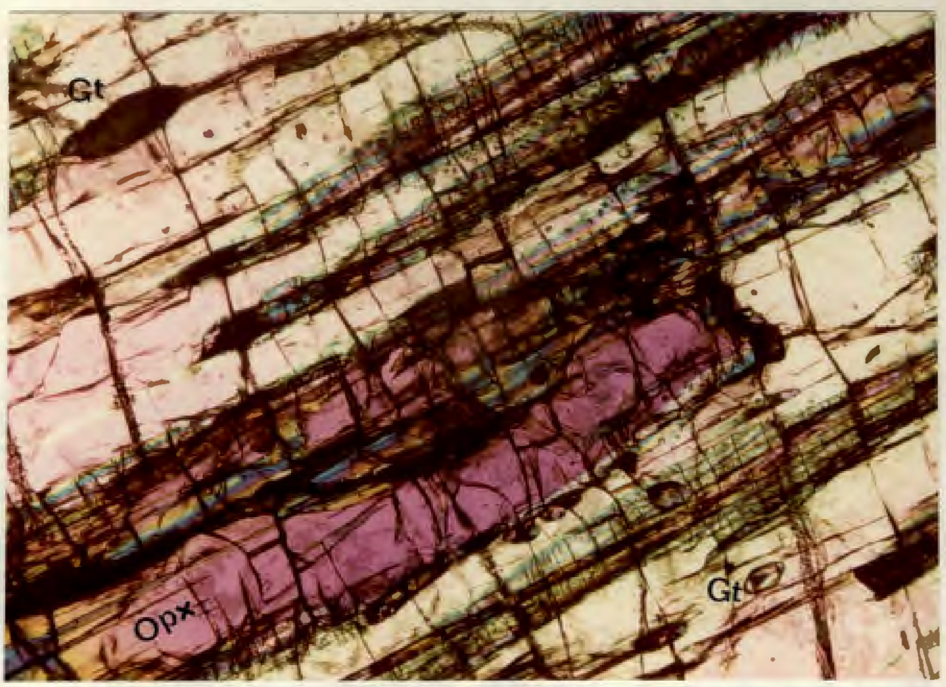

Plate 5. Further illustration of garnet and orthopyroxene exsolution from clinopyroxene in xenolith PC33.

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 orthpyroxene, and small blebs of garnet and chromite (exsolved phases). Along the margin there are small polygonal grains of clino- 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.

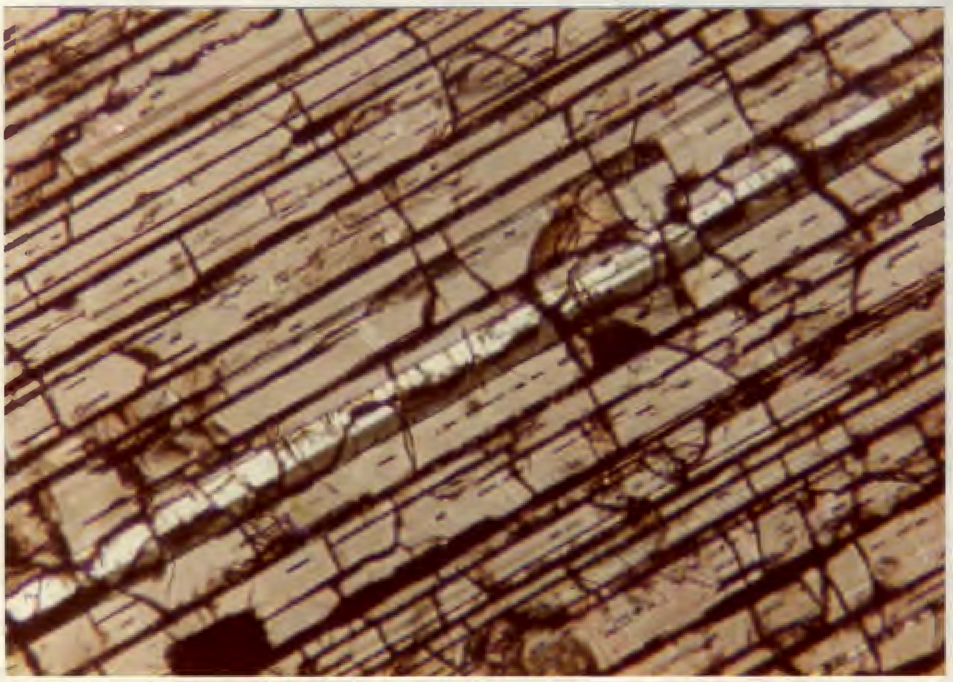

Plate 8. Orthopyroxene megacryst PC20B showing well developed cleavage and exsolution of clinopyroxene lamellae.

