THE PETROLOGY OF PYROXENITE XENOLITHS
FROM KAULA ISLAND, HAWAII

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN GEOLOGY AND GEOPHYSICS

DECEMBER 1982

By

Alicia A. Presti

Thesis Committee:

Michael O. Garcia, Chairman
Kost A. Pankiwskyj
John M. Sinton

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Geology and Geophysics.

THESIS COMMITTEE

Michael O Garcia
Chairman

John M Sinton

ACKNOWLEDGEMENTS

I would like to thank Michael O. Garcia for microprobe training, and my thesis committee members Michael O. Garcia, John M. Sinton, and Kost A. Pankiwskyj, for helpful discussions and constructive criticisms on the initial drafts of this thesis. Also, I would like to thank David Mattey, Michael Smith, and Chuck Ferrall for their comments, as well as several scientists, who in passing through Honolulu, gave their time in valuable discussion.

THE PETROLOGY OF PYROXENITE XENOLITHS FROM KAULA ISLAND, HAWAII

ABSTRACT

Kaula Island marks the third known occurrence of garnet-bearing xenoliths along the Hawaiian Island chain. This study characterizes the petrography and mineral chemistry (determined by electron microprobe) of a suite of ten pyroxenite xenoliths (some of which contain garnet), two dunite samples, and a clinopyroxene megacryst from Kaula Island, Hawaii. Through the investigation of mineral/textural features, temperature and/or pressure changes which occurred in pyroxenite xenolith history are examined, and a sequence of these "events" is suggested.

Two such features, clinopyroxene "patches" and kelyphitic orthopyroxene and spinel intergrowths, have glass associated with them, and are particularly well-developed in Kaula pyroxenites. Clinopyroxene "patches" are texturally similar to a fracture-localized "sieve" texture (Wass, 1979). The clinopyroxene in these irregularly-shaped "patches" is markedly lower in Na, Al, and Fe than the clinopyroxene host grain. The presence of glass at the margins and within the "patches", along with the compositional trend observed, implies melting of the clinopyroxene. The cause of melting is thought to be decompression during ascent of the xenolith. Kelyphitic orthopyroxene and spinel intergrowths occur in garnet and at

garnet/clinopyroxene grain boundaries, and have two occurrences, as a coarse-grained rim and as a fibrous intergrowth. Through mass-balancing calculations, it is suggested that the reaction which produced this feature involved garnet, clinopyroxene, and a fluid. A decrease in pressure is implied, and decompressional melting is the advocated mechanism. Because of the presence of potassium and phosphorus in both glasses, a K(REE)P-rich component is invoked, either as a fluid or as melted phlogopite + phosphatic phase, in the reactions which produced these features.

A third association involving glass which occurs in Kaula pyroxenites, is skeletal olivine + glass. This feature is problematic because the fluid from which it formed was different from the other glasses, and cannot be derived from them. Mass-balancing calculations suggest a higher proportion of phlogopite may have contributed to this melt compared to the others; also, there may have been some contamination from the host basanitoid. Evidence of xenolith/host basanitoid interaction is common, such as olivine invading pyroxene at the xenolith/host basanitoid contact and fractures containing basanitoid that extend into the xenolith.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

I. INTRODUCTION

The significance of garnet pyroxenites and pyroxenites as mantle constituents is a controversial issue (see Frey, 1980). The rarity of garnet-bearing xenoliths in oceanic settings and the petrologic implications of garnet as a high pressure phase in ultramafic and some mafic rocks suggest that their role should not be dismissed without careful consideration. The intent of this work is to deduce, from textures and mineral compositions of the xenoliths, processes which have occurred in the mantle and during ascent of the xenoliths, in order to place constraints on xenolith history. In Salt Lake pyroxenites, for example, Jackson and Wright (1970) noted textures dominated by garnet coronas on spinel with discontinuous rims of orthopyroxene or olivine separating spinel from clinopyroxene. They pointed out that, based on experimental work, the reaction clinopyroxene + spinel --> garnet + olivine should occur with increasing pressure or decreasing temperature, and so must record an event in the mantle prior to the incorporation of the xenolith into the host basalt. Green (1966) considered the unmixing of garnet and orthopyroxene from cpx, as well as the reaction cpx + sp --> gt + ol, to indicate cooling of the pyroxenite at depth. Mineral textural features in Kaula pyroxenites also provide a record of some of the "events" in xenolith history. Two features, cpx "patches" and kelyphitic intergrowths, have glass associated with them, and are important records of temperature and/or pressure changes experienced by the xenolith. Also there are features in the xenoliths resulting from host basanitoid-xenolith interaction. Ringwood (1975) suggested that contamination of xenoliths by the host basalt is a potentially important problem that could result in the distortion of the abundances of some trace elements by up to three orders of magnitude. In this study, features relating to the history of some pyroxenites (including garnet-bearing members) from Kaula Island, Hawaii are investigated through petrographic observation and determination of mineral chemistry by electron microprobe.

Geology of Kaula Island

Kaula Island is a crescent-shaped tuff cone located approximately 33 km W-SW of Niihau Island in the Hawaiian Island chain (see Figures 1 and 2). Wave action has breached its eastern side, cut a cliff around the island, and has locally produced a bench 2.5 to 3.0 m above sea level. The island rests on the SE edge of a broad submarine platform formed on an older shield volcano. This edifice is part of an elongate submarine ridge that includes the shield volcanoes on Niihau and Kauai, and trends obliquely to the overall trend of the Hawaiian Ridge (Grooms, 1980). Approximately 150 meters of well-bedded palagonitic tuff comprise the subaerial portion of Kaula Island. An unconformity in the tuff units is best exposed in the cliff at the northern end of the island. No lava flows are present. The tuff contains lapilli- and ash-size fragments of altered volcanic glass, lava, olivine, augite, and magnetite (Palmer, 1936). Accidental angular blocks of volcanic

Figure 1. — Map showing the location of Kaula, Niihau, and Kauai Islands, Hawaii. From Grooms (1980), modified after Macdonald and Abbott (1977).

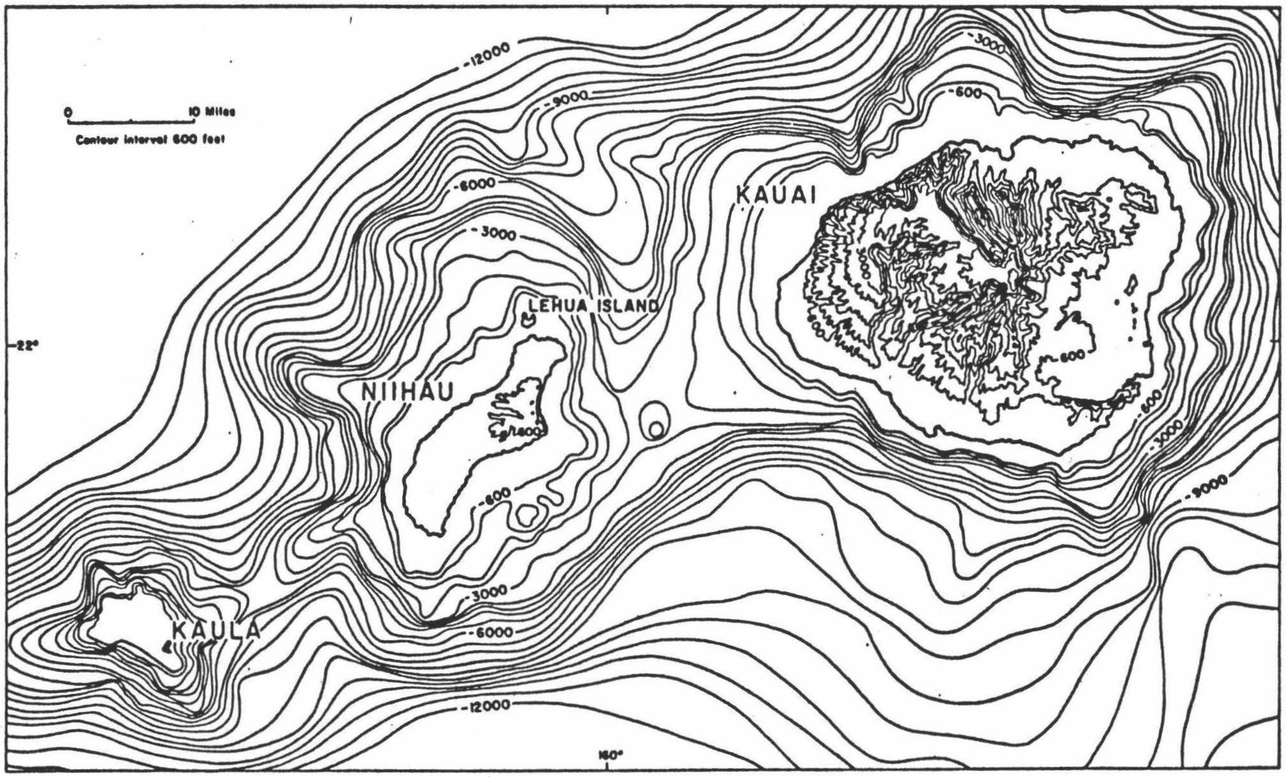
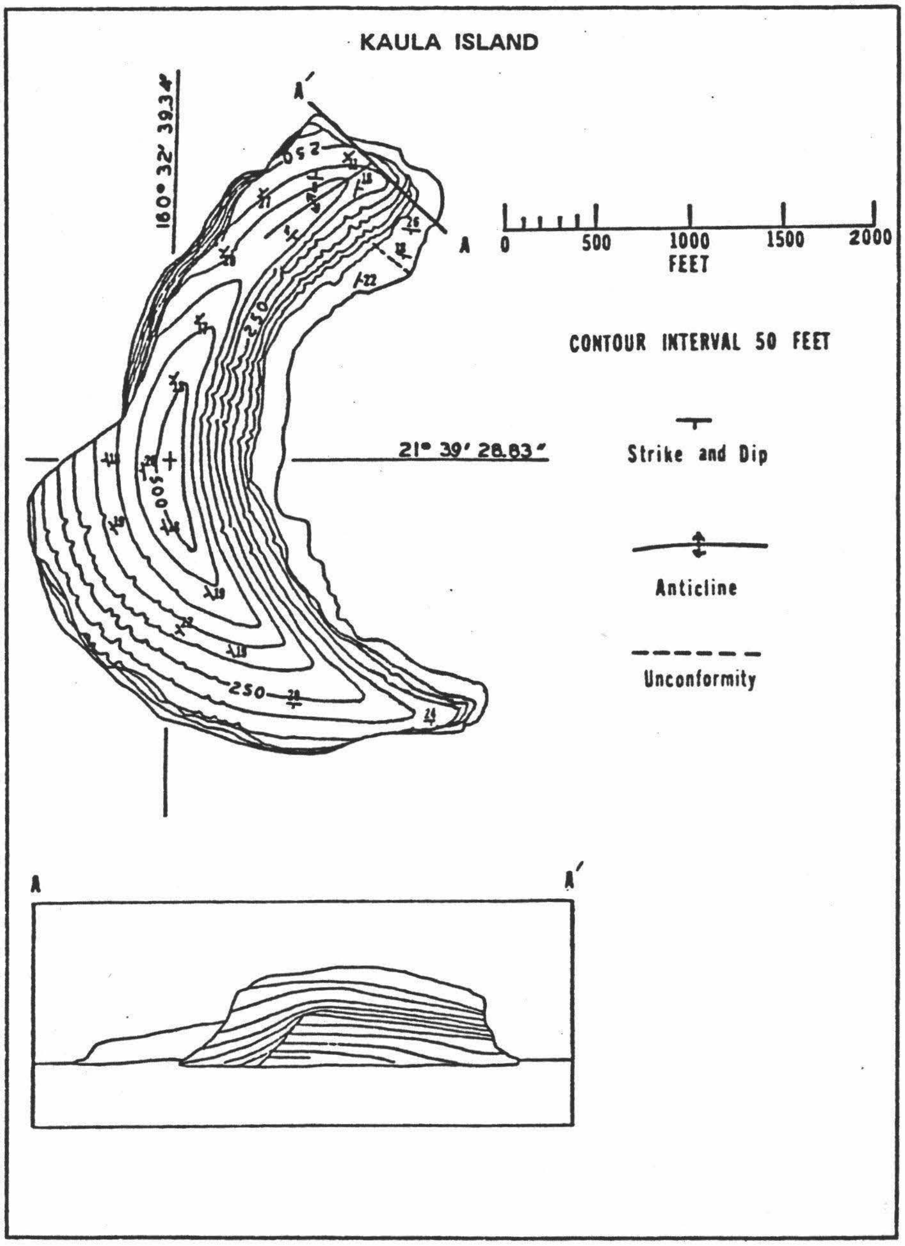

0 10 Miles
Contour interval 600 feet
-12000
-9000
-6000
-3000
-600
KAUAI
LEHUA ISLAND
NIIHAU
1200
600
3000
KAULA
22°
160°

Figure 2. -- Map and cross-section showing geologic features of Kaula Island, Hawaii. The strike and dip of the beds are indicated. Samples used in this study were collected from the northeast portion of the island, on the inner side of the bay. From Grooms (1980), modified after Palmer (1936).


KAULA ISLAND
160° 32' 39.34"
21° 39' 28.83"
A′
A
0
500
1000
1500
2000
FEET
CONTOUR INTERVAL 50 FEET
Strike and Dip
Anticline
Unconformity
250
500
250
250
A
A′

rocks, coral fragments, and mafic and ultramafic nodules up to 0.5 m in diameter are embedded in the tuff, generally forming bomb sags.

Grooms (1980) grouped the accidental volcanic blocks into three categories: 1) basanitoids which lack plagioclase, with xenocrysts of cpx, spinel, and rare anorthoclase, as well as rare small ultramafic and mafic xenoliths, 2) plagioclase-phyric basalts without inclusions, and 3) biotite phonolites without inclusions. K-Ar dating of the biotite phonolites yielded an age of approximately 4 million years (Grooms, 1980).

Olivine nodules were reported on Kaula Island as early as 1927 (Palmer, 1927). Further collection of samples from Kaula Island had not been possible until recently, because of the use of the island by the military as an aerial bombing target. In 1980, a variety of mafic and ultramafic xenoliths (including dunites, lherzolites, pyroxenites, and gabbro) were collected there by D.G. Grooms and M.O. Garcia in conjunction with two environmental assessment projects conducted by several U.S. government and state agencies. The pyroxenites, many of which bear garnet and/or spinel, were selected as the main subject in this study. Also chosen for study were: 1. an olivine websterite because it is the only sampled pyroxenite with appreciable olivine (24%), and olivine plays an important role in Salt Lake pyroxenites, 2. a composite xenolith because of its potential role in providing a link between pyroxenites and some dunites, and 3. a dunite, for the purpose of comparing mineral compositions among xenolith suites.

II. PREVIOUS WORK ON HAWAIIAN PYROXENITES

Xenoliths from the well-known Hawaiian garnet pyroxenite occurrence, Salt Lake and adjacent craters on Oahu, have been the subject of much petrologic debate (eg., Frey, 1980; Wilkinson, 1976). In particular, the following questions about garnet pyroxenites and pyroxenites have been raised: a) are the pyroxenite xenoliths genetically related to dunite and lherzolite xenoliths in the same tuff deposits (particularly when occurring as composites), and if so, through what mechanisms? b) how do the pyroxenites form? c) what role do they play in the generation of Hawaiian basalts? and d) are they volumetrically important in the mantle? In addressing these questions, four origins have been proposed for garnet pyroxenites and pyroxenites.

1. They represent liquids, parents, and residua related to the partial melting which produced their nephelinitic hosts (Beeson and Jackson, 1970);
2. They are subcalcic clinopyroxene cumulates precipitated at 13-18 kbar pressure (40-60 km depth). Green (1966) proposed an olivine-rich alkalic basalt or basanite as the magma from which they accumulated. Wilkinson (1976) and Herzberg (1978) stated that the liquid from which the pyroxenites crystallized was picritic and derived by the anatexis of spinel lherzolites;
3. They originated as trapped pockets of fractionated basaltic magma which crystallized at 13-18 kbar pressure (Kuno, 1969).

III. PROPOSED WORK

In this study, the thermal history of Kaula garnet pyroxenites and pyroxenites is deduced from examination of mineral textures and compositions. Also, features produced in the xenolith by interaction with the enclosing basalt are investigated. Finally, these xenoliths offer an additional opportunity to examine the upper mantle under the Hawaiian Ridge, as well as provide a comparison with results of others on samples from Salt Lake Crater.

IV. METHODS OF STUDY

Mineral analyses were obtained using a Cameca-MBX electron microprobe with natural and synthetic standards. 5 X 7 photographic prints of the thin sections were used in order to facilitate grain location during microprobe work. Programs of standard calibrations for each mineral group analyzed are included in Appendix A. Both internal and external standards were used where available (the mineral which was used in the standardization process was analyzed against itself, and other mineral standards were analyzed as internal controls). Instrument operating conditions were 15 kV and 10 to 15 nA beam current (lower value used for glass analyses). A focused beam (1 micron beam diameter) was used for mineral analyses, and a slightly defocused beam (approx. 5 micron beam diameter) for glass analyses. (The latter beam size was selected as a compromise between the size limitation imposed by the dimensions of the glass patches and the detrimental burning effect of the intensity of a focused beam.) Each mineral analysis presented in Appendices C through I (Mineral Analyses) and used as a member in the average (N =) presented in the Mineral Composition Tables is an average of three to six analyses from a small area of a grain. Due to the large grain size of some of the minerals involved, two or three areas within the same grain were commonly analyzed to check for overall homogeneity. To check for zoning, some core and rim analyses were made. Two to six grains (occasionally more) were analyzed for each xenolith sample. Raw data were corrected for dead time of detectors and spectrometer background. A correction for beam current drift was unnecessary because a beam current regulation system continuously controls the current to within 0.1 nA/hour. Mineral analyses were then obtained using ZAF correction methods (Henoc and Tong, unpubl.). Accuracy is estimated to be 1-2% for major elements and 5-10% for minor elements. Complete mineral and glass microprobe results are given in Appendices C through I.

V. PETROGRAPHY OF KAULA PYROXENITE AND DUNITE XENOLITHS

Two clinopyroxenites (cpxites), six websterites, one olivine websterite, a composite consisting of dunite and websterite, a dunite, and a clinopyroxene megacryst were examined in this study. The modes for these samples are presented in Table 1, and plotted on Figure 3. Because of the coarse grain size and non-uniform distribution of phases (particularly garnet and spinel), the modes are considered to be approximate. Because of mineral or textural variation seen in hand sample, two thin sections were sometimes made from the same rock (see Table 1). Full petrographic descriptions are presented in Appendix B.

Mineralogy

Pale green clinopyroxene (cpx) occurs in all of the samples studied here and is the most abundant mineral in the pyroxenites. Its modal proportion varies from 34% (KA 102) to 71% (KA 110 A,B). In the dunites, cpx constitutes only 1-3% of the rock. Orthopyroxene (opx) commonly occurs as exsolution blebs and lamellae of variable sizes, and as myrmekitic exsolution. Spinel exsolution from cpx as small thin plates or rods is particularly prominent in some samples.

Commonly displayed in Kaula pyroxenite clinopyroxenes is a feature here termed cpx "patches", which are irregularly-shaped areas within cpx grains where extinction behavior and birefringence are slightly different compared to the host grain (see Plate I). Translucent gold- and rust-colored glass and cloudy opaque brown material outline the

TABLE 1

MODAL PROPORTIONS OF MINERALS IN KAULA PYROXENITE AND DUNITE XENOLITHS

Smpl # (KA #)	Name	CPX	OPX	GT	SP	OL	Fibr px+sp /sp rxn rim	glass	phl	opaq	unk. non-opaq
107	Gt sp cpxite	46	5	19	16	tr	7	2	-	1	4
105	Gt cpxite	58	7	19	4	tr	-	-	-	10	2
108A)	Webst area	60	27	-	2	tr	2	-	-	6	3
108B)	of Webst/Gt sp webst	55	32	tr	1	-	3	-	-	7	2
109	Gt webst	64	19	9	2	-	2	tr	tr	2	1
106	Sp webst	64	20	tr	5	tr	3	-	-	4	3
103	Sp webst	64	13	-	7	tr	14	-	-	-	2
110A)	Webst	71	25	tr	1	tr	1	-	-	1	tr
110B)	(cpxite w/ exsol. opx)	69	23	1	tr	-	5	tr	-	1	1
104	Webst	55	43	-	-	-	-	-	-	2	tr
102	Ol webst	34	25	-	5	24	7	-	-	1	4
101	Compos. D	1	6	-	3	90	-	-	-	-	-
	dun/webst W	50	40	-	2	2	-	-	tr	-	6
100	Sp dunite	3	-	-	8	89	-	-	-	-	-

Footnotes: For samples KA 107 through 104, full rectangular slides were used, and approx. 800 to 1300 points counted, except for KA 110 A and B, where half of a rectangular slide was counted, resulting in approx. 440 points.

For KA 102 to KA 100, circular slides were used, so 400 to 430 points were counted.

For samples KA 108 and 110, "A" and "B" designate two slides made from the same rock because of mineral or textural variation seen in hand sample. The A,B notation will not always be used later.