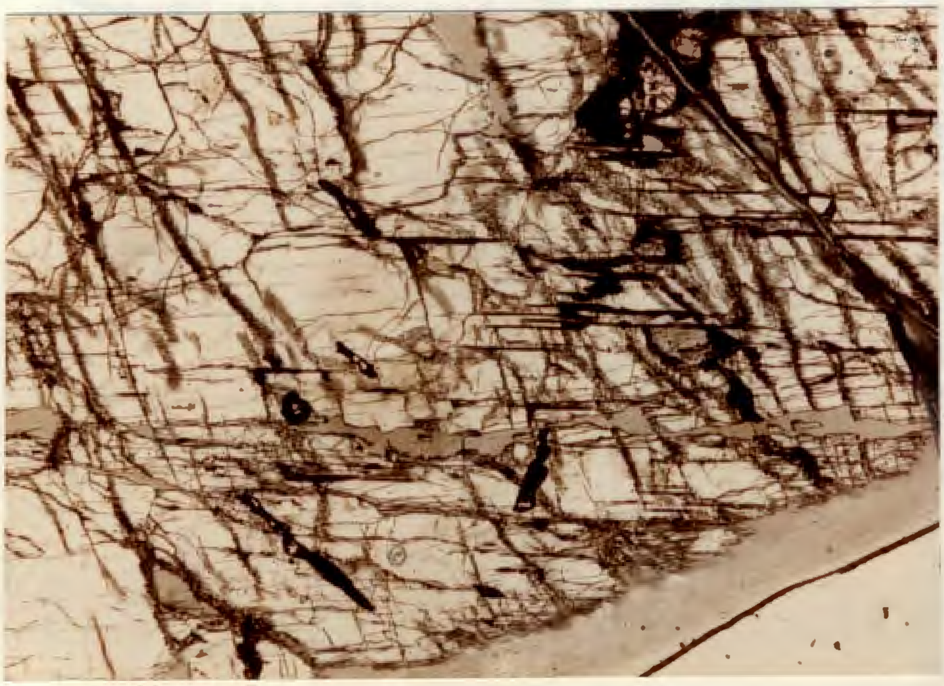

Plate 9. Orthopyroxene megacryst PC24B with roundish to elongated exsolved garnets.

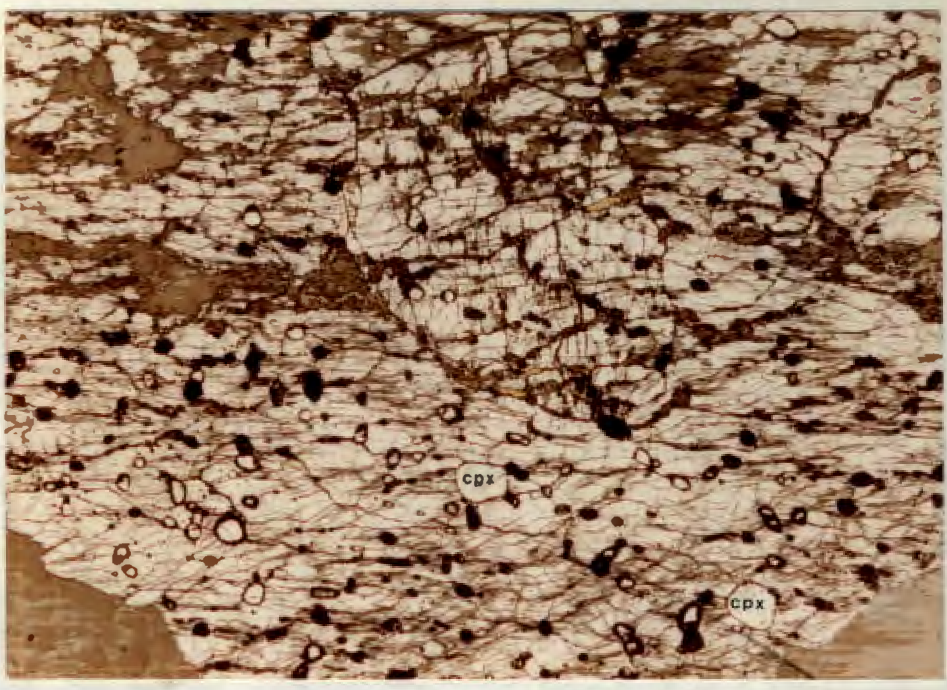

Plate 10. Orthopyroxene megacryst PC27 with small roundish exsolved garnets and three inclusions of clinopyroxene(cpx). Readjustment of this crystal as a result of deformation has resulted in limited recrystallization along deformation bands (centre and right Hand side of top part of plate).