Abbreviations: CPX = clinopyroxene, OPX = orthopyroxene, GT = garnet, SP = spinel, OL = olivine, px = pyroxene, fibr = fibrous, rxn = reaction, phl = phlogopite, opaq = opaque, unk. = unknown, cpxite = clinopyroxenite, webst = websterite, exsol. = exsolved, compos. = composite, dun = dunite

Figure 3. -- Plot of modal proportions in Kaula pyroxenite and dunite xenoliths.

Symbols: solid symbols = this study (abbreviated sample numbers used), open symbols = from Grooms (1980), triangles = spinel abundance 1 to 4%, circles = spinel abundance 5% or greater, OL = olivine, OPX = orthopyroxene, CPX = clinopyroxene, GAR = garnet, DU = dunite field, LZ = lherzolite field, OW = olivine websterite field, WB= websterite field, GW = garnet websterite field.

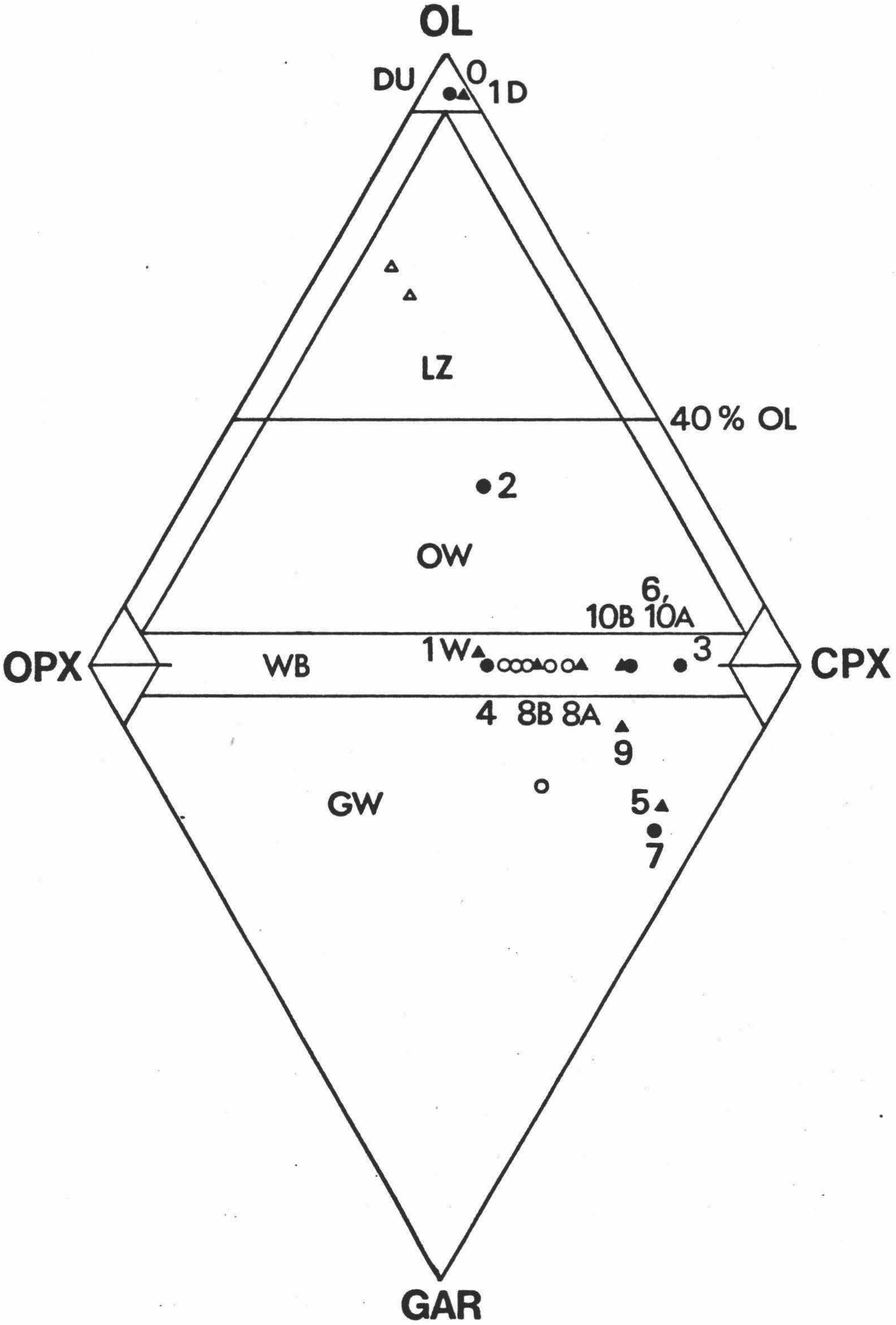
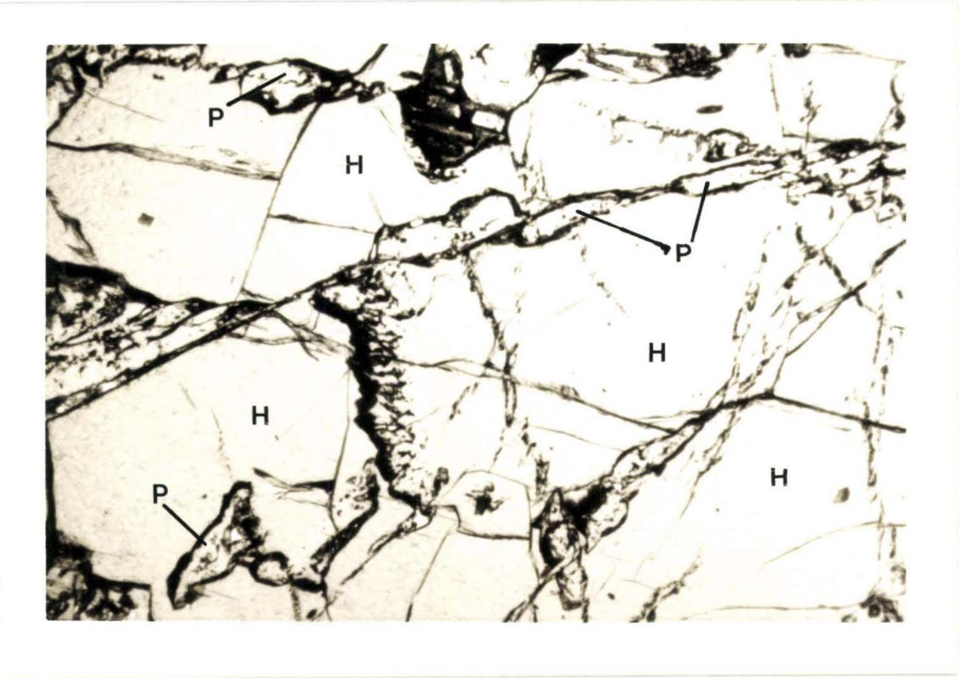

OL
DU
0
1D
LZ
40 % OL
2
OW
6,
10B 10A
OPX
WB
1W
3
CPX
4
8B
8A
9
GW
5
7
GAR

Plate I. — Photomicrographs of clinopyroxene "patches" in a garnet-spinel clinopyroxenite (KA 107).

A. Clinopyroxene "patches" with a linear pattern. One optically continuous clinopyroxene host grain comprises the entire field of view. Plane polarized light, black and white photomicrograph.

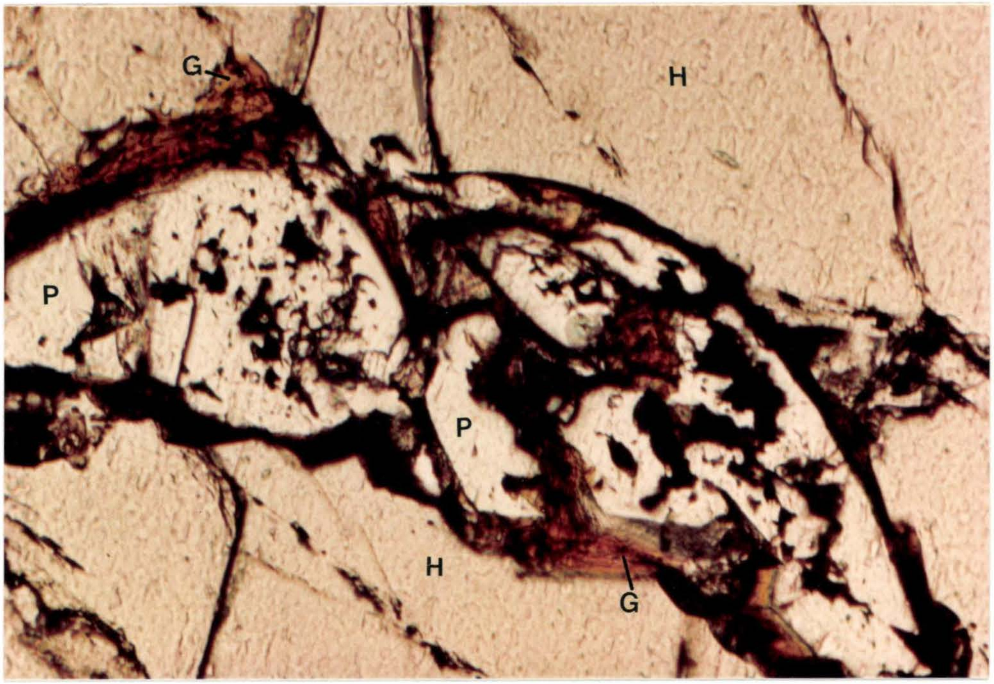
B. Detail of a clinopyroxene "patch". Close-up of Plate 2B. Plane polarized light, color photomicrograph.

Symbols: P = clinopyroxene "patch", H = clinopyroxene host grain, G = glass.



A

1 mm



B

0.1 mm

patches, and small beads of glassy material are present within the patches. Rare microcrystallites occur in the glass. The brown, cloudy opaque material which presumably replaced glass is probably fine-grained clay, based on its high silica (44-50 wt%) and alumina (23-27 wt%) content. It has low relief and an irregular, dull surface under reflected light.

The distribution of patches within cpx grains is erratic. Although some appear to follow cleavage planes, they generally lack a preferred orientation. Instead, their occurrence and distribution seems to be controlled by an irregular fracture system. The best examples of patches are seen in KA 107 (garnet-spinel clinopyroxenite; see Plate 1), but they are present in most of the pyroxenites to a limited extent.

In some cases, where cpx is in contact with the host basanitoid, this feature has developed as a rim (KA 108 and 38megacryst). Patchy rims are present in KA 102 (olivine websterite), but host basanitoid is not present in the specimen. Patchy rims are similar in petrographic appearance to cpx patches, except that they occur along cpx grain margins. (Note that the use of the term "rim" is different than the "core-rim" usage; in this study, "rims" refers to the patchy-type rim, unless reference is explicitly made to "core and rim").

Irregular areas and veins of glass producing a sieved appearance in cpx were observed in xenoliths and megacrysts from New South Wales (Wass, 1979). "Porous" rims were reported in lherzolite and wehrlite xenoliths from several localities in Hawaii (White, 1966).

Clinopyroxene also rarely occurs as a thin (approx. 0.1 mm), tan-colored overgrowth at the contact of the xenolith or megacryst and host basanitoid. This overgrowth of cpx is similar in appearance to cpx which grew from the host basanitoid. Similar overgrowths were observed by White (1966) and Wass (1979).

Orthopyroxene, generally pleochroic pale green to straw yellow, occurs as exsolution lamellae and blebs, and as rare discrete grains. An exception is in KA 104 (websterite), where opx occurs as common porphyroclasts. It also occurs as part of garnet kelyphitic rims and fibrous intergrowths, discussed below. Its modal abundance ranges from 5% (KA 107) to 43% (KA 104) in the pyroxenites. Opx is present in only one of the dunites, KA 101D; its mode is 6%. Minor cpx exsolution lamellae and blebs are common in opx.

Garnet is colorless in thin section but deep red in hand sample. Some of the pyroxenites and both dunites lack garnet. Its abundance ranges from a trace (in KA 108, 106, 110) to 19% (in KA 105, 107). Garnet has been observed in three modes of occurrences; as large (up to 1.5 cm diameter) porphyroblasts, as lobate grains enclosing spinel, and as small, isolated grains. Micro-inclusions or exsolutions of thin spinel platelets occur in one garnet sample (KA 105, gt cpxite).

Garnet kelyphitic opx + spinel intergrowth is common in Kaula garnets. It has two modes of occurrence: 1) in thin bands between cpx and garnet, where optically continuous opx encloses scattered euhedral spinel (see Plate II); this is referred to as "coarse kelyphitic rim", since the mineral phases are clearly recognizable (> 0.2 mm size), and

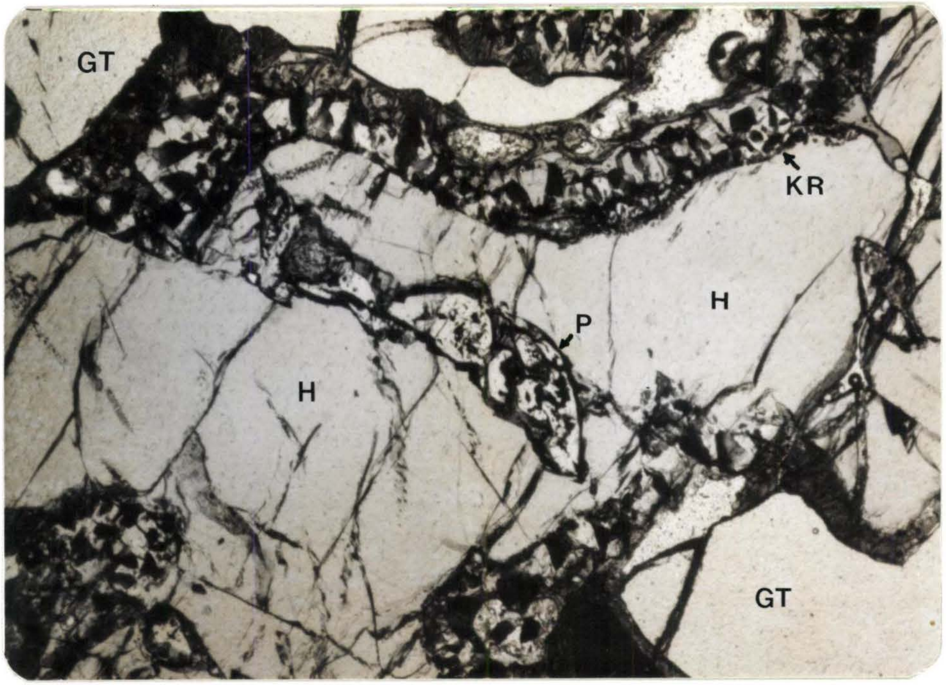
Plate II. — Photomicrographs of a coarse kelyphitic rim in a garnet-spinel clinopyroxenite (KA 107).

A. Coarse kelyphitic rim along garnet/clinopyroxene grain margin. (Clinopyroxene "patch" in center of photo.) Plane polarized light, black and white photomicrograph.

B. Same view as A., cross-polarized light, color photomicrograph. (Box indicates area of Plate 1B.)

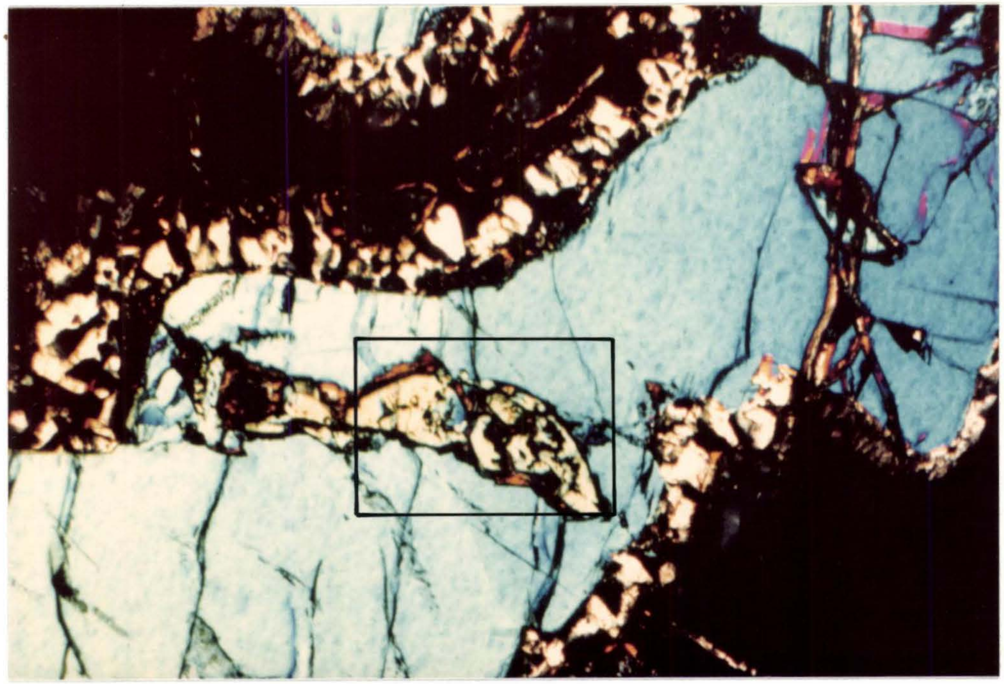
Symbols: KR = kelyphitic rim, H = clinopyroxene host grain, P = clinopyroxene "patch", GT = garnet.

Plate II



A

1 mm



B

1 mm

2) in garnet and near coarse kelyphitic rims, where pyroxene and spinel form a fibrous, radial intergrowth (see Plate III); this is referred as "fibrous kelyphitic intergrowth" or "fibrous intergrowth". In the second type, the two phases are discernable only in areas where the individual platelets making up the fibers are coarsest (0.02 mm diam). Rarely, brown turbid material occurs in fractures and as an inner rim with a kelyphitic outer rim. Glass with fine opaque particles and sulfides is also common near kelyphitic features.

The breakdown of garnet to an intergrowth of spinel + pyroxene was reported in Salt Lake xenoliths by Green (1966) and Kuno (1969). It is not always petrographically obvious that the coarse kelyphitic rims are produced from garnet; in many cases the texture looks like it formed from reaction between cpx and garnet, and might be better termed "garnet-cpx reaction". However, to be consistent with Green's terminology, it will be referred to as "coarse kelyphitic rim". Also, although the most common configuration of the coarse kelyphitic intergrowth rim is as a thin band, it may also be found as equant clusters. These two features are best developed in KA 107, a garnet-spinel cpxite, and KA 108, a websterite/ garnet-spinel websterite.

Gray green to dark gray spinel ranges in abundance from a trace (KA 110B) to 16% (KA 107) in the pyroxenites. It is not present in KA 104. Spinel occurs as inclusions in garnet and cpx, and interstitially; it has a lobate shape, commonly with rounded, smooth grain boundaries. It is also present in kelyphitc rims on garnet as

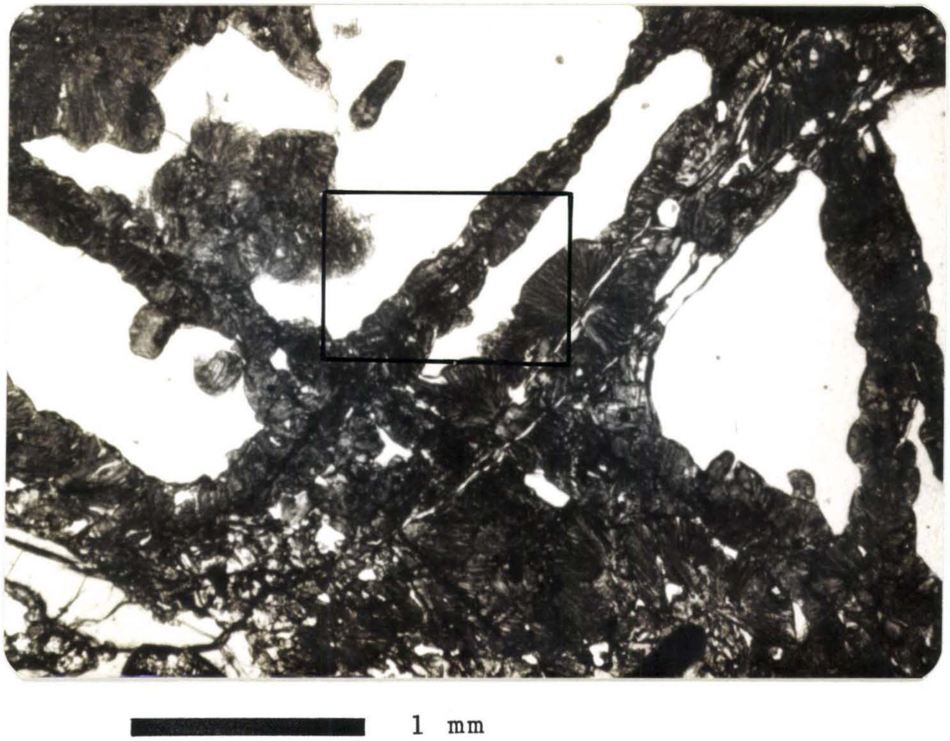
Plate III. — Photomicrographs of fibrous intergrowth in a garnet-spinel websterite (KA 108).

A. Fibrous intergrowth. (Box indicates area of Plate 3B.)

B. Detail of fibrous intergrowth.

Colorless area = garnet. Both plane polarized light, black and white photomicrographs.