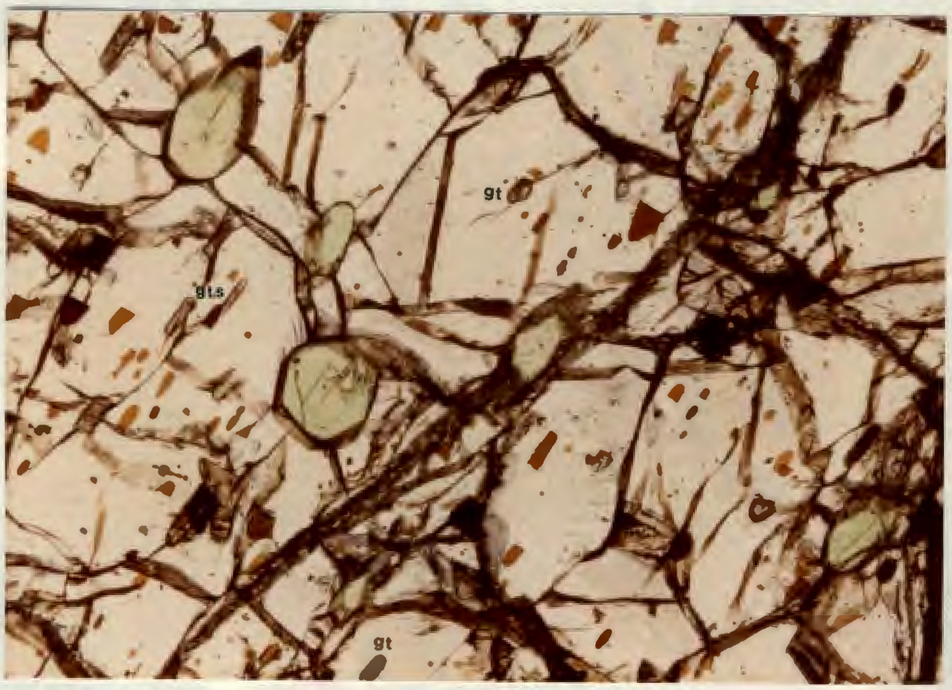

Plate 11. Orthopyroxene megacryst PC28 with inclusions of clinopyroxene (green), chromite(brown) and garnet (colourless-gt). The parallel and preferred orientation of these phases and the simultaneous extinction of the clinopyroxene suggest structural control by the orthopyroxene host.