Plate III



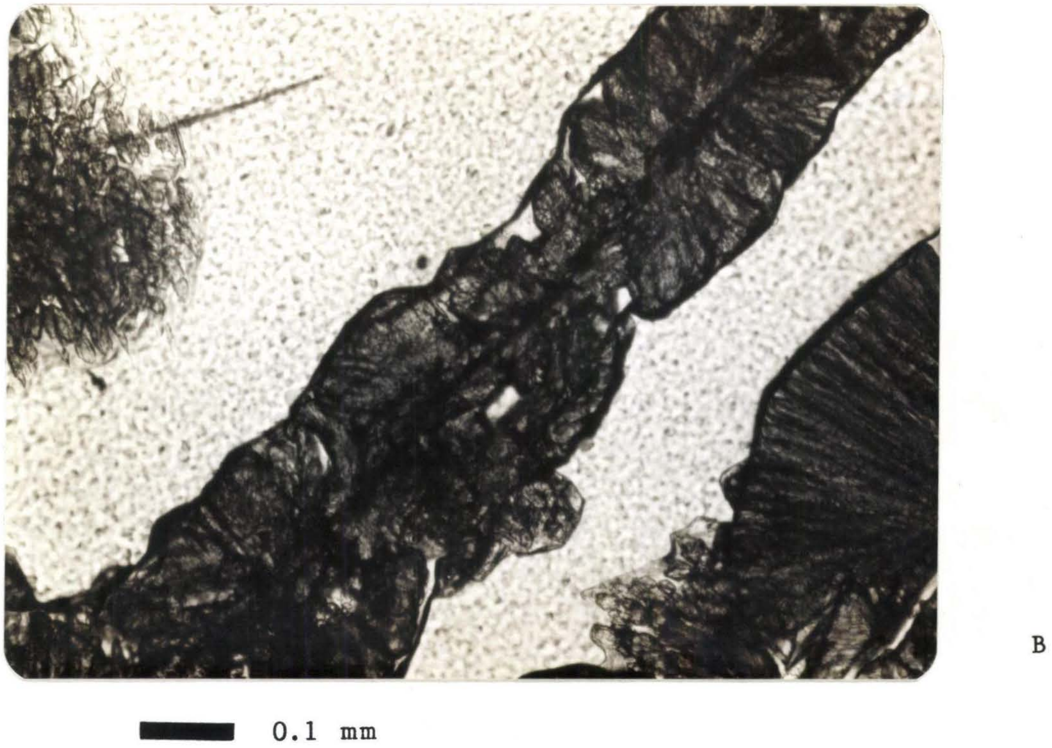


Plate III., continued. -- Photomicrographs of fibrous intergrowth in a garnet-spinel websterite (KA 108).

C, D. Details of fibrous intergrowth. In both photos, fibrous intergrowth = top half, coarse kelyphitic rim = lower half. Both plane polarized light. C is a color photomicrograph, D is a black and white photomicrograph.

Symbols: O = orthopyroxene, S = spinel, G = glass.

Plate III (con'd)

C

D

small euhedral grains, as part of a fibrous intergrowth with pyroxene (eg., KA 108 A,B), and as exsolution in cpx and opx. In the dunites, spinel comprises 3 to 8% of the rocks. KA 101D has anhedral to subhedral gray green spinel. It occurs interstitially and as inclusions in olivine and pyroxene. KA 100 has lobate, red-brown spinel, up to 4 mm in length, which includes olivine and cpx grains and occurs interstitially.

Olivine is present in most of the pyroxenites as a trace constituent, except in KA 102 (olivine websterite: 24% olivine). Olivine has a variety of occurrences: 1) interstitial, 2) included in cpx, 3) isolated grains, 4) skeletal grains in glass, 5) small grains in a triangular patch and vein areas, and 6) as an overgrowth (secondary olivine) in areas where the enclosing basalt has invaded the xenolith. Most grains are lobate to very irregular in shape, suggestive of resorption. In the dunites, olivine is the chief constituent, making up 90% of the rocks. Weakly-developed kink-banding is present in the dunites and in KA 102. Thin, dusty opaque reaction rims on olivine occur in KA 102.

Trace amounts of pale brown glass are present in several pyroxenite samples. Glass occurs: a) near coarse kelyphitic rims and fibrous intergrowths, b) surrounding and within cpx "patches", c) with skeletal olivine, in pockets inside the xenolith, and d) in veins, rarely extending from the xenolith into the host basalt. Color varies from pale brown to rust and gold-orange; in places glass has been replaced by cloudy, brown clay. Some areas of glass contain crystallized phases, for example, skeletal olivine, plagioclase microcrystallites, blebs of sulfides, or fine opaque particles. Rare vesicles occur in the glass.

Rock textures

The pyroxenite samples typically have a medium to coarse allotriomorphic-granular texture (as used by Pike and Schwarzmann, 1977). Also exhibited in these specimens are porphyroblastic, poikilitic/subpoikilitic, and porphyroclastic textures. Reaction textures between various phases in these rocks are fairly common, and in some cases involves glass; these will be discussed below. The two dunites (KA 101D, 100) are medium-grained and equigranular. Triple point grain junctions are common. One sample (KA 100) has a weak foliation, defined by spinel.

Clinopyroxene morphology and texture

Because it is the predominant mineral present, variations in cpx morphology strongly influence the texture of the pyroxenites.

Two cpx morphologies are observed. In one type, cpx grains are variable to large in size (2.0 mm to 3.0 cm), and have easily discernable and traceable grain boundaries. Cpx of this type commonly have cpx patches, bleb-like inclusions in healed fractures, and relatively small amounts of opx exsolution. In KA 107 (garnet-spinel clinopyroxenite), KA 105 (garnet cpxite, see Plate IV), KA 103 (spinel

Plate IV. -- Clinopyroxene morphology in a garnet clinopyroxenite (KA 105).

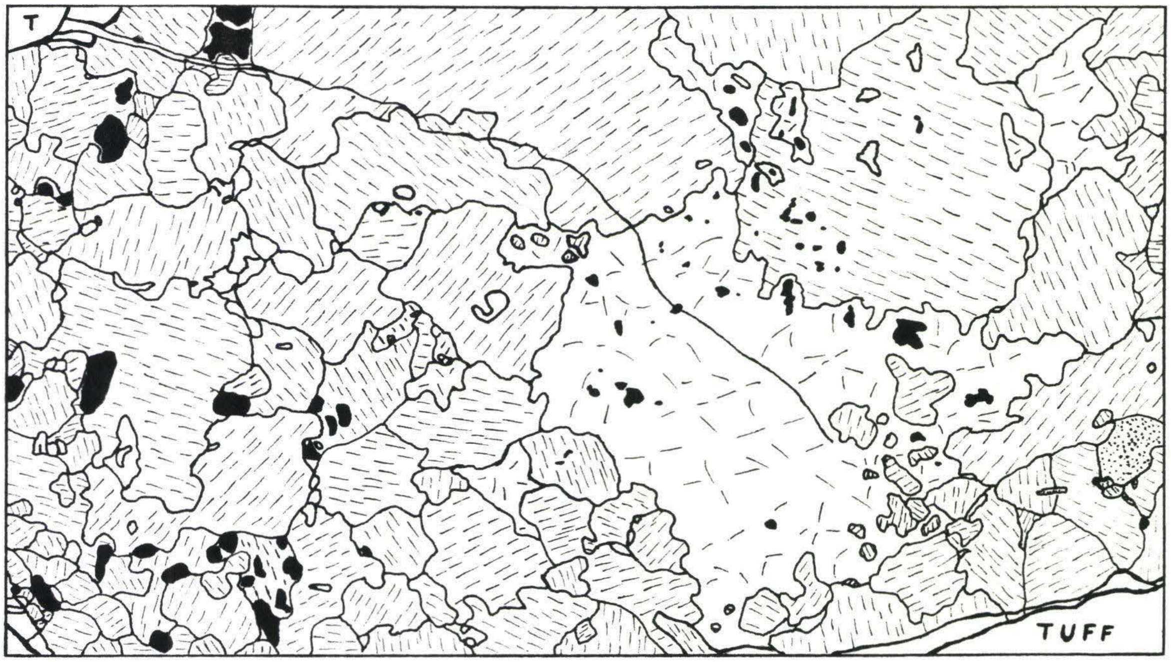
Clinopyroxene: large to variable-sized, with easily discernable and traceable grain margins.

A. Sketch of grain relationships.

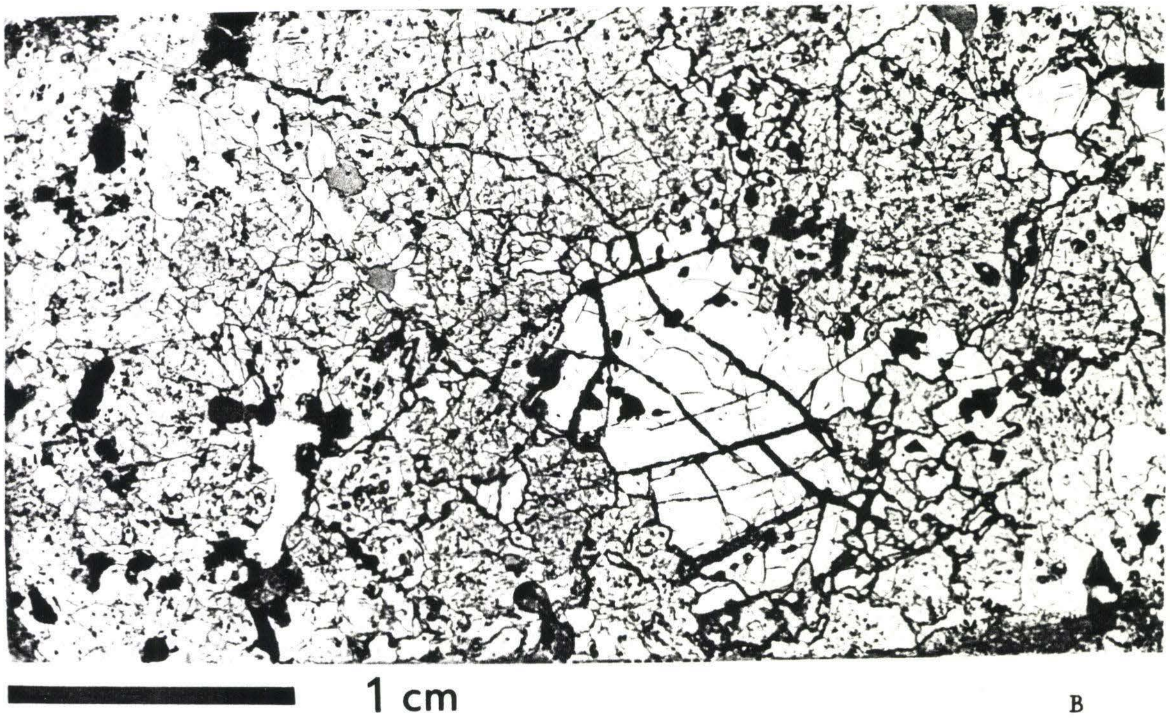
B. Photograph of the thin section, showing the area used for the sketch.

Symbols: parallel dashes = clinopyroxene, random dashes = garnet, solid black = spinel, small dots = olivine, no symbol = orthopyroxene, T = tuff.

Plate IV



A



B

websterite), KA 108 (websterite/ garnet-spinel websterite), KA 102 (olivine websterite), and KA 101W (websterite), the cpx is predominantly of this type. In the second type, variable-sized (1.0 mm to 1.0 cm) cpx is deformed. Grain boundaries based on optical continuity are commonly convoluted and cross-cut by segments of neighboring grains. The opx exsolution in this type of cpx occurs in a variety of sizes and shapes (lamellae, rods, and blebs) within the same optically continuous host grain. Associated with these, in one sample (KA 104 websterite), are smaller mosaic-like cpx grains which lack opx exsolution and are distinctive due to their clarity, small size, and equant morphology. The disrupted type of cpx is characteristic of KA 104, 106 (sp webst), and 110 (webst), although the latter two have a few of the cpx grains with discernable boundaries (see Plate V, KA 106). KA 109 (gt webst) has both types: variable-sized, easily discernable cpx in a band near porphyroblastic garnet, surrounded by the extensively exsolved and disrupted type (see Plate VI, KA 109).

In some of the pyroxenites, large, optically continuous cpx grains have areas where spinel and/ or garnet formed at the expense of the cpx. In one case, (KA 107, gt sp cpxite), one optically continuous clinopyroxene grain comprises almost the entire thin section (3.0 cm length). In many places there is so much garnet and spinel that the cpx has been reduced to small "islands", yet optical continuity between the cpx islands and the main cpx grain is commonly still preserved. The optical continuity of the cpx around areas of garnet, spinel, and reaction suggests that the original cpx was partially consumed by the

Plate V. -- Clinopyroxene morphology in a spinel websterite (KA 106).

A. Sketches showing detail of clinopyroxene grain relatonships. (1) = large to variable-sized clinopyroxene grains with easily discernable and traceable grain margins. (2) = Variable-sized to small clinopyroxene grains, with complex, disrupted grain relationships; clinopyroxene grain margins are difficult to discern.

B. Photograph of the thin section, showing the location of the sketches. Both types of clinopyroxene are present in a random distribution, although the disrupted type is more common in this sample.

Symbols: no pattern = clinopyroxene, solid black = spinel.

Plate V

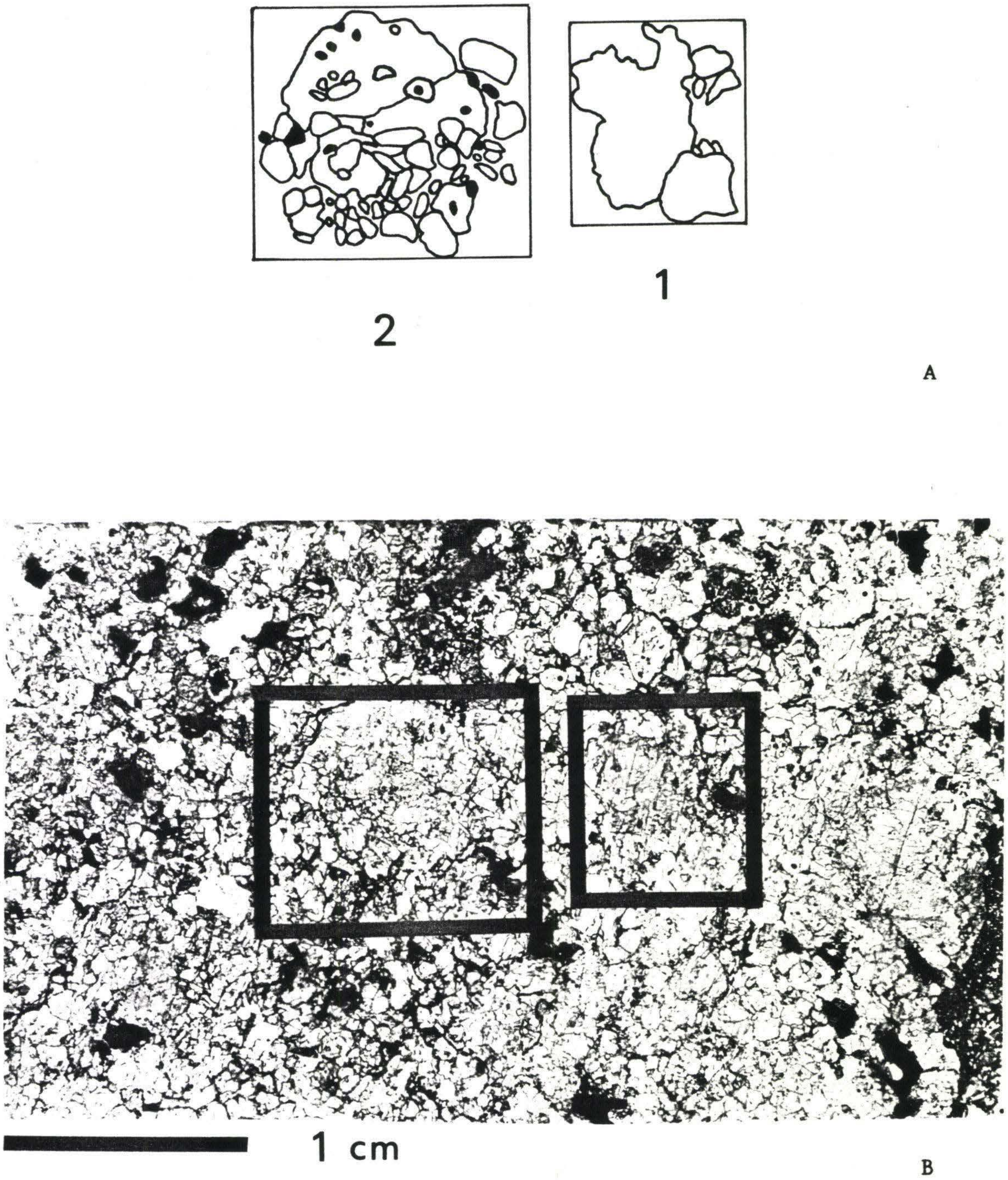


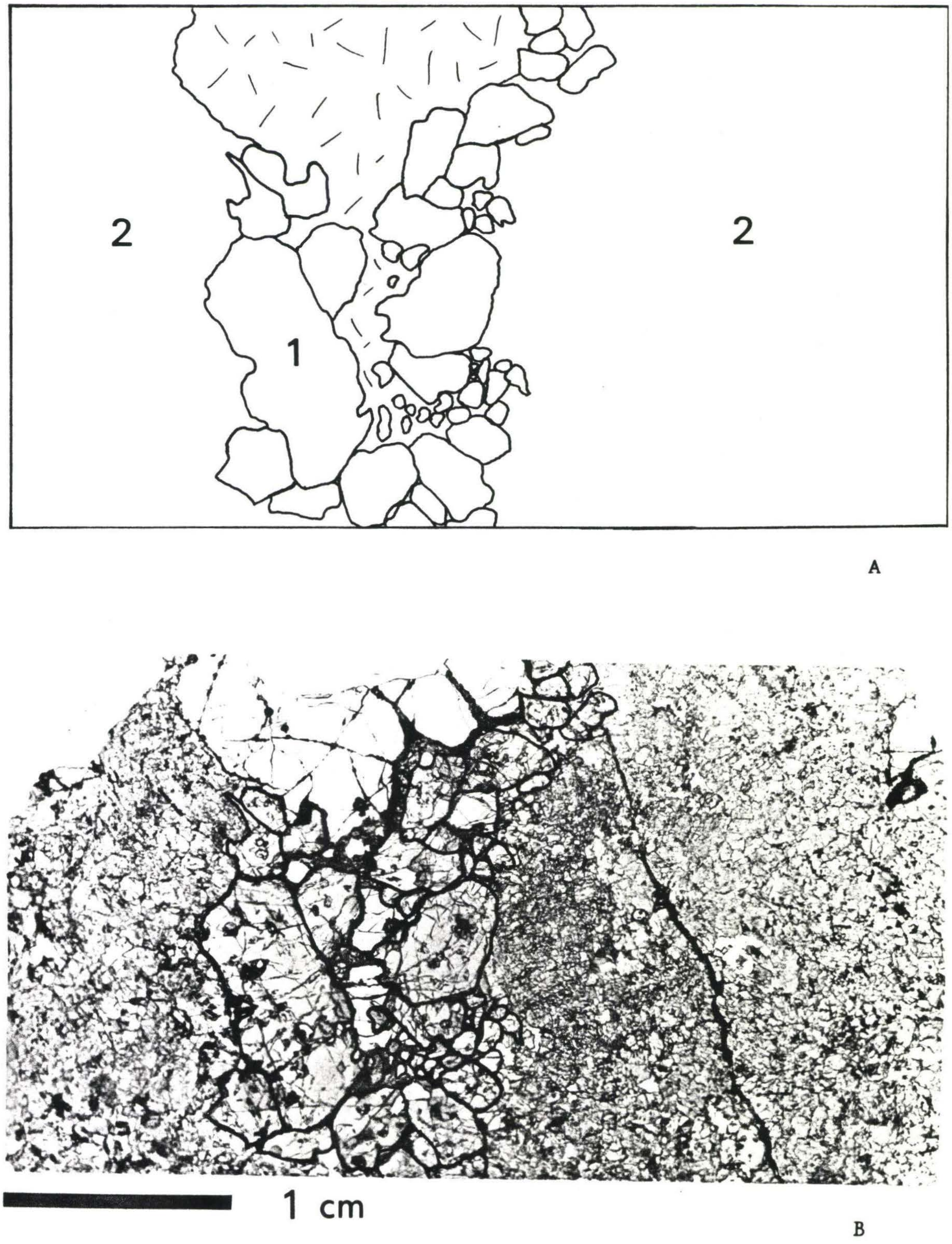
Plate VI. -- Bands of contrasting clinopyroxene morphology in a garnet websterite (KA 109).

A. Sketch showing the location of (1) a band of large to variable-sized clinopyroxene with easily discernable and traceable grain margins, and with garnet; grain margins within the band are outlined, and (2) areas of disrupted and chaotic clinopyroxene, where grain margins are difficult to discern.

B. Photograph of the thin section of KA 109. (Clinopyroxene grains within the band have been outlined on the photograph).

Symbols: no pattern = clinopyroxene, random dashes = garnet.

Plate VI



formation of one or more of these phases.

Generally, Kaula pyroxenites lack foliation. However, one exception is a crude subparallel banding which can be seen in certain areas of one pyroxenite, KA 110B. It is defined by the combination of the following: a) elongate cpx grains, based on optical continuity, b) long, narrow cpx grains with a different optical orientation, included in larger cpx grains, and c) the roughly parallel orientation of opx exsolution to features a) and b). Opx exsolution of the same optical orientation clearly crosses subgrains and grain boundaries.

Due to mineral reactions, a dichotomous texture is present in one pyroxenite, KA 108 (websterite/ garnet-spinel websterite; see Plate VII). This sample has a cpx-rich area juxtaposed with an area composed of garnet, spinel, and extensively developed kelyphitic opx + spinel intergrowths, both coarse and fibrous. Also in the latter area are glass, opaque material, and a few cpx grains. Rare clusters of equant opx grains occur in both areas. Opx which is part of the coarse kelyphitic intergrowth is generally quite coarse compared to occurrences of this feature in other Kaula samples. It is interesting that the garnet in this rock has no or very small spinel cores.

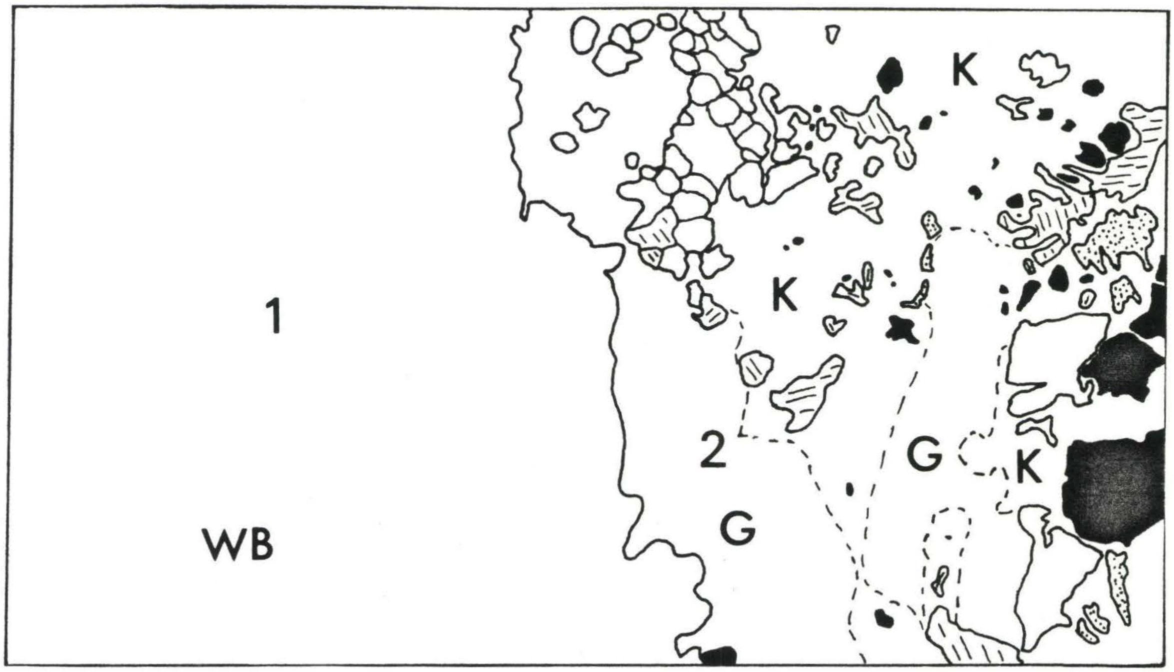
Plate VII. — Abrupt change in texture and mineralogy in a websterite/ garnet-spinel websterite (KA 108).

A. Sketch showing (1) websterite area, and (2) area rich in garnet, spinel, and garnet kelyphitic intergrowths.

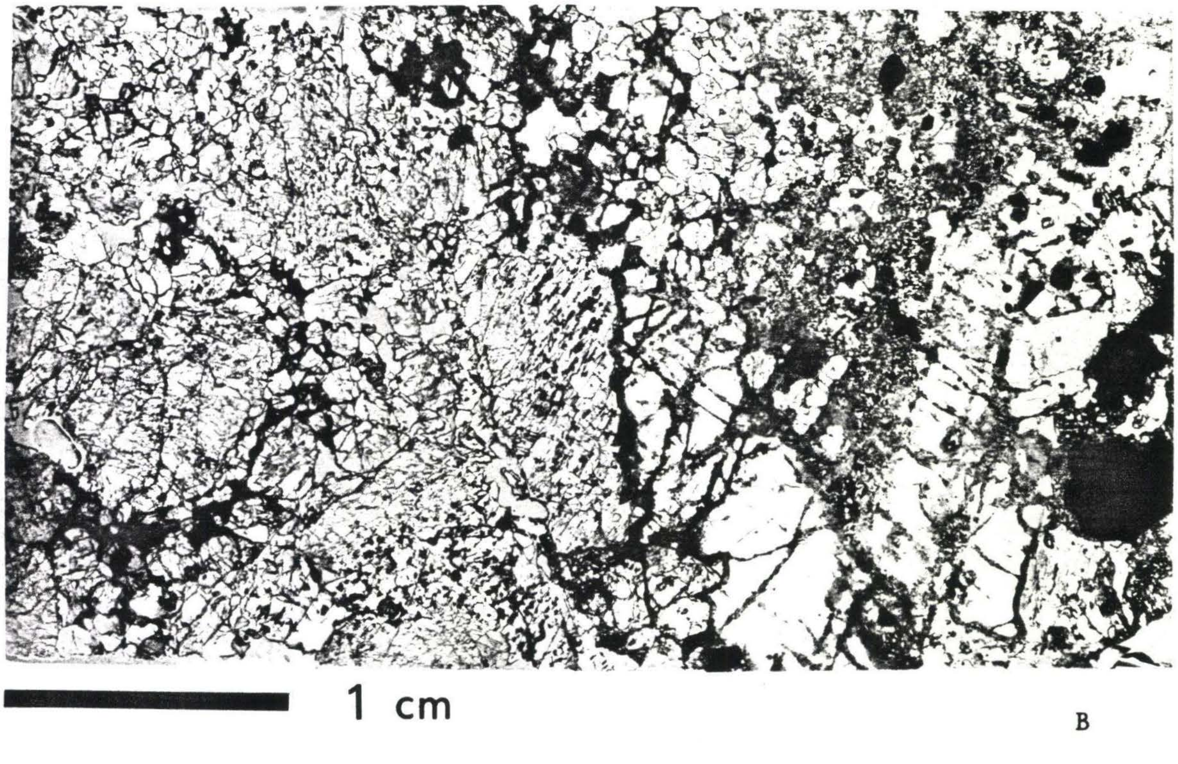
B. Photograph of the thin section showing the same area as in the sketch.

Symbols: WB = websterite, G = garnet, K = kelyphitic intergrowths, parallel dashes = clinopyroxene, solid black = spinel, dots = olivine, outlined grains with no pattern = orthopyroxene, large areas with no pattern (on side 2) = garnet and kelyphitic intergrowths: major areas of each separated by the dashed line.

Plate VII



A



B

Other Petrographic Notes on Kaula Xenolith Thin Sections

A petrographic summary of points not mentioned in the above section is presented below, in order to supplement the descriptions of the rocks examined in this study.

In KA 107 (garnet-spinel clinopyroxenite), there is only one small area in the cpx where opx exsolution is visible. About a dozen thin, short, planar lamellae are present, and in this same location is the only occurrence in this rock of gray-green spinel exsolution (as small platelets). Cpx patches are very well developed. Slight changes in extinction angle in some areas of the cpx grains are common, and probably define subgrains. The subgrain boundaries thus defined are very irregular in places. Rarely a cpx grain has a thin overgrowth rim of cpx. Garnet forms partial or complete coronas around spinel. The ratio of the amount of garnet in a corona to its spinel interior varies remarkably through the thin section. Coarse kelyphitic rims at garnet/cpx margins are pervasive. Fibrous intergrowth occurs at grain margins, and with glass, at grain margins and in cpx fractures.

KA 105 (garnet clinopyroxenite) has porphyroblastic garnet with serrated margins, spinel and cpx inclusions, and garnet breakdown products; uneven distribution of ovoid spinel; an area of discrete opx grains; and regions in cpx especially rich in spinel.

KA 103 (spinel websterite) is notable for profuse spinel inclusions/exsolutions in/from cpx, large irregularly shaped opx bleb exsolutions from cpx, and small oval inclusions of olivine mantled by opx in cpx.

KA 104 (websterite) has large, rather equant opx porphyroclasts which stand out against extensively exsolved, disrupted cpx and mosaic cpx grains. The exsolution of cpx from opx is much more rational and less extensive than the exsolution of opx from cpx.

KA 102 (olivine websterite) is characterized by olivine-rich and pyroxene-rich areas. Olivine and pyroxene grain margins have thin, dusty opaque rims. Spinel is included in olivine and cpx and occurs interstitially. Vapor bubbles (<0.01 mm diam.) in fluid inclusions occur in an opx grain with a dusty appearance and which grades into an opx + spinel intergrowth area.

KA 101, a composite xenolith, consists of websterite and dunite with a sharp, fairly straight contact between the two. The websterite is generally coarser grained than the dunite; triple points are fairly common in both rock types. The distribution of pyroxene varies towards the contact through the websterite area. Furthest from the contact, in the websterite area, are variable-sized cpx. The type, size, and amount of opx exsolution in cpx varies from grain to grain and within a grain, and in some cases two orientations of opx exsolution are present. Some small discrete opx grains are present in this area, but often it is ambiguous whether they formed by coalescence and migration of exsolutions or originated as discrete grains. The cpx has prominent dusty opaques within areas in the grains, and occasionally a cpx patch occurs. Also present in trace amounts are irregularly shaped interstitial spinel, other spinel as exsolution from opx and cpx, and also small subhedral to skeletal olivine grains in a vein. Moving toward the contact from this area, large opx with cpx exsolution predominate, with smaller opx grains present at the contact. Trace phlogopite is included in one of the large opx. A train of small subhedral to euhedral spinel parallels the contact, just inside of the dunite portion (interstitial and included in olivine). The dunite is much more equigranular than the websterite, and the pyroxene is scattered randomly among the olivine (no foliation). Opx tends to be coarser-grained than cpx. Rarely, cpx is present as a cluster of a few small grains, as if a larger grain had been broken. Spinel is included in olivine and rarely occurs interstitially.

KA 100 is noted for its large olivine and red-brown spinel (both up to 4 mm length). The spinel defines a foliation. Olivine also includes spinel. Cpx has no opx exsolution. Vapor bubbles (<0.01 mm diam.) in fluid inclusions have been found in both cpx and olivine.

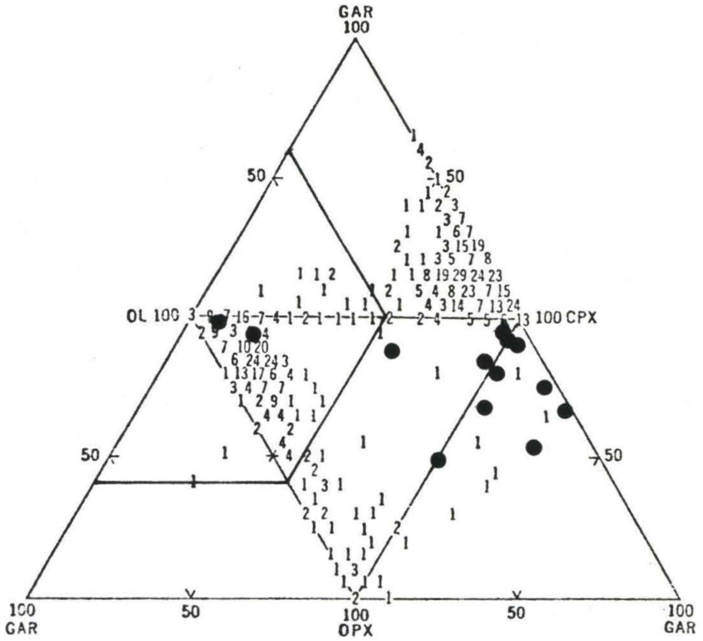
Comparison with Pyroxenite Xenoliths from Salt Lake Crater

A broad comparison between Salt Lake and Kaula pyroxenite xenoliths can be made by viewing a tetrahedral plot of mineral proportions (Figure 4). Salt Lake pyroxenites cluster in two groups: a) cpx-rich with garnet and olivine, and b) opx-rich with olivine

Figure 4. -- Tetrahedral plot of mineral proportions in xenoliths from Salt Lake Crater and Kaula Island, Hawaii.

Symbols: numbers = total number of specimens at a single plot point, Salt Lake Crater xenoliths (Jackson, 1966). Solid circles = Kaula xenoliths, this study. The heavy line (at 40% olivine) is the boundary between the peridotite field on the left and the pyroxenite field on the right. Mineral symbols as in Figure 3.

Modified from Jackson, 1966.


GAR
100
50
OL 100
100 CPX
50
50
100
GAR
50
100
OPX
50
100
GAR

cpx. Kaula pyroxenites occupy an area (cpx-rich with opx and garnet) that does not overlap with Salt Lake pyroxenite fields. Salt Lake pyroxenites are known for their variability, but typically consist of large (up to 1.5 cm diam.), anhedral cpx and opx grains with unevenly distributed garnet, olivine, spinel, and rare phlogopite, amphibole, and/or plagioclase. In comparing Salt Lake and Kaula pyroxenites in light of Beeson and Jackson's (1970) petrographic descriptions, the main distinguishing feature between the two is the total lack of garnet as an exsolution phase in pyroxene in Kaula rocks. Technically, none of the Kaula pyroxenites fit into the Beeson and Jackson (1970) classification scheme. However, if the requirements regarding garnet exsolution in the Beeson and Jackson definitions of Type 1 through 3 pyroxenites are ignored, then five out of six Kaula garnet-bearing pyroxenites can be fit into that classification system. The large garnet grains in Kaula samples (KA 109, 105) have lobate to serrate contacts with neighboring cpx grains; the optical continuity of cpx across areas of garnet suggests that garnet may have formed at the expense of cpx.

To further investigate the differences and similarities between Kaula and Salt Lake pyroxenites, a suite of thin sections (Pankiwskyj collection) was examined. In Kaula samples, the grain size distinction between the coarse kelyphitic rim and the fibrous intergrowth is notable. Although kelyphitic intergrowth was reported in Salt Lake pyroxenites by Green (1966), no mention of grain size distinctions was made. However, in examining some Salt Lake pyroxenite thin sections, both the coarse and fibrous forms were observed. Rare cpx "patches" have also been observed in some Salt Lake pyroxenites. Kaula pyroxenites tend to contain much less or no olivine in association with garnet, compared with Salt Lake samples. However, the absence of olivine in a pyroxenite which contains garnet, spinel, and phlogopite was noted in one Salt Lake sample (SL 152). This particular sample also contains pervasive reaction; areas of yellow-browm to rust-colored glass, skeletal olivine and glass, fibrous intergrowth, and coarse kelyphitic rim are common.

VI. MINERAL CHEMISTRY

Compositions of each mineral phase and the mineral textural features described in the petrography section are discused below. Petrographic correlations of grain size, shape, and occurrence with chemistry are noted. For summarized mineral compositions, see Tables 2-6.

Clinopyroxene

The clinopyroxenes in the pyroxenites and in the dunite portion of the composite xenolith (KA 101D) from Kaula Island are aluminous augites. The cpx in KA 100 (dunite) is diopside.

In Kaula pyroxenites, cpx occurs as a) large to variable-sized, easily discernable grains, b) variable-sized, disrupted grains, c) patches with glass inside the large grains, and d) rare patchy rims and overgrowths on large grains.

The compositions of the large to variable-sized, easily discernable cpx are generally uniform. For example, in KA 103 (spinel websterite), cpx composition is quite uniform throughout the rock, despite differences in grain size and amount of spinel exsolution. The six locations analyzed within a large optically continuous grain show as little variation in composition as four other smaller grains also analyzed in the same section. This variation is very small and considered to be within the error of the measurements (<2 % relative for each oxide).

However, where there is a variation in composition in this type of cpx, the petrography suggests that reaction has occurred in the rock, and provides a possible reason for the deviation. For example, in KA 108A (webst/ gt-sp webst), fibrous intergrowth, glass, and fine opaques surround the margins of some small grains that have unusual compositions (lower Al_2O_3, Cr_2O_3, and CaO than large cpx grains). Another example is in KA 105 (gt cpxite), where cpx composition is uniform except for a small unusual grain included in garnet which has a thin overgrowth rim and lacks exsolution. It is higher in SiO_2, CaO, and MgO, and is gradational for all elements except SiO_2 between the cpx host and patch compositions; see Table 2.

TABLE 2

CLINOPYROXENE COMPOSITIONS: KAULA PYROXENITE AND DUNITE XENOLITHS

	KA 107		KA 105			KA 108A	
	ave. host	ave. patch	ave. host	incl. in gt	patch	large grains	sm, rxn area
N =	11	2	11	1	1	4	10
Wt. %							
SiO2	48.77	50.94	49.38	50.41	49.34	48.22	48.68
TiO2	1.14	0.62	0.87	0.83	0.58	1.25	1.40
Al2O3	9.69	6.37	9.58	8.37	8.24	10.23	9.20
Cr2O3	0.02	0.08	0.03	0.04	0.12	0.19	0.08
FeO	8.48	6.03	7.11	6.84	5.89	7.46	8.32
MnO	0.11	0.08	0.12	0.14	0.15	0.18	0.17
MgO	12.88	15.21	13.95	14.42	15.95	12.74	12.99
CaO	16.64	19.82	16.94	17.21	18.06	17.29	16.89
Na2O	2.26	1.08	1.90	1.73	1.02	2.07	2.05
SUM	99.98	100.23	99.87	99.99	99.35	99.65	99.77
Fe2O3	4.52	2.39	3.07	1.92	3.13	3.71	3.71
FeO	4.50	3.88	4.34	5.11	3.07	4.13	4.98
SUM	100.42	100.47	100.18	100.18	99.66	100.02	100.15

Cations on the basis of 6 oxygens

	KA 107		KA 105			KA 108A	
	ave. host	ave. patch	ave. host	incl. in gt	patch	large grains	sm, rxn area
Si	1.779	1.851	1.795	1.832	1.798	1.765	1.784
Al z	0.221	0.149	0.205	0.168	0.202	0.235	0.216
Al y	0.196	0.123	0.206	0.191	0.152	0.206	0.181
Ti	0.031	0.017	0.024	0.023	0.016	0.035	0.039
Cr	0.001	0.002	0.001	0.001	0.003	0.006	0.002
Fe 3	0.121	0.065	0.084	0.053	0.086	0.102	0.102
Fe 2	0.137	0.118	0.132	0.155	0.094	0.126	0.153
Mn	0.003	0.002	0.004	0.004	0.005	0.006	0.005
Mg	0.700	0.824	0.756	0.781	0.867	0.695	0.709
Ca	0.650	0.772	0.660	0.670	0.705	0.678	0.663
Na	0.160	0.076	0.134	0.122	0.072	0.147	0.146
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg no.	73.0	81.8	77.8	79.0	82.8	75.2	73.6
Wo	0.403	0.433	0.403	0.403	0.403	0.422	0.406
En	0.435	0.463	0.463	0.469	0.494	0.432	0.435
Fs	0.162	0.104	0.134	0.128	0.103	0.146	0.159

Footnotes: N = number of grains or locations in grains used in the average.

Structural formulae recalculated to 4.000 cations; ferric iron calculated based on stoichiometry.

Mg no. = Mg number, Mg/(Mg+Fe) X 100, calculated with sum of total Fe as FeO.

Fs = Fe + Mn.

K2O was measured in cpx, but none was detected.