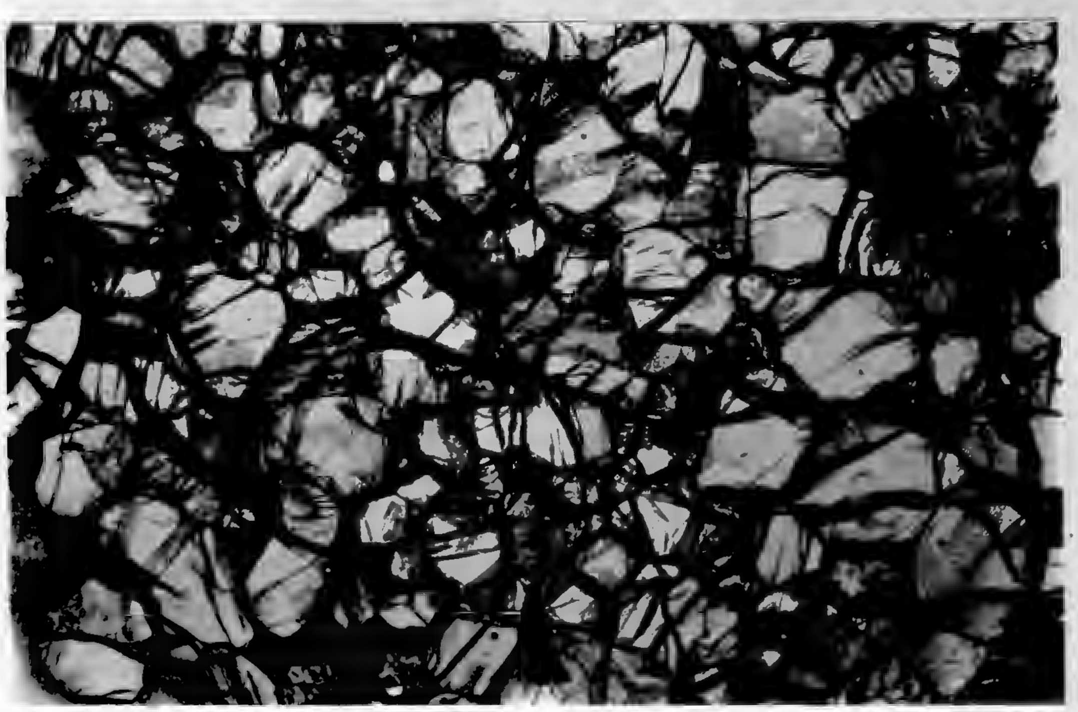

Plate 12. Xenolith PC65, illustrating the extreme case in Type IV pyroxenites, where all orthopyroxenes show signs of polygonisation. The grains are equant, with a bimodal size distribution and with slightly curved to straight grain boundaries joining at ~120° triple junctions.

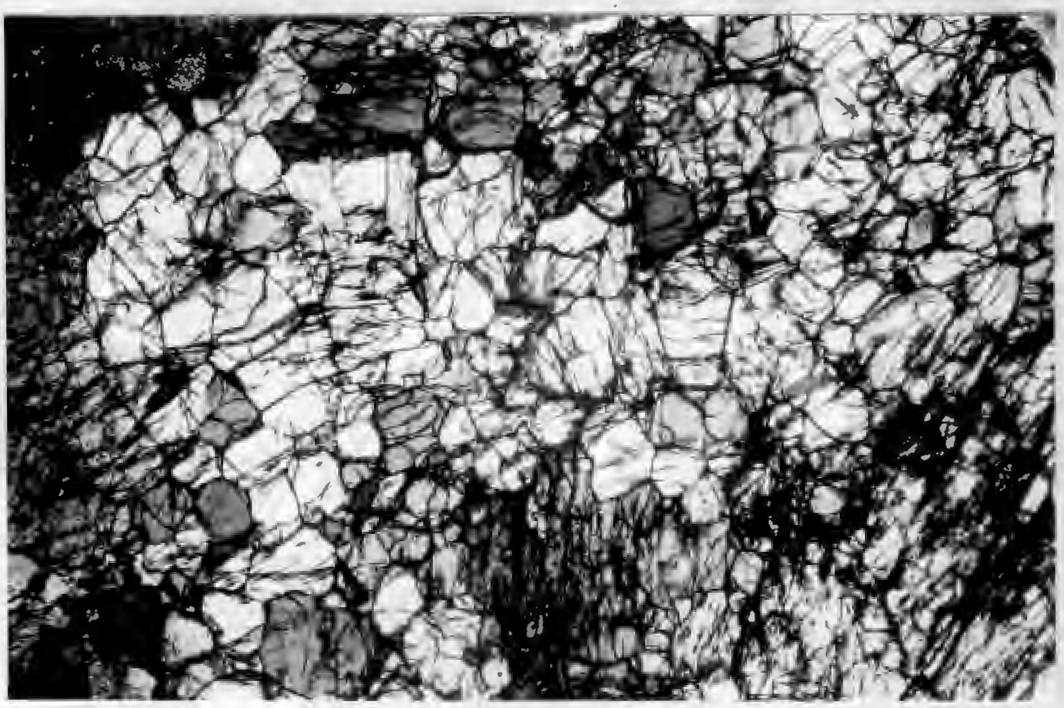

Plate 13. Xenolith PC60, illustrating the large orthopyroxene grains with irregular grain boundaries and a cracked appearance in contrast to the enclosed or partially enclosed smaller grains which have regular grain boundaries, smoothly curved or straight and frequently display 120° triple points.

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.