TABLE 2., (Continued) CLINOPYROXENE COMPOSITIONS

	KA 108A, cont'd			KA 109			KA 106
	host	patch	rim	ave.	host	patch	ave. large
N =	1	1	1	8	2	2	4
Wt. %							
SiO_2	48.25	48.45	48.47	49.44	49.29	50.24	49.31
TiO_2	1.41	1.23	1.21	0.87	0.96	0.63	0.72
Al_2O_3	9.10	7.01	6.50	8.85	8.61	6.38	9.38
				(8.14-9.53)			
Cr_2O_3	0.06	0.02	0.03	0.17	0.14	0.21	0.13
FeO	8.69	7.38	6.91	6.58	7.07	5.91	6.90
MnO	0.15	0.14	0.11	0.14	0.13	0.12	0.15
MgO	12.98	15.61	14.52	13.88	13.88	15.94	14.59
CaO	16.34	17.90	19.86	18.12	17.08	18.94	17.35
				(17.37-18.54)			
Na_2O	2.09	0.85	0.76	1.89	1.69	0.77	1.76
SUM	99.07	98.59	98.37	99.94	98.85	99.14	100.29
Fe_2O_3	4.04	3.53	3.14	3.95	2.06	1.82	4.26
FeO	5.05	4.20	4.09	3.02	5.21	4.27	3.06
SUM	99.48	98.94	98.68	100.34	99.06	99.32	100.72
Cations on the basis of 6 oxygens							
Si	1.781	1.794	1.806	1.797	1.816	1.844	1.782
Al z	0.219	0.206	0.194	0.203	0.184	0.156	0.218
Al y	0.177	0.100	0.092	0.176	0.190	0.120	0.182
Ti	0.039	0.034	0.034	0.024	0.027	0.017	0.020
Cr	0.002	0.001	0.001	0.005	0.004	0.006	0.004
Fe 3	0.112	0.098	0.088	0.108	0.057	0.050	0.116
Fe 2	0.156	0.130	0.127	0.092	0.161	0.131	0.093
Mn	0.005	0.004	0.003	0.004	0.004	0.004	0.005
Mg	0.714	0.861	0.807	0.752	0.762	0.872	0.786
Ca	0.646	0.710	0.793	0.706	0.674	0.745	0.672
Na	0.150	0.061	0.055	0.133	0.121	0.055	0.123
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg no.	72.7	79.0	78.9	79.0	77.8	82.8	79.0
Wo	0.396	0.394	0.436	0.425	0.407	0.413	0.402
En	0.437	0.477	0.444	0.452	0.459	0.484	0.470
Fs	0.167	0.129	0.120	0.123	0.134	0.103	0.128

TABLE 2., (Continued) CLINOPYROXENE COMPOSITIONS

	KA 106, cont´d		KA 103	KA 110 A,B			
	ave. disrpt.	ave. patch	ave.	ave.	host ave.	patch ave.	highly exsol.
N=	5	2	10	9	2	2	1
Wt. %							
SiO2	49.78	49.73	49.93	49.73	49.21	50.39	50.68
TiO2	0.73	0.63	0.71	0.69	0.85	0.75	0.33
Al2O3	8.43	7.98	8.24	8.75 (7.95-9.66)	8.92	6.26	7.81
Cr2O3	0.25	0.16	0.04	0.18	0.16	0.23	0.20
FeO	6.76	6.42	5.85	6.07	6.26	4.62	7.87
MnO	0.13	0.14	0.10	0.12	0.10	0.09	0.12
MgO	14.78	15.58	14.22	13.66	13.50	17.89	19.44
CaO	17.46	18.08	18.73	18.43	17.79	18.01	12.30
Na2O	1.73	1.29	1.82	1.85	1.78	0.50	1.19
SUM	100.05	100.02	99.65	99.47	98.57	98.74	99.94
Fe2O3	3.81	3.81	3.80	2.92	2.07	1.18	3.35
FeO	3.33	2.99	2.44	3.45	4.40	3.56	4.85
SUM	100.43	100.40	100.03	99.76	98.78	98.86	100.28

Cations on the basis of 6 oxygens

Si	1.805	1.803	1.816	1.816	1.815	1.843	1.819
Al z	0.195	0.197	0.184	0.184	0.185	0.157	0.181
Al y	0.165	0.144	0.169	0.192	0.203	0.112	0.150
Ti	0.020	0.017	0.019	0.019	0.024	0.021	0.009
Cr	0.007	0.005	0.001	0.005	0.005	0.007	0.006
Fe 3	0.104	0.104	0.104	0.080	0.057	0.032	0.091
Fe 2	0.101	0.091	0.074	0.105	0.136	0.109	0.146
Mn	0.004	0.004	0.003	0.004	0.003	0.003	0.004
Mg	0.799	0.842	0.771	0.743	0.742	0.975	1.040
Ca	0.678	0.703	0.730	0.721	0.703	0.706	0.473
Na	0.121	0.090	0.129	0.131	0.127	0.035	0.083
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg no.	79.6	81.2	81.2	80.0	79.4	87.3	81.5
Wo	0.402	0.403	0.434	0.436	0.428	0.387	0.270
En	0.474	0.483	0.458	0.450	0.452	0.534	0.595
Fs	0.124	0.114	0.108	0.114	0.120	0.079	0.135

TABLE 2., (Continued) CLINOPYROXENE COMPOSITIONS

	KA 104		KA 102		KA 101 W,D		KA 100
	large	small mosaic	ave.	patchy rim	webst.	dunite	ave.
N =	1	2	8	2	4	1	7
Wt. %							
SiO2	49.83	50.52	49.81	48.53	48.23	49.08	52.14
TiO2	0.55	0.47	1.13	0.45	1.74	1.32	0.49
Al2O3	9.24	8.37	8.68	10.95	9.76	8.66	4.71
Cr2O3	0.36	0.53	0.07	0.01	0.02	0.39	1.42
FeO	5.12	5.16	6.54	7.75	7.41	5.54	3.14
					(6.04-8.37)		
MnO	0.17	0.14	0.12	0.17	0.13	0.14	0.08
MgO	13.70	14.13	13.66	16.94	14.05	14.52	15.90
					(13.58-14.73)		
CaO	18.99	18.98	17.98	14.19	16.85	17.75	20.30
					(16.02-17.84)		
Na2O	1.73	1.71	1.76	0.73	1.86	1.69	1.45
SUM	99.69	100.01	99.77	99.72	100.05	99.09	99.64
Fe2O3	2.20	2.08	1.82	1.40	4.00	2.52	1.68
FeO	3.14	3.29	4.90	6.50	3.81	3.28	1.63
SUM	99.91	100.22	99.95	99.86	100.45	99.34	99.81
			Cations on the basis of 6 oxygens				
Si	1.813	1.832	1.818	1.760	1.754	1.797	1.894
Al z	0.187	0.168	0.182	0.240	0.246	0.203	0.106
Al y	0.209	0.190	0.192	0.228	0.173	0.170	0.095
Ti	0.015	0.013	0.031	0.012	0.047	0.036	0.013
Cr	0.010	0.015	0.002	0.000	0.001	0.011	0.041
Fe 3	0.060	0.058	0.050	0.038	0.109	0.069	0.046
Fe 2	0.095	0.099	0.150	0.197	0.116	0.100	0.050
Mn	0.005	0.004	0.004	0.005	0.004	0.004	0.003
Mg	0.743	0.764	0.743	0.916	0.762	0.792	0.861
Ca	0.740	0.737	0.703	0.551	0.657	0.696	0.790
Na	0.122	0.120	0.125	0.051	0.132	0.120	0.102
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg no.	82.7	83.0	78.8	79.6	77.2	82.4	90.0
Wo	0.450	0.444	0.426	0.323	0.398	0.419	0.452
En	0.452	0.459	0.451	0.536	0.462	0.476	0.492
Fs	0.098	0.097	0.123	0.141	0.140	0.105	0.056

TABLE 2., (Continued) CLINOPYROXENE COMPOSITIONS

	KA 38megacryst				KA 38
	host	patch	rim	over-grwth	basani. grdmss
N=	3	2	1	1	1
Wt. %					
SiO_2	48.08	49.71	48.73	43.03	41.66
TiO_2	1.72	1.05	1.26	3.46	4.47
Al_2O_3	9.49	7.70	7.96	9.56	9.92
Cr_2O_3	0.01	0.01	0.03	0.10	0.04
FeO	8.92	7.11	6.65	8.09	8.10
MnO	0.13	0.16	0.15	0.08	0.10
MgO	13.05	14.56	14.67	11.40	11.07
CaO	15.98	17.98	19.17	22.98	22.96
Na_2O	2.07	1.30	0.97	0.50	0.44
SUM	99.45	99.58	99.59	99.20	98.76
Fe_2O_3	3.72	2.11	2.89	6.32	6.17
FeO	5.58	5.21	4.05	2.41	2.55
SUM	99.82	99.79	99.88	99.83	99.38

Cations on the basis of 6 oxygens

	host	patch	rim	over-grwth	basani. grdmss
Si	1.769	1.822	1.787	1.618	1.579
Al z	0.231	0.178	0.213	0.382	0.421
Al y	0.180	0.154	0.131	0.041	0.022
Ti	0.048	0.029	0.035	0.098	0.127
Cr	0.000	0.000	0.001	0.003	0.001
Fe 3	0.103	0.058	0.080	0.179	0.176
Fe 2	0.172	0.160	0.124	0.076	0.081
Mn	0.004	0.005	0.005	0.003	0.003
Mg	0.716	0.795	0.802	0.639	0.625
Ca	0.630	0.706	0.753	0.926	0.932
Na	0.148	0.092	0.069	0.036	0.032
Sum	4.000	4.000	4.000	4.000	4.000
Mg no.	72.3	78.5	79.7	71.5	70.9
Wo	0.388	0.409	0.427	0.508	0.513
En	0.441	0.462	0.455	0.351	0.344
Fs	0.171	0.129	0.118	0.141	0.143

In pyroxenite samples which contain both of the two cpx morphologies (easily discernable and disrupted), variablility in composition is common, but there is not a consistent relationship between cpx morphology and composition. For example, in KA 106 (spinel webst), the large, easily discernable cpx have higher alumina (9.4 wt%) than grains from the disrupted area (8.4 wt%); however, in KA 110 (webst), although alumina content is variable (8.0-9.7 wt%), there is no apparent correlation between cpx grain size or form and chemistry.

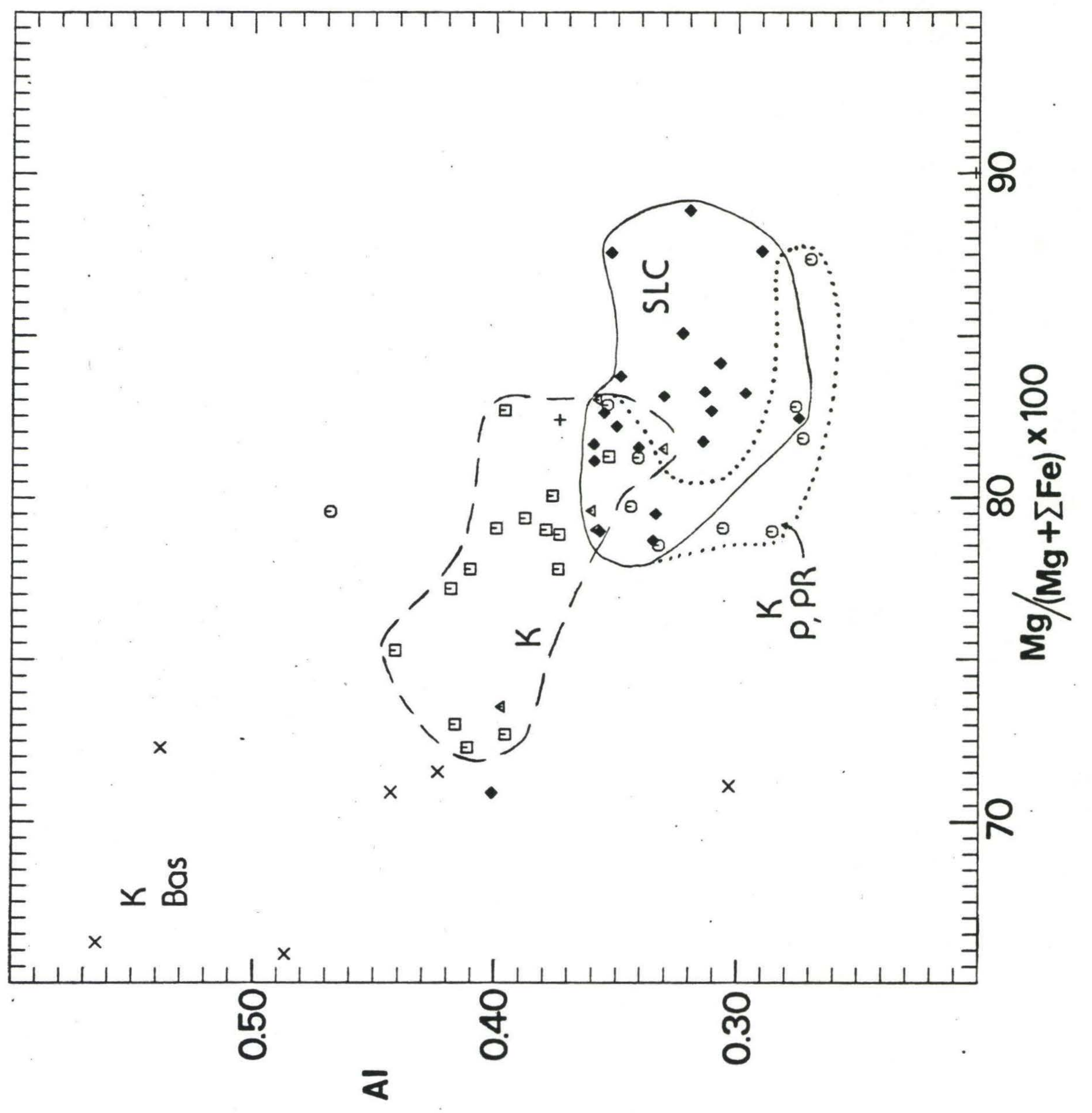
KA 104 (websterite) is a special case, since it has mosaic cpx associated with the disrupted-type cpx. A large disrupted cpx grain with prominent opx exsolution (as blebs and slightly irregular lamellae) has a higher alumina content (9.2 wt%) compared with two very small exsolution-free cpx grains in "mosaic" areas (8.2, 8.5 wt%). The large grain also has lower MgO and SiO_2 compared to the two mosaic grains.

In the websterite section of the composite, KA 101, Mg number of cpx varies substantially, from 74.7 to 81.3.

Although there is some overlap between cpx of the two suites, Kaula pyroxenite cpx has higher Al content and lower Mg number compared with Salt Lake Crater pyroxenite cpx (Figure 5). Kaula cpx patches and patchy rims tend to plot closer to the field of Salt Lake cpx than to Kaula cpx host grains. (Wilkinson, 1976; Reid and Eggleton, 1977; Beeson and Jackson, 1970; and Sen, 1981).
and 102).

Figure 5. -- Plot of Al versus Mg number (in atomic proportions per 6 oxygen atoms) in clinopyroxene in Kaula and Salt Lake pyroxenites.

Symbols: K = field of Kaula clinopyroxene, K P, PR = field of Kaula clinopyroxene patches and patchy rims, K Bas and symbol "X" = Kaula basanitoid groundmass clinopyroxene and bulk basanitoid recast as a pyroxene, SLC = field of clinopyroxene in pyroxenites from Salt Lake Crater. Squares = Kaula clinopyroxene host grains, triangles = other Kaula clinopyroxene grains, hexagons = Kaula patches and patchy rims, crosses = dunite, solid diamonds = Salt Lake clinopyroxene.


Al
0.50
0.40
0.30
70
80
90
Mg/(Mg+ΣFe) x100
K
Bas
K
SLC
K
P, PR

In both of the dunites, the cpx is more Al-rich (KA 101D: 8.7 wt%, KA 100: 4.7 wt%) and Na-rich (KA 101D: 1.7 wt%, KA 100: 1.5 wt%) than cpx in dunites from the Koolau shield, Oahu (Al_2O_3 2.1-2.7 wt%, Na_2O: 0.2-0.4 wt%; Sen, 1981). The cpx in KA 100 is also more Cr-rich (1.4 wt%) compared with Koolau dunite cpx (0.2-0.7 wt%, Sen, 1981).

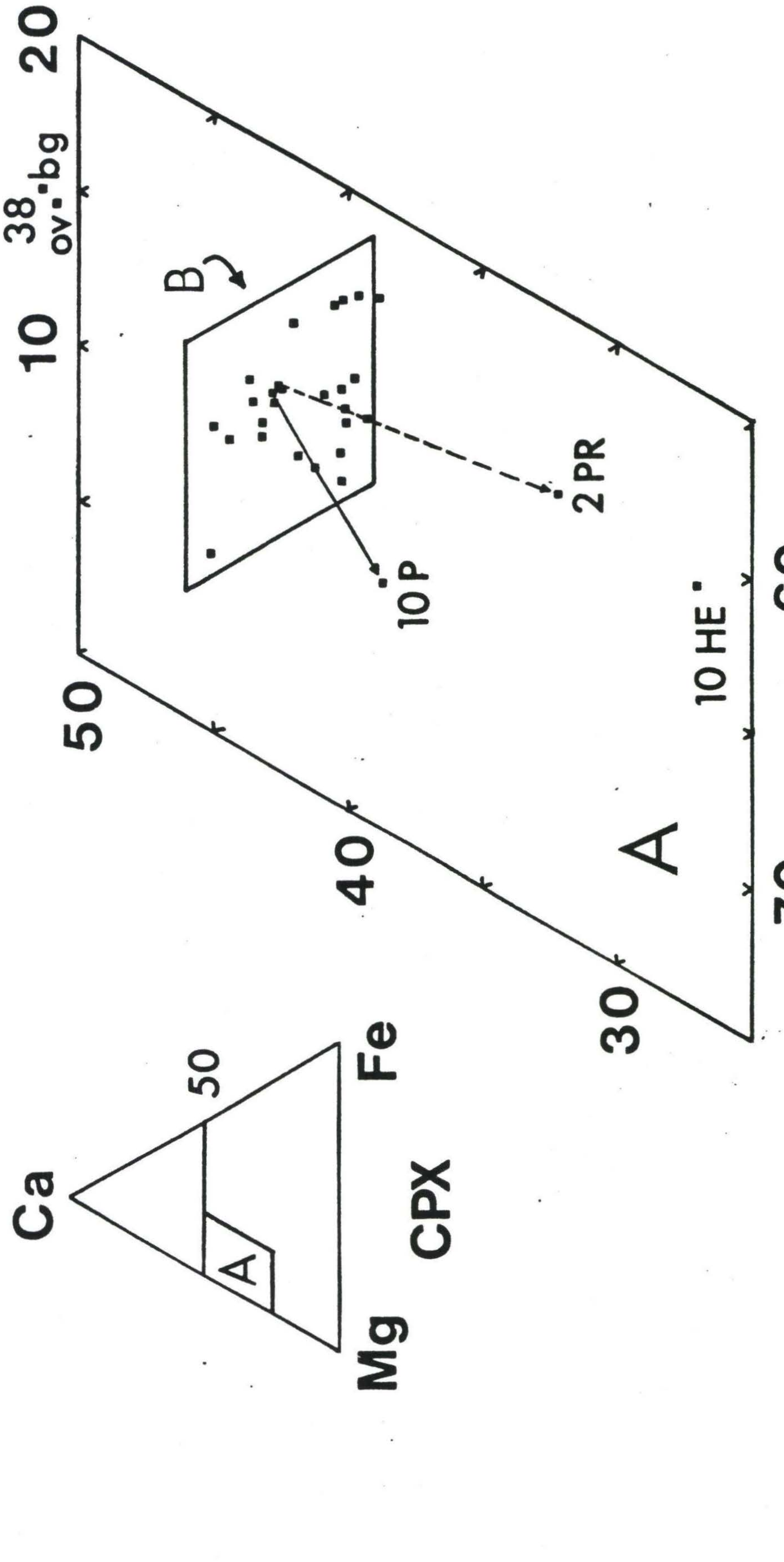
Clinopyroxene "Patches" and Rims

Clinopyroxene "patches" (in KA 107, 105, 108, 109, 106, 110, and 38megacr) generally exhibit a constant compositional trend relative to cpx host grains: the patches have higher SiO_2, MgO, and CaO, and lower TiO_2, Al_2O_3, FeO, and Na_2O (refer to Table 2). Measurements made within the same patch were slightly variable, but the trends were consistent relative to the host grain. Plots of these compositions on the pyroxene quadrilateral and on an Al-Mg-Ca triangle illustrate some of these trends. On the pyroxene quadrilateral, cpx host to patch trends show considerable variation in Ca, but all trends increase in Mg/Fe ratio (Figure 6). On the Al-Mg-Ca plot, cpx host to patch trends (KA 108, 38megacr) show a decrease in Al with either constant or slightly increasing Mg to Ca ratio (Figure 7).

Cpx rims in two samples (KA 108 and 38megacr) compositionally differ from their cpx host grains in the same manner as the patches. However, the rims in one sample, KA 102 (ol webst) do not follow this pattern: instead, Al_2O_3, FeO, and MgO increase from cpx host to rim, while SiO_2, CaO, TiO_2, and Na_2O decrease (Table 2). On the pyroxene quadrilateral, two rims (KA 108, 38megacr) have increasing Ca with

Figure 6. — Pyroxene quadrilateral plot of clinopyroxene in Kaula mafic and ultramafic xenoliths. Inset "B" is on the following page.

Symbols: numbers = abbreviated sample numbers, P = clinopyroxene patch, PR = clinopyroxene patchy rim, HE = highly exsolved, ov = clinopyroxene overgrowth, bg = basanitoid groundmass clinopyroxene, Mo = mosaic cpx grain, Sm = small cpx grain near kelyphitic intergrowth, In = cpx inclusion in garnet, Di = disrupted cpx, W = websterite, D = dunite, squares = cpx host grains, inverted triangles = other cpx grains, solid squares = cpx patches, solid triangles = cpx patchy rims, circles = dunite cpx. Note: in samples that had some variation in cpx host composition, the arrow connects patch and host compositions in the same grain.


Ca
Mg
Fe
50
A
CPX
20
10
38
ov
bg
B
2PR
10P
10HE
50
40
30
A
70
60

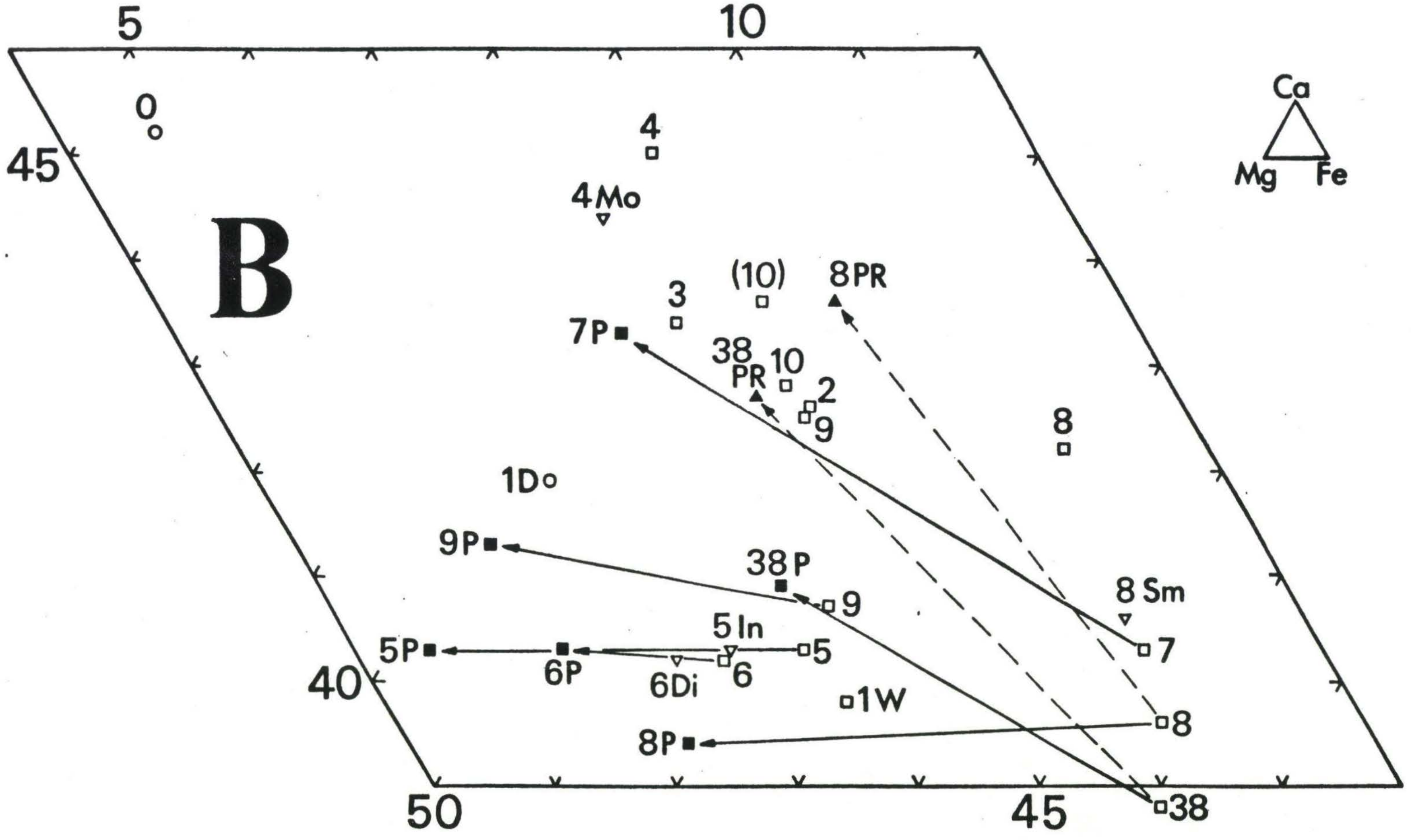
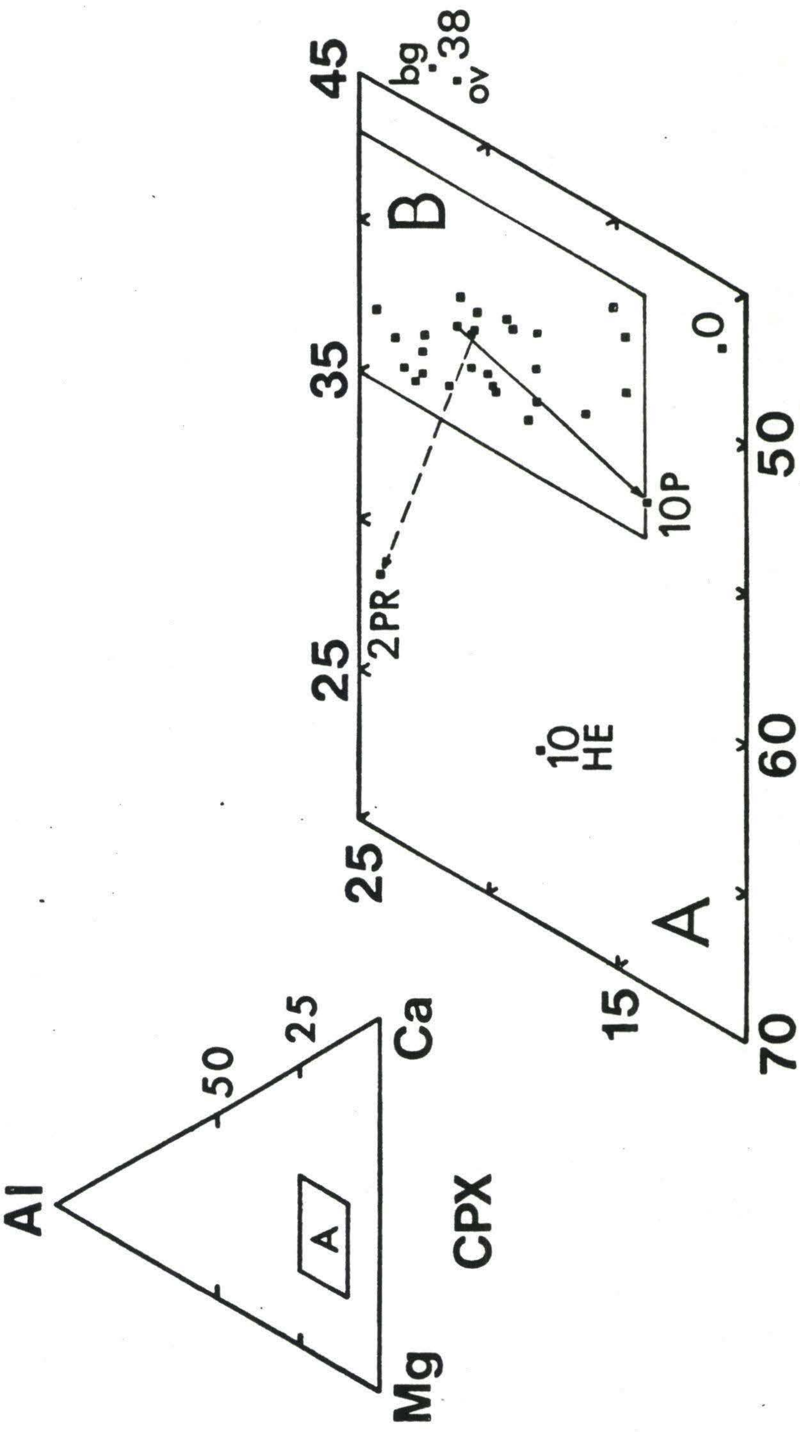
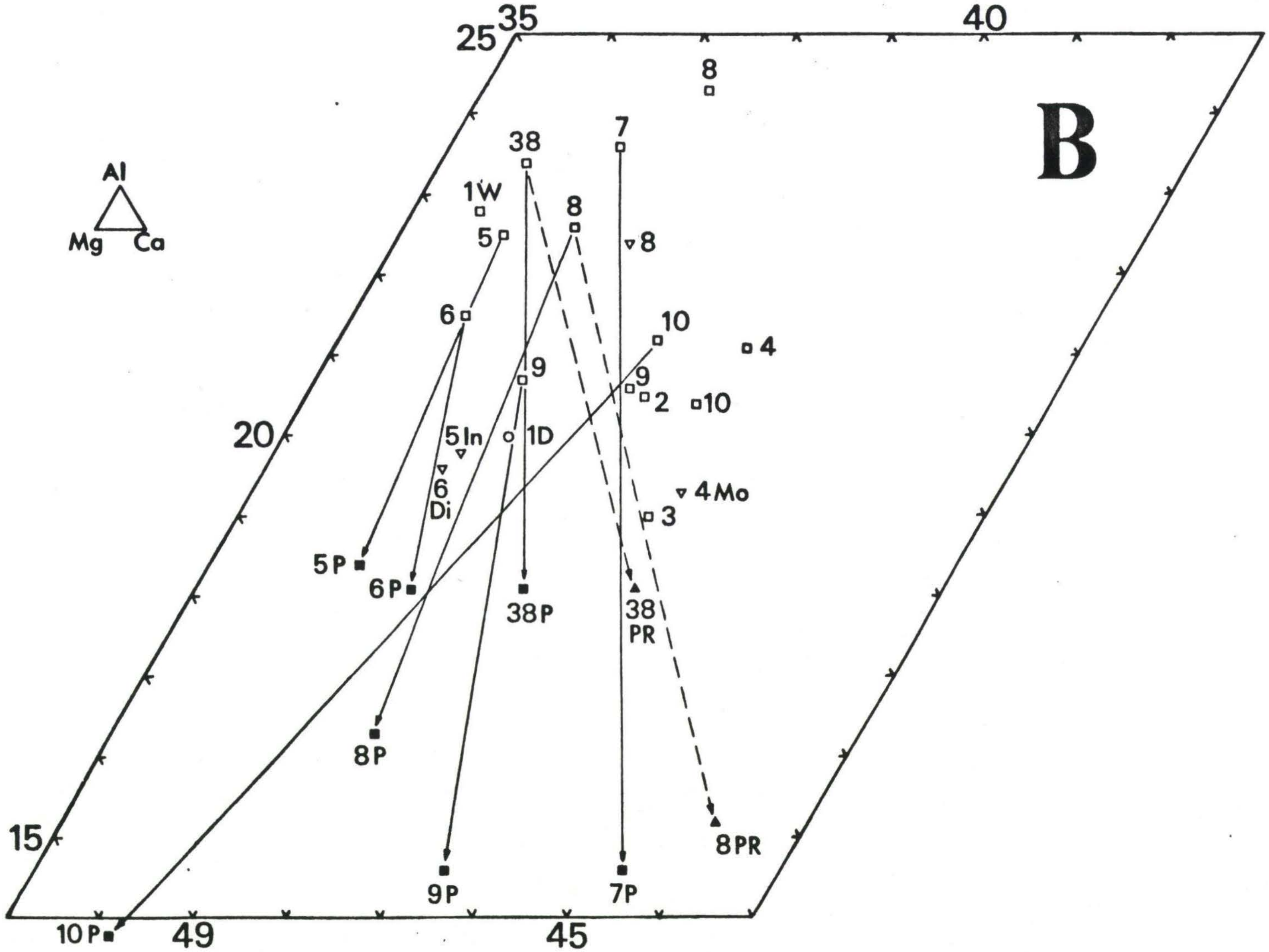

B
Ca
Mg
Fe
5
10
45
40
50
45
0
4
4Mo
3
(10)
8PR
7P
38
PR
10
2
9
8
1D
9P
38P
9
8Sm
7
5In
5P
6P
5
6
6Di
1W
8
8P
38

Figure 7. — Al-Mg-Ca plot of clinopyroxene in Kaula mafic and ultramafic xenoliths. Inset "B" is on the following page.

Symbols : as in Figure 6.


Al
Ca
Mg
CPX
50
25
A
B
45
35
25
25
15
70
60
50
0
10P
2PR
10
HE
bg
ov
38

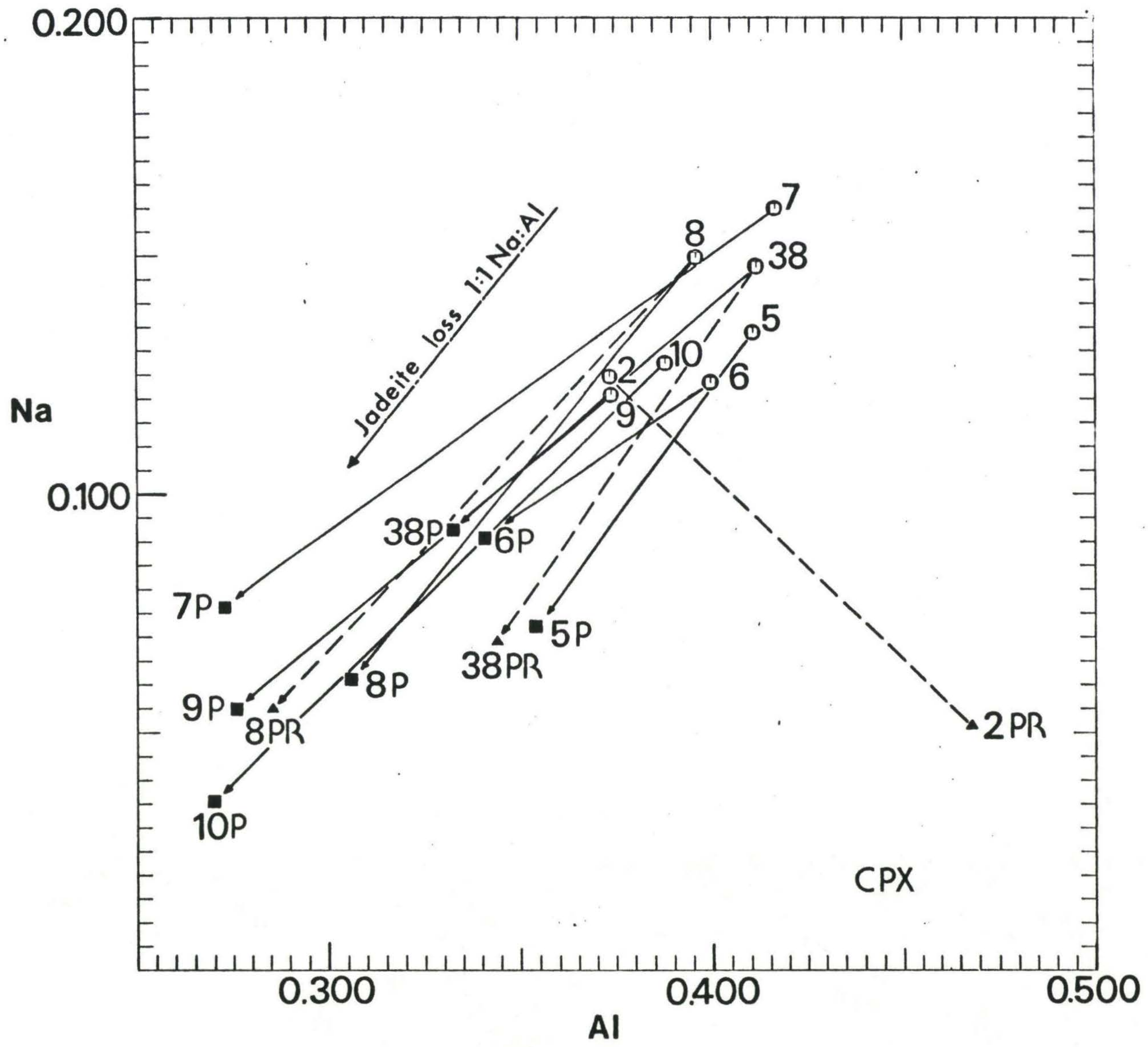

B
Al
Mg
Ca
25
35
40
20
15
49
45
8
7
38
1W
5
8
8
6
10
4
9
9
2
10
5 In
1D
6
Di
4 Mo
3
5 P
6 P
38 P
38
PR
8 P
8 PR
9 P
7 P
10 P

increasing Mg/Fe ratio. The rims in KA 102, however, show a much greater loss in Ca relative to the increase in Mg/Fe ratio (Figure 6). On the Al-Mg-Fe plot, two rims (KA 108, 38megacr) behave like patches, relative to the cpx hosts. However, the trend of cpx host to rim in KA 102 stands out markedly; Ca decreases with a nearly constant Mg to Al ratio (Figure 7).

The relationship between cpx patch and cpx host compositions involves the reduction of the jadeite component of the cpx (Figure 8). In cases such as KA 108 and KA 105, where cpx host-patch trends parallel the jadeite loss line, the loss of jadeite component could explain all the reduction in Na and Al. In samples that have a trend with a more positive slope than the jadeite loss line (eg., KA 107), another Al-bearing component was lost. The most likely components to explain Al loss in addition to jadeite loss are Ca-Tschermak´s and/or Mg-Tschermak´s molecules. To explain the decrease in Al with an accompanying increase in Ca and/or Mg, it is reasoned that Ca-Tschermak´s and/or Mg-Tschermak´s were lost, but the diopside component increased. Samples which have a trend with a slope slightly more negative than the jadeite loss line (eg., KA 38) may have lost acmite in addition to jadeite, to explain the Na loss which was not accounted for by jadeite. Jadeite component loss is also involved in the formation of rims from cpx host except in sample KA 102, which has strong Na decrease but a mild Al increase.

Figure 8. -- Plot of Na versus Al (in atomic proportions per 6 oxygen atoms) in clinopyroxene in Kaula pyroxenites.

Symbols: numbers = abbreviated sample numbers, circles = clinopyuroxene host grains, solid squares and "P" = clinopyroxene patches, solid triangles and "PR" = clinopyroxene patchy rims.



0.200
Na
0.100
0.300
0.400
0.500
Al
Jadeite loss 1:1 Na:Al
CPX
7
8
38
5
2
10
6
9
7P
38P
6P
5P
38PR
8P
9P
8PR
10P
2PR

The cpx overgrowth on KA 38megacryst and groundmass cpx from KA 38 are compositionally very different from xenolith cpx; they are included in the plots to demonstrate that patches and rims do not trend toward the host basanitoid cpx composition.

Orthopyroxene

The opx in Kaula pyroxenites are aluminous bronzites (Table 3). The most striking variation in composition occurs in the kelyphitic-type opx (KA 107, 108A), which is compositionally distinct from opx occurring as an exsolution or discrete grain. It is discussed under Garnet Kelyphitic Intergrowths.

Considering just exsolution opx and opx occurring as discrete grains, there is no observable correlation between mode of opx occurrence (exsolution vs. discrete grain) and composition in Kaula pyroxenites. In some samples, opx occurring as an exsolution has different SiO_2, Al_2O_3, MgO, and FeO contents compared with discrete grains in the same rock (KA 105, 108A, 109, 103, 110B, and 101W); however, the variation trends are not consistent. Slightly varying compositions occur for different forms of opx exsolution (lamellar vs. bleb) in two cases (KA 105 and 110B). In other specimens, exsolution opx and discrete grains are compositionally indistinguishable (KA 106 and 102).