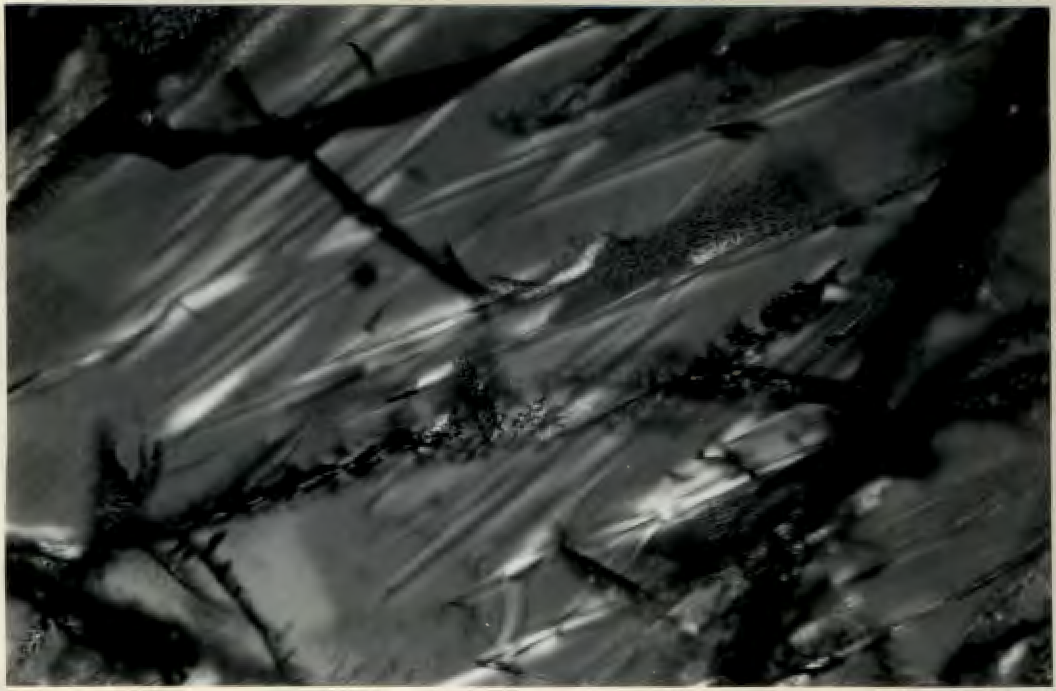

Plate 16. Illustration of two sets of lamellae in clinopyroxene crystal from xenolith PC26. The same phenomena is also observed in clinopyroxenes of pyroxenite PC43.

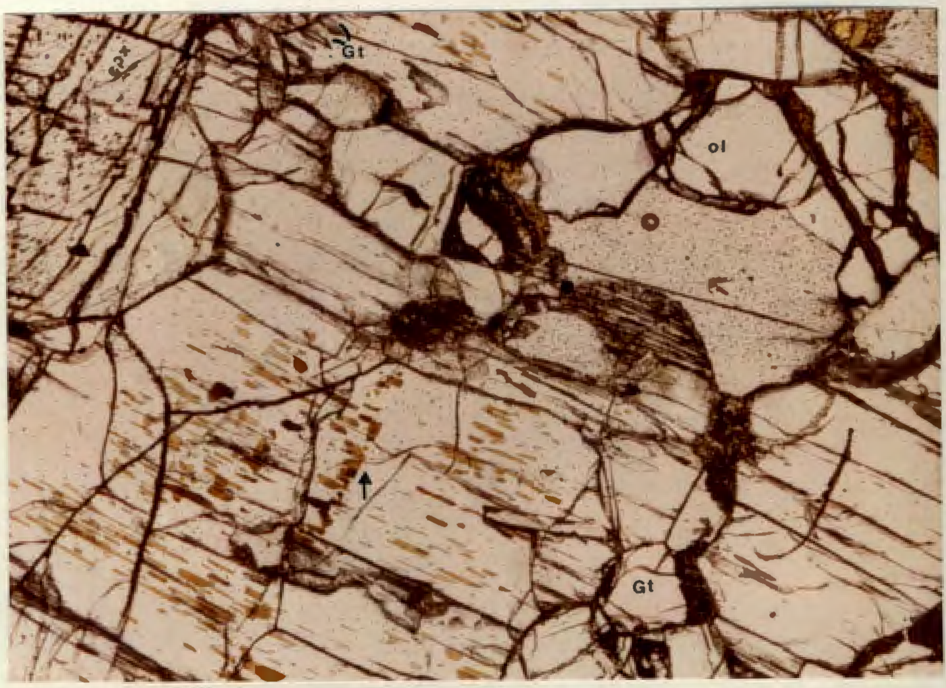

Plate 17. Illustration of chromite lamellae in orthopyroxene in olivine bearing pyroxenite(PC47); note exsolution of chromite along an incipient kink band (→). A few very small garnet lamellae can also be seen in this microphotograph (eg. gt- in top part of plate). Discrete grains of garnet, clinopyroxene and olivine are also illustrated.