TABLE 3

ORTHOPYROXENE COMPOSITIONS: KAULA PYROXENITE AND DUNITE XENOLITHS

	KA 107				KA 105		
	in cpx	kelyph rim	kelyph rim	vein pheno	lg irr blb ex	sm ovl exsln	grain
N =	1	1	1	1	4	1	1
Wt. %							
SiO_2	48.60	49.78	51.35	51.37	50.52	51.59	50.70
TiO_2	0.29	0.12	0.27	0.60	0.27	0.26	0.28
Al_2O_3	10.85	9.95	5.75	7.58	8.27	7.14	7.55
Cr_2O_3	0.03	0.04	0.01	0.03	0.05	0.03	0.04
FeO	13.72	12.74	13.12	9.22	12.26	12.12	12.13
MnO	0.28	0.31	0.29	0.18	0.19	0.11	0.15
MgO	24.12	25.56	26.26	28.31	26.70	27.33	27.04
CaO	2.07	2.01	2.23	1.99	1.15	1.12	1.19
Na_2O	0.09	0.09	0.04	0.11	0.20	0.21	0.21
SUM	100.05	100.60	99.32	99.39	99.63	99.91	99.29
Fe_2O_3	1.88	2.19	1.80	1.06	2.04	1.59	2.33
FeO	12.03	10.77	11.50	8.27	10.43	10.69	10.03
SUM	100.24	100.82	99.50	99.50	99.84	100.07	99.52
	Cations on the basis of 6 oxygens						
Si	1.741	1.763	1.848	1.815	1.798	1.829	1.809
Al z	0.259	0.237	0.152	0.185	0.202	0.171	0.191
Al y	0.199	0.178	0.092	0.131	0.145	0.128	0.127
Ti	0.008	0.003	0.007	0.016	0.007	0.007	0.008
Cr	0.001	0.001	0.000	0.001	0.001	0.001	0.001
Fe 3	0.051	0.058	0.049	0.028	0.055	0.042	0.063
Fe 2	0.360	0.319	0.346	0.244	0.311	0.317	0.299
Mn	0.008	0.009	0.009	0.005	0.006	0.003	0.005
Mg	1.288	1.349	1.408	1.491	1.417	1.445	1.438
Ca	0.079	0.076	0.086	0.075	0.044	0.043	0.045
Na	0.006	0.006	0.003	0.008	0.014	0.014	0.015
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg no.	75.8	78.1	78.1	84.6	79.5	80.1	79.9
Ca	0.044	0.042	0.045	0.041	0.024	0.023	0.025
Mg	0.721	0.745	0.742	0.808	0.773	0.781	0.777
Fe	0.235	0.213	0.213	0.151	0.203	0.196	0.198

TABLE 3., (Continued) ORTHOPYROXENE COMPOSITIONS

	KA 108A					KA 109		KA 106
	kelyphitic core	kelyphitic rim	inclu in cpx	sm blb exsln	grain	rd blb exsln	grain	exsln, grain
N =	1	1	2	1	4	2	5	4
Wt. %								
SiO2	47.28	46.76	50.97	50.12	50.90	50.51	50.25	51.45
TiO2	0.35	0.32	0.32	0.25	0.35	0.23	0.21	0.25
Al2O3	12.26	13.49	7.12	8.23	6.66	6.45	7.41	6.75
Cr2O3	0.10	0.16	0.07	0.17	0.15	0.14	0.12	0.12
FeO	13.39	13.49	13.07	12.27	13.18	12.13	12.39	11.80
MnO	0.70	0.73	0.39	0.26	0.32	0.17	0.20	0.16
MgO	23.98	23.39	26.67	27.04	26.81	28.26	27.93	27.84
CaO	1.90	1.52	1.05	1.01	1.11	1.05	1.00	1.17
Na2O	0.04	0.03	0.21	0.18	0.21	0.16	0.16	0.18
SUM	100.00	99.89	99.86	99.53	99.69	99.11	99.67	99.72
Fe2O3	2.90	2.00	2.34	3.00	2.78	4.46	4.57	2.44
FeO	10.78	11.69	10.97	9.57	10.68	7.93	8.28	9.61
SUM	100.29	100.09	100.10	99.83	99.97	99.58	100.12	99.96
Cations on the basis of 6 oxygens								
Si	1.693	1.678	1.817	1.784	1.818	1.800	1.782	1.824
Al z	0.307	0.322	0.183	0.216	0.182	0.200	0.218	0.176
Al y	0.210	0.248	0.116	0.130	0.098	0.070	0.092	0.107
Ti	0.009	0.009	0.009	0.007	0.009	0.006	0.006	0.007
Cr	0.003	0.005	0.002	0.005	0.004	0.004	0.003	0.003
Fe 3	0.078	0.054	0.063	0.080	0.075	0.125	0.122	0.065
Fe 2	0.323	0.351	0.327	0.285	0.319	0.236	0.246	0.285
Mn	0.021	0.022	0.012	0.008	0.010	0.005	0.006	0.005
Mg	1.280	1.251	1.417	1.435	1.428	1.501	1.477	1.471
Ca	0.073	0.058	0.040	0.039	0.042	0.040	0.038	0.044
Na	0.003	0.002	0.015	0.012	0.015	0.011	0.011	0.013
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg no.	76.1	75.6	78.4	79.7	78.4	80.6	80.1	80.8
Ca	0.041	0.034	0.021	0.021	0.023	0.021	0.020	0.024
Mg	0.721	0.720	0.763	0.777	0.762	0.787	0.782	0.787
Fe	0.238	0.246	0.216	0.202	0.215	0.192	0.198	0.190

TABLE 3., (Continued) ORTHOPYROXENE COMPOSITIONS

	KA 103		KA 110B				
	grain	irreg lam exs	med eq exsln	lg irr blb exs	grain		grain (c,r)
					core	rim	
N =	1	1	4	1	1	1	2
Wt. %							
SiO2	52.56	50.57	51.87	52.36	50.81	52.87	52.58
TiO2	0.21	0.21	0.18	0.12	0.18	0.11	0.18
Al2O3	6.09	9.06	6.70	5.59	8.42	5.39	5.40
Cr2O3	0.07	0.01	0.13	0.08	0.13	0.08	0.09
FeO	10.73	10.50	11.35	11.61	11.59	11.06	11.47
MnO	0.12	0.12	0.18	0.19	0.20	0.19	0.17
MgO	28.94	27.63	28.37	28.54	27.68	29.01	28.96
CaO	1.01	1.02	0.99	1.07	0.89	0.96	1.00
Na2O	0.12	0.13	0.15	0.14	0.14	0.14	0.14
SUM	99.85	99.25	99.92	99.70	100.04	99.81	100.00
Fe2O3	1.38	1.24	2.10	2.19	2.22	1.69	2.37
FeO	9.49	9.38	9.47	9.64	9.59	9.54	9.34
SUM	99.99	99.37	100.13	99.92	100.26	99.98	100.24
Cations on the basis of 6 oxygens							
Si	1.853	1.793	1.831	1.855	1.794	1.866	1.855
Al z	0.147	0.207	0.169	0.145	0.206	0.134	0.145
Al y	0.106	0.171	0.110	0.088	0.144	0.090	0.079
Ti	0.006	0.006	0.005	0.003	0.005	0.003	0.005
Cr	0.002	0.000	0.004	0.002	0.004	0.002	0.003
Fe 3	0.037	0.033	0.056	0.058	0.059	0.045	0.063
Fe 2	0.280	0.278	0.280	0.285	0.283	0.282	0.275
Mn	0.004	0.004	0.006	0.006	0.006	0.006	0.005
Mg	1.521	1.460	1.493	1.507	1.456	1.526	1.522
Ca	0.038	0.039	0.037	0.041	0.034	0.036	0.038
Na	0.008	0.009	0.010	0.010	0.010	0.010	0.010
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg no.	82.8	82.4	81.7	81.4	81.0	82.4	81.8
Ca	0.020	0.021	0.020	0.021	0.018	0.019	0.020
Mg	0.809	0.805	0.798	0.794	0.792	0.806	0.800
Fe	0.170	0.174	0.182	0.184	0.189	0.175	0.180

TABLE 3., (Continued) ORTHOPYROXENE COMPOSITIONS

	KA 104	KA 102	KA 101		
	grain	grain, exsln	dun grain	webst exsln	webst grain
N =	3	12	3	1	1
Wt. %					
SiO_2	52.36	52.20	53.04	50.57	51.93
TiO_2	0.14	0.28	0.37	0.52	0.51
Al_2O_3	6.32	6.06	6.40	7.55	7.40
Cr_2O_3	0.37	0.05	0.23	0.02	0.02
FeO	9.94	11.53	9.20	13.60	9.85
MnO	0.19	0.17	0.15	0.22	0.15
MgO	29.29	28.34	29.07	26.19	28.65
CaO	0.98	0.96	1.10	1.16	1.04
Na_2O	0.16	0.16	0.16	0.21	0.12
SUM	99.75	99.75	99.74	100.04	99.67
Fe_2O_3	1.77	1.68	0.00	2.25	0.44
FeO	8.34	10.02	9.20	11.58	9.45
SUM	99.92	99.92	99.74	100.27	99.71
	Cations on the basis of 6 oxygens				
Si	1.842	1.849	1.864	1.804	1.831
Al z	0.158	0.151	0.136	0.196	0.169
Al y	0.104	0.101	0.129	0.122	0.138
Ti	0.004	0.008	0.010	0.014	0.014
Cr	0.010	0.001	0.006	0.001	0.001
Fe 3	0.047	0.045	0.000	0.060	0.012
Fe 2	0.246	0.297	0.271	0.345	0.279
Mn	0.006	0.005	0.005	0.007	0.004
Mg	1.536	1.496	1.523	1.393	1.505
Ca	0.037	0.036	0.042	0.044	0.039
Na	0.011	0.011	0.011	0.015	0.008
SUM	4.000	4.000	4.000	4.000	4.000
Mg no.	84.0	81.4	84.9	77.4	83.8
Ca	0.020	0.019	0.023	0.024	0.021
Mg	0.821	0.796	0.828	0.753	0.818
Fe	0.159	0.184	0.150	0.223	0.160

Compared to opx in pyroxenites from Salt Lake, Kaula exsolution opx and discrete grains tend to have slightly higher Al_2O_3 contents (5.4-8.4 wt% Kaula vs. 4.1-7.2 wt% Salt Lake). Salt Lake opx also lacks correlation between the mode of opx occurrence (exsolution vs. discrete grain) and chemistry (Beeson and Jackson, 1970; Wilkinson, 1976; and Sen, 1981).

Garnet

Kaula garnets are pyropes, based on comparison with analyses in Deer and others, (1966) (Table 4). For most oxides, there is slight variation within a rock and from rock to rock; FeO and MgO show the most variation, with Mg numbers varying smoothly from 68.3 (KA 108A) to 73.5 (KA 105). Rims tend to be slightly higher in Fe (lower in Mg) than cores. However, grain to grain variation within the same rock is usually as large or larger than the core to rim variation. For example, in KA 109, a small lobate grain is richer in Fe than the most Fe-rich part (i.e., the rim) of the large grain (see Table 4).

Salt Lake pyroxenite garnets have wider variation in some components compared with Kaula garnets. The Mg numbers of Salt Lake garnets range from 68.3 to 75.9, except for two samples with Mg numbers of 63.3 and 80.0; therefore, Kaula garnets have Mg numbers within the range of those of Salt Lake garnets. Alumina content in Salt Lake garnet varies from 21.8 wt% to 23.2 wt%, whereas Kaula has a higher but more constant alumina content (23.3 - 23.8 wt%) (Wilkinson, 1976; Beeson and Jackson, 1970; and Sen, 1981).

TABLE 4

GARNET COMPOSITIONS: KAULA PYROXENITE XENOLITHS

	KA 107			KA 105	KA 108A
	grain A		gr.B-D	grain	grain
	core	rim	ave.	ave.	ave.
N =	1	1	3	10	5
Wt.%					
SiO2	40.75	40.57	40.53	40.99	40.94
TiO2	0.35	0.42	0.38	0.32	0.46
Al2O3	23.25	23.32	23.51	23.44	23.28
Cr2O3	0.02	0.05	0.03	0.04	0.11
FeO	13.21	13.56	13.59	11.68	13.72
				(11.25-12.28)	
MnO	0.33	0.35	0.34	0.32	0.39
MgO	17.09	16.75	16.75	18.16	16.59
				(17.61-18.70)	
CaO	5.06	5.11	5.11	5.19	4.89
Na2O	0.01	0.03	0.05	0.04	0.03
SUM	100.07	100.16	100.29	100.18	100.41
	Cations on the basis of 24 oxygens				
Si	5.913	5.895	5.882	5.903	5.931
Al z	0.087	0.105	0.118	0.097	0.069
Al y	3.890	3.889	3.903	3.881	3.906
Ti	0.038	0.046	0.042	0.035	0.050
Cr	0.002	0.006	0.004	0.005	0.013
Fe 2	1.603	1.648	1.650	1.407	1.662
Mn	0.041	0.043	0.042	0.039	0.048
Mg	3.697	3.628	3.623	3.898	3.582
Ca	0.787	0.796	0.795	0.801	0.759
Na	0.003	0.008	0.014	0.011	0.008
Sum	16.060	16.063	16.071	16.076	16.029
Mg no.	69.8	68.8	68.7	73.5	68.3
Ca	0.128	0.130	0.130	0.130	0.125
Mg	0.603	0.593	0.593	0.634	0.592
Fe	0.268	0.277	0.277	0.235	0.283

TABLE 4., (Continued) GARNET COMPOSITIONS

	KA 109			KA 110B
	large grain core	large grain rim	small grain	grain ave.
N =	2	2	2	4
Wt.%				
SiO2	41.22	41.13	41.29	41.06
TiO2	0.35	0.36	0.22	0.29
Al2O3	23.77	23.70	23.77	23.52
Cr2O3	0.15	0.10	0.15	0.10
FeO	11.44	12.22	12.92	12.58
MnO	0.37	0.35	0.42	0.42
MgO	17.61	17.22	16.48	16.77
CaO	5.24	5.17	5.10	5.26
Na2O	0.05	0.05	0.02	0.03
SUM	100.20	100.30	100.37	100.03
Cations on the basis of 24 oxygens				
Si	5.925	5.925	5.958	5.944
Al z	0.075	0.075	0.042	0.056
Al y	3.952	3.950	4.001	3.957
Ti	0.038	0.039	0.024	0.032
Cr	0.017	0.011	0.017	0.011
Fe 2	1.375	1.472	1.559	1.523
Mn	0.045	0.043	0.051	0.051
Mg	3.773	3.698	3.545	3.618
Ca	0.807	0.798	0.789	0.816
Na	0.014	0.014	0.006	0.008
Sum	16.022	16.025	15.991	16.017
Mg no.	73.3	71.5	69.5	70.4
Ca	0.134	0.133	0.133	0.136
Mg	0.629	0.615	0.596	0.602
Fe	0.237	0.252	0.271	0.262

Garnet Kelyphitic Intergrowths

A) Coarse Kelyphitic Rims

The coarse kelyphitic rims consist of subhedral opx and euhedral to subhedral spinel (Plate 2) which are coarse enough to analyze by microprobe (KA 107 and 108A). Alumina contents of the opx in kelyphitic rims are extremely variable; up to 13.5 wt % Al_2O_3 were measured in this type of opx (in KA 108A). This may be caused by spinel solid solution or minor, submicroscopic spinel lamellae in the opx. Dawson (1981) reported opx with up to 10 wt% Al_2O_3 in kelyphitic rims in garnet lherzolites from Letseng kimberlites. Other distinguishing features of kelyphitic-type opx are its lower MgO, Mg number, and Na_2O, and higher CaO values compared to other Kaula opx occurrences. Also, it displays more variation in its Fe, Mg, and Si contents than other opx occurrences; for example, its Mg number varies from 75.6 to 84.6 (see Table 3). The compositions of spinel in kelyphitic rims are also somewhat variable: Al_2O_3 - 62.59-63.89%; FeO - 17.33-19.85%), and MgO - 17.56-19.34% (see Table 5).

B) Fibrous Intergrowth

Well-developed fibrous intergrowths (in KA 108, see Plate III) were analyzed, using a glass standardization program and a slightly defocused beam (approx. 5 micron beam diameter), to test the petrographic observation that garnet was the host mineral for the fibrous intergrowth (overall composition of garnet) and that the intergrowth is composed of pyroxene and spinel. Representative analyses are given in Table 6. The wide range in composition of the

TABLE 5

SPINEL COMPOSITIONS: KAULA PYROXENITE AND DUNITE XENOLITHS

	KA 107		KA 105	KA 108A	
	large ovoid	small euhedral	ovoid	large ovoid	small euhed.
N =	11	6	6	3	1
Wt.%					
TiO_2	0.56	0.19	0.45	1.15	0.36
Al_2O_3	58.74	63.35	61.70	53.51	62.28
	(57.51-59.80)	(62.59-63.89)	(61.04-62.20)	(52.66-54.00)	
Cr_2O_3	0.24	0.11	0.35	0.70	0.26
				(0.50-1.04)	
FeO	23.91	18.08	18.81	29.77	19.30
	(21.75-26.03)	(17.33-19.85)	(17.96-19.71)	(28.92-30.87)	
MnO	0.07	0.17	0.06	0.08	0.18
MgO	16.41	18.49	18.57	14.74	17.78
	(15.47-17.39)	(17.56-19.34)	(18.14-19.04)	(14.30-15.08)	
SUM	99.93	100.39	99.94	99.95	100.16
Fe_2O_3	7.94	4.57	5.57	11.87	4.83
FeO	16.77	13.96	13.80	19.09	14.96
Sum	100.73	100.85	100.50	101.14	100.64
	Cations on the basis of 32 oxygens				
Ti	0.088	0.029	0.070	0.186	0.056
Al	14.529	15.222	14.943	13.585	15.099
Cr	0.040	0.018	0.057	0.119	0.042
Fe 3	1.254	0.702	0.861	1.924	0.747
Fe 2	2.943	2.381	2.371	3.439	2.573
Mn	0.012	0.029	0.010	0.015	0.031
Mg	5.133	5.619	5.688	4.732	5.451
Sum	24.000	24.000	24.000	24.000	24.000
Mg no.	55.0	64.6	63.8	46.9	62.1

Footnote: Structural formulae recalculated to 24.000 cations. Ferric iron calculated based on stoichiometry.

TABLE 5., (Continued) SPINEL COMPOSITIONS

	KA 109	KA 106		KA 103
	small subhed.	large ovoid	small subhed.	cpx inclu
N =	7	19	2	5
Wt.%				
TiO2	0.29	0.39	0.21	0.26
	(0.12-0.63)			
Al2O3	63.43	60.20	64.59	62.59
	(61.36-64.82)	(57.90-62.49)		
Cr2O3	0.82	1.52	0.87	0.27
	(0.45-1.68)	(1.14-2.56)		
FeO	15.87	19.66	13.81	17.87
	(14.47-16.58)	(17.79-20.78)		
MnO	0.13	0.02	0.08	0.04
MgO	19.45	18.14	20.54	18.85
-----	------	------	------	------
SUM	99.99	99.93	100.10	99.88
Fe2O3	3.75	6.05	3.11	5.04
FeO	12.49	14.21	11.01	13.33
Sum	100.37	100.54	100.41	100.39

Cations on the basis of 32 oxygens

Ti	0.044	0.061	0.032	0.040
Al	15.205	14.687	15.327	15.099
Cr	0.132	0.249	0.138	0.044
Fe 3	0.574	0.943	0.471	0.777
Fe 2	2.125	2.460	1.854	2.282
Mn	0.022	0.004	0.014	0.007
Mg	5.897	5.597	6.164	5.751
Sum	24.000	24.000	24.000	24.000
Mg no.	68.6	62.2	72.6	65.3

TABLE 5., (Continued) SPINEL COMPOSITIONS

KA 102

	oliv inclu	cpx inclusion		ovoid	subhed.
		core	rim		
N =	3	1	1	14	5
Wt.%					
TiO2	0.61	0.46	0.46	0.50	0.17
Al2O3	59.12	60.53	60.65	60.35	64.66
				(59.13-61.19)	(63.90-65.60)
Cr2O3	1.02	0.16	0.13	0.99	0.38
				(0.69-1.50)	
FeO	20.80	20.44	19.73	20.05	16.35
				(18.86-20.47)	(14.64-18.14)
MnO	0.03	0.12	0.03	0.04	0.09
MgO	18.35	18.20	18.91	18.15	18.62
					(17.50-19.57)
SUM	99.93	99.91	99.91	100.08	100.27
Fe2O3	7.63	7.00	7.29	6.33	2.65
FeO	13.93	14.14	13.17	14.35	13.96
Sum	100.69	100.61	100.64	100.71	100.54
Cations on the basis of 32 oxygens					
Ti	0.095	0.071	0.071	0.078	0.026
Al	14.452	14.743	14.708	14.698	15.482
Cr	0.167	0.026	0.021	0.162	0.061
Fe 3	1.191	1.088	1.129	0.985	0.405
Fe 2	2.417	2.444	2.266	2.480	2.372
Mn	0.005	0.021	0.005	0.007	0.015
Mg	5.673	5.606	5.800	5.590	5.638
Sum	24.000	24.000	24.000	24.000	24.000
Mg no.	61.1	61.3	63.1	61.7	67.0

TABLE 5., (Continued) SPINEL COMPOSITIONS

	KA 101			KA 100
	dunite side	near/on contact	webst side	lobate
N =	4	5	2	6
Wt. %				
TiO2	0.63	0.65	0.74	0.74
Al2O3	57.03	58.42	61.00	32.44
Cr2O3	5.56	4.06	0.42	32.99
		(3.84-4.35)		
FeO	17.40	17.24	18.45	17.65
MnO	0.00	0.00	0.08	0.00
MgO	19.03	19.36	19.00	16.27
SUM	99.65	99.73	99.69	100.09
Fe2O3	5.46	5.55	5.84	5.09
FeO	12.49	12.25	13.20	13.07
Sum	100.20	100.29	100.28	100.60

Cations on the basis of 32 oxygens

Ti	0.099	0.101	0.115	0.129
Al	14.027	14.267	14.798	8.833
Cr	0.917	0.665	0.068	6.026
Fe 3	0.858	0.865	0.905	0.884
Fe 2	2.179	2.122	2.271	2.526
Mn	0.000	0.000	0.014	0.000
Mg	5.920	5.979	5.829	5.603
Sum	24.000	24.000	24.000	24.000
Mg no.	66.1	66.7	64.7	62.2

TABLE 6

REPRESENTATIVE ANALYSES OF FIBROUS INTERGROWTHS IN KA 108B

Wt %	1 (Gt)	2 (Gt,opx)	3 (Opx)	4 (Sp,opx)
SiO2	41.56	38.26	48.70	33.37
TiO2	0.45	0.22	0.09	0.33
Al2O3	22.98	23.66	10.81	30.28
FeO	14.82	14.91	14.10	13.80
MnO	0.36	0.30	0.37	0.36
MgO	15.96	22.08	23.69	20.69
CaO	4.88	1.15	1.70	1.03
Na2O	0.05	0.02	0.11	0.02
K2O	0.01	0.00	0.00	0.00
P2O5	0.08	0.03	0.26	0.03
-----	------	------	------	------
Sum	101.15	100.63	99.83	99.92

Footnote: analyses labels = suggested mineral(s) influencing the fibrous intergrowth composition or mineral which the composition resembles.

intergrowths may suggest that the areas analyzed contained a variable mixture of opx and spinel. One analysis (#1) has a garnet composition. The high MgO contents (22.1-23.7 wt% MgO) of analyses #2 and #3 are similar to coarse kelyphitic opx (23.4-24.0 wt% MgO) analyzed from the same rock. Also, high alumina in analysis #4 (30.3 wt% Al_2O_3) suggests the influence of spinel. Since many of the analyses were not clearly garnet, opx, or spinel, these results are viewed with reservation.

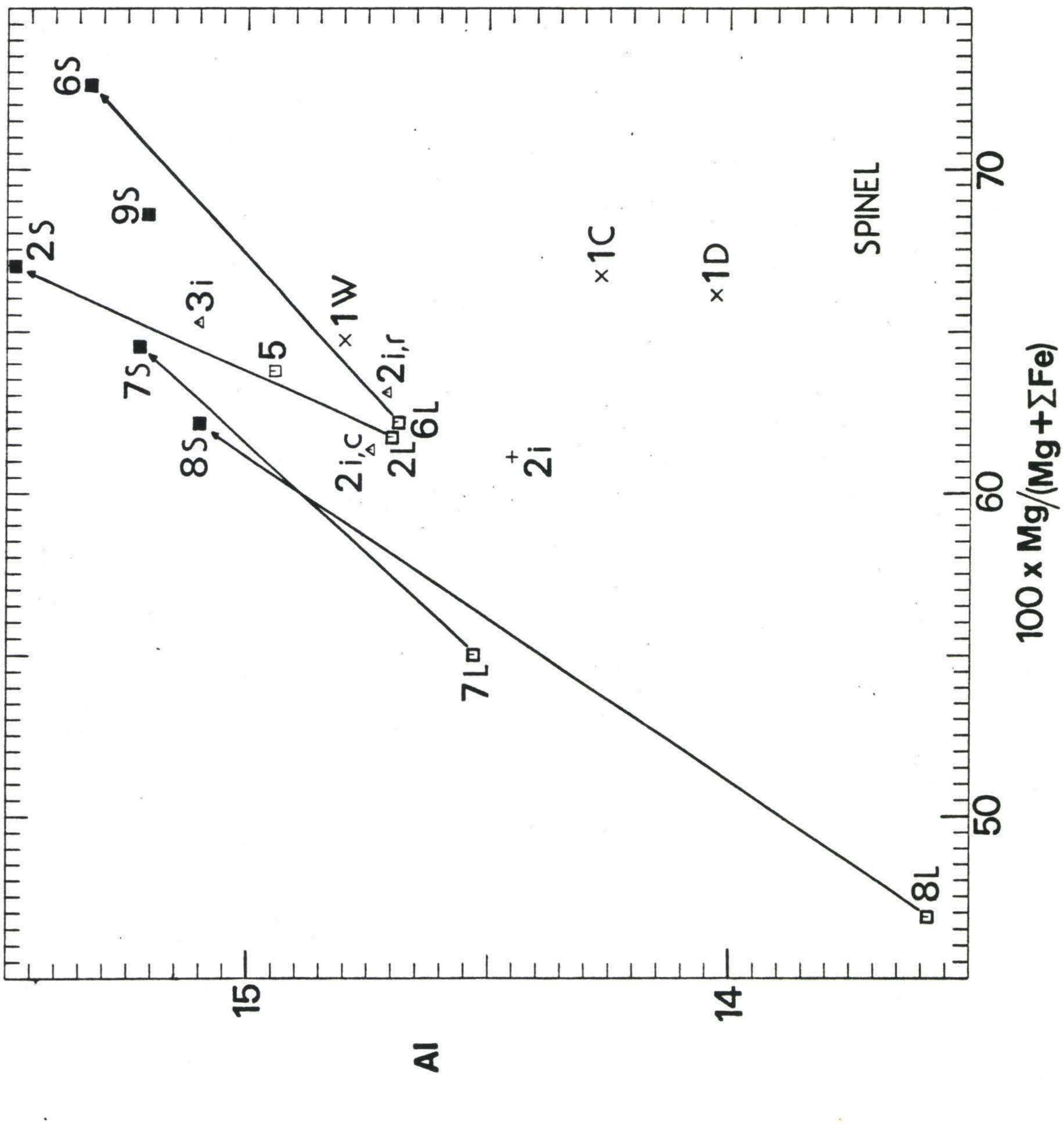
Spinel

Kaula spinels are pleonastes except for the Cr-spinel in the dunite, KA 100 (Deer and others, 1966) (see Table 5). Spinels in Kaula pyroxenites display the following characteristics: a) small euhedral spinels always have higher Al and Mg, and lower Fe, Ti, and Cr contents, compared to large ovoid spinels in the same rock (e.g., see Figure 9), and b) generally, both large ovoid and small euhedral spinels have considerable ranges in Al, Mg, and Fe.

The high Al_2O_3 content and Al/Cr ratio in the small euhedral or subhedral spinels, which are part of the kelyphitic rim feature, are thought to be a result of the formation of the spinel from garnet; the pressure relationship of spinel Al/Cr ratio increasing with increasing pressure (Haggerty, 1979) is not considered applicable in this reaction.

Figure 9. -- Plot of Al versus Mg number (in atomic proportions per 32 oxygen atoms) in Kaula spinels.

Symbols: numbers = abbreviated sample numbers, open squares and "L" = large ovoid, solid squares and "S" = small subhedral, X = composite xenolith (KA 101), W = websterite, D = dunite, C = contact between dunite and websterite, i = inclusion, i,c = inclusion core, i,r = inclusion rim, triangles = inclusions in cpx, cross = inclusion in olivine.


Al
15
14
50
60
70
100 x Mg/(Mg+ΣFe)
SPINEL
6S
9S
2S
3i
5
7S
8S
1W
2i,r
6L
2L
2i,c
2i
1C
1D
7L
8L

In comparison with Salt Lake pyroxenite spinels, Kaula spinels are higher in Al_2O_3 (Kaula: 52.7-65.6 wt% , Salt Lake: 42.0-56.0 wt%) and lower in Cr_2O_3 (Kaula: 0.1-2.6 wt%, Salt Lake: 2.4-16.3 wt%) (Wilkinson, 1976; Sen, 1981).

A compositional break is shown in the composite xenolith KA 101, best demonstrated by the variation in $\%Cr_2O_3$ (5.56% on dunite side, 3.84-4.35% at the contact, 0.42% on the websterite side).

The spinel in KA 100 is much more Cr-rich (32.99%) compared with the other spinels (maximum 5.56% in KA 101D).

Olivine

Fe and Mg show the most variation of olivine components, both from rock to rock and within some individual rocks. Forsterite percent varies from Fo 77.6 (KA 108A) to 83.8 (KA 103) in the pyroxenites (Table 7). The olivine in KA 107, with a Fo percent of about 84, is a special case since it had crystallized from glass. Although there is no glass present in the triangular area where olivine occurs in KA 110A, fractures which can be traced from the triangular area into the host basanitoid suggest that the olivine in KA 110A may also be secondary. Fo % values are higher for the dunites; Fo 85.5 for KA 101D and 90.1 for KA 100. Some core/rim analyses indicate very slight differences in SiO_2, FeO, and MgO, but are not always consistent. In KA 102 (olivine websterite), an olivine inclusion in spinel analyzed no differently than other olivine grains in that rock. Two samples (KA 107, 110A) have higher CaO contents (0.20, 0.23%) compared with four

TABLE 7

OLIVINE COMPOSITIONS: KAULA PYROXENITE AND DUNITE XENOLITHS

	KA 107	KA 105	KA 108A	KA 106	KA 103	KA 110A
	skel. ol in glass	relict grains	ovrgrth (2ndry)	large grain	sm incl. in cpx	in triang area
N =	10	4	2	1	3	6
Wt. %						
SiO2	39.49	39.19	38.66	39.12	39.43	39.64
FeO	15.29	17.69	20.60	18.42	15.38	15.49
	(14.63-15.93)	(16.85-18.47)				(14.49-16.35)
MnO	0.18	0.15	0.21	0.18	0.08	0.22
MgO	44.71	42.42	39.92	42.58	44.71	44.63
	(44.16-45.20)					(44.07-45.29)
CaO	0.23	0.15	0.10	0.11	0.11	0.20
NiO	0.12	0.16	0.09	n.d.	0.17	0.16
SUM	100.02	99.75	99.60	100.41	99.87	100.33
			Cations on the basis of 4 oxygens			
Si	0.994	1.000	1.001	0.994	0.994	0.995
Fe 2	0.322	0.377	0.446	0.392	0.324	0.325
Mn	0.004	0.003	0.005	0.004	0.002	0.005
Mg	1.677	1.613	1.541	1.613	1.680	1.671
Ca	0.006	0.004	0.003	0.003	0.003	0.005
Ni	0.003	0.003	0.002	---	0.004	0.003
Sum	3.006	3.000	2.999	3.006	3.006	3.005
% Fo	83.9	81.1	77.6	80.4	83.8	83.7

TABLE 7., (Continued) OLIVINE COMPOSITIONS

	KA 102	KA 101	KA 100
	grains	dun & webst	grains
N =	7	8	10
Wt. %			
SiO2	39.34	39.59	40.46
FeO	17.40	13.84	9.64 (9.28-10.32)
MnO	0.17	0.16	0.11
MgO	43.25 (42.94-43.58)	45.68	49.30 (48.71-49.65)
CaO	0.09	0.09	0.07
NiO	0.23	0.25	0.31
SUM	100.49	99.63	99.88
	Cations on the basis of 4 oxygens		
Si	0.995	0.994	0.994
Fe 2	0.368	0.291	0.198
Mn	0.004	0.004	0.002
Mg	1.631	1.710	1.805
Ca	0.002	0.004	0.002
Ni	0.005	0.003	0.006
Sum	3.005	3.006	3.006
% Fo	81.6	85.5	90.1

other rocks (KA 105, 108, 106, 103: values 0.07-0.15%). The high CaO contents suggest that the olivine in KA 107 and 110A formed at low pressures (Simkin and Smith, 1970).

Sen (1981) presented ranges in the forsterite content of olivine from the three xenolith suites of the Koolau Shield, Oahu (pxite suite: Fo 80-86; dunite suite: 82-89; lherzolite suite: 87-92). White (1966) reported CaO contents of 0.07-0.14 wt% for secondary olivine after opx in xenoliths from Hawaii; however, this occurrence of olivine has lower FeO (8.4-12.5 wt%) and higher MgO (46.6-50.4 wt%) compared with the secondary olivine in KA 108 (FeO 20.6 wt%, MgO 39.9 wt%).

Glass

Glasses in Kaula pyroxenite xenoliths are aluminous and Fe-rich. In general, sample to sample variation is slightly greater than the variation within a sample (Table 8). Mg number varies from 42.2 (KA 107, area of skeletal olivine and glass) to 48.1 (KA 109). These compositions are very similar to those reported for glasses in Salt Lake pyroxenites (Helz, 1979).

Most of the glasses are Hy and Di normative with either normative Ol or Qtz. They may be classified as having transitional to tholeiitic affinities, based on the average Indicator Ratio (Coombs, 1963), which varies from 0.39 to 0.63. Less commonly there are occurrences of Ne and Ol normative glasses: a) the glass that occurs with skeletal olivine (KA 107), and b) the glass immediately surrounding the cpx patches (KA 107). These may be classified as having alkaline basalt

TABLE 8

GLASS COMPOSITIONS: KAULA PYROXENITE XENOLITHS

	KA 107		KA 108	109	KA 110	
	kelyph assoc	area: gl +skel ol	kelyph assoc	kelyph assoc	vein	vein, low K
N =	9	2	7	3	3	1
Wt.%						
SiO2	46.32 (45.27-47.51)	46.42	47.68 (47.39-47.97)	48.10 (47.32-48.74)	48.87 (48.50-49.24)	49.02
TiO2	1.17 (0.96-1.38)	2.91	0.85 (0.70-0.96)	1.20 (1.14-1.30)	0.63 (0.54-0.72)	0.47
Al2O3	18.97 (18.20-19.43)	18.09	19.03 (18.55-19.33)	19.62 (18.97-20.31)	19.54 (19.36-19.72)	19.70
Fe2O3	1.71 (1.61-1.79)	1.49	1.67 (1.58-1.75)	1.41 (1.34-1.46)	1.38 (1.37-1.38)	1.36
FeO	11.38 (10.72-11.91)	9.89	11.14 (10.49-11.62)	9.41 (8.91-9.74)	9.15 (9.14-9.19)	9.06
MnO	0.30	0.00	0.37	0.31	0.34	0.30
MgO	6.33 (5.93-6.68)	4.59	5.99 (5.83-6.14)	5.56 (5.32-5.91)	5.37 (5.24-5.43)	5.27
CaO	11.36 (10.82-11.84)	11.56	12.23 (12.00-12.49)	10.90 (10.67-11.03)	11.73 (11.48-11.94)	12.22
Na2O	1.16 (1.00-1.47)	2.21	0.36 (0.18-0.56)	1.16 (0.90-1.58)	0.96 (0.86-1.11)	1.14
K2O	0.60 (0.46-0.94)	1.87	0.10 (0.05-0.19)	1.43 (1.27-1.53)	0.95 (0.86-1.09)	0.44
P2O5	0.33	0.33	0.26	0.26	0.33	0.34
SUM	99.62	99.35	99.68	99.36	99.25	99.32
			CIPW Norms			
Q	0.0	0.0	4.4	0.1	2.6	3.1
Or	3.6	11.1	0.6	8.5	5.7	2.6
Ab	9.9	15.9	3.1	9.9	8.2	9.7
An	45.0	34.1	50.2	44.4	46.5	47.7
Ne	0.0	1.6	0.0	0.0	0.0	0.0
Di	7.9	17.8	7.5	6.9	8.2	9.3
Hy	12.4	0.0	16.3	13.0	13.2	12.9
Ol	5.0	11.0	0.0	0.0	0.0	0.0
Mt	2.5	2.2	2.4	2.1	2.0	2.0
Il	2.2	5.6	1.6	2.3	1.2	0.9
Ap	0.8	0.8	0.6	0.6	0.8	0.8
K2O/NA2O	0.52 (0.44-0.64)	0.85	0.27 (0.21-0.30)	1.3 (0.97-1.5)	0.99 (0.98-1.0)	0.39
Mg No.	46.6	42.2	45.8	48.1	47.9	47.7
I.R.	0.44	-0.08	0.63	0.50	0.53	0.51

Footnote: Ferric iron calculated based on ferric/ferrous ratio of 0.15.

I.R. = ave. Indicator Ratio (Coombs, 1963), defined as Hy + 2Q/(Hy + 2(Q + Di)); if Ne in norm : - (Ne/(Ne + Di))

P2O5 measurements may be questionable due to possible interference of a secondary Ca peak.

TABLE 8., (Continued) GLASS COMPOSITIONS

	KA 107		
	Pale brown glass near cpx patches		
Wt %			
SiO2	40.64	40.64	45.81
TiO2	2.04	2.07	1.25
Al2O3	15.72	15.83	18.51
Fe2O3	1.80	1.97	1.56
FeO	11.99	13.12	10.40
MgO	7.50	7.88	6.54
CaO	11.12	11.47	10.63
Na2O	2.04	2.19	1.87
K2O	0.72	0.61	0.89
P2O5	0.48	0.61	0.02
Sum	94.05	96.39	97.48
	CIPW NORMS		
Or	4.5	3.7	5.4
Ab	9.7	7.5	16.2
An	33.6	32.7	40.5
Ne	4.7	6.4	0.0
Di	17.9	18.3	11.1
Ol	21.5	22.9	15.1
Mt	2.8	3.0	2.3
Il	4.1	4.1	2.4
Ap	1.2	1.5	0.0
K2O/Na2O	0.35	0.28	0.48
Mg no.	49.5	48.5	49.7
I.R.	-0.21	-0.26	0.13

affinities, as their average Indicator Ratios are -0.08 and -0.23, respectively (Coombs, 1963). The normative plagioclase in most of the glasses has a bytownite composition. The glass that occurs with skeletal olivine (KA 107) has normative labradorite plagioclase and the glass in KA 108 has normative anorthite plagioclase.

VII. DISCUSSION

One goal of this study has been to use the mineral chemistry and textures of Kaula pyroxenites to interpret events in xenolith history. An event (a temperature and/or pressure change experienced by a xenolith) may produce a chemical and/or textural feature in a xenolith. Such a feature serves as a record of the event. What is ultimately sought is an understanding of the processes which caused these changes, and the relative timing of one event with respect to another.

The presence of glass inside a xenolith is a petrographic clue that an event has possibly been recorded in a xenolith. In Kaula pyroxenites, glass occurs in three distinct associations: 1) within and around the margins of cpx patches, 2) in and near kelyphitic spinel + opx intergrowths, and 3) in localized, discrete pockets with skeletal olivine. Migration of liquid formed in one of these three associations is thought to explain the glass observed in veinlets inside some Kaula xenoliths; rarely, a veinlet can be traced to the contact with the host basanitoid. In the first two associations, the formation of the glass appears to be directly related to the formation of the mineral/textural feature with which it occurs, based on the intimate petrographic association of the glass with the feature. Therefore, discussion of the event in which the glass formed is addressed through discussion of the formation of these two features, cpx patches and opx + spinel intergrowths. The formation of glass in the third association, skeletal olivine + glass, is more enigmatic; evidently, it is not associated with a mineral/textural feature. However, all three associations are particularly well-developed in one Kaula sample; the textural relationship of the skeletal olivine + glass association relative to the other two associations plays a role in deducing the relative timing of formation of the features.

Formation of Cpx Patches

Aspects relating to the formation of cpx patches are discussed in this section. These topics include the evidence used to infer that melting was the mechanism which produced cpx patches from cpx host grains, constraints on the melting process, and various models which could cause melting. The cpx patches are important because they imply a pressure or temperature change in the xenolith´s history.

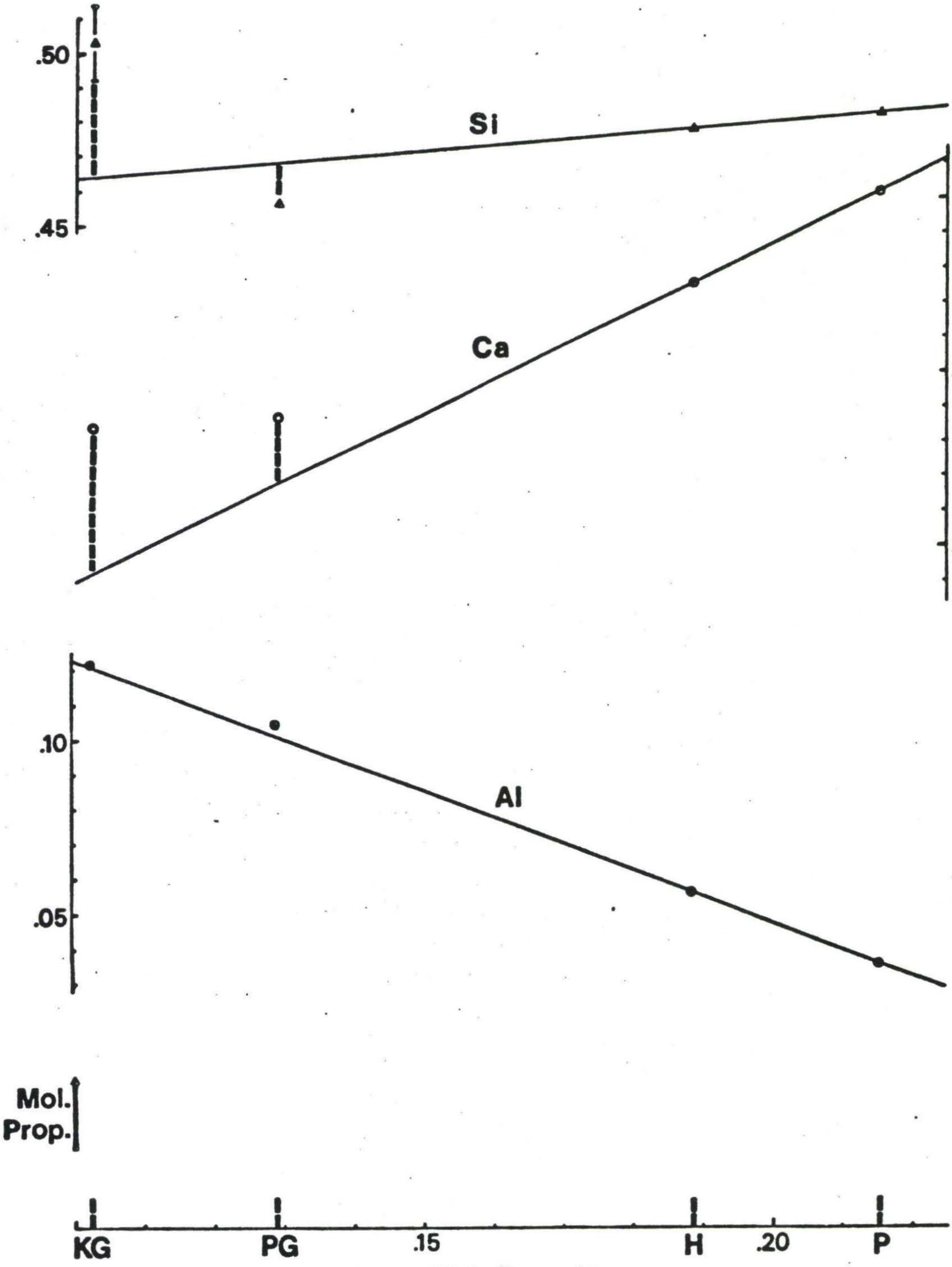
The presence of glassy material at the edges of, and within, the cpx patches provides evidence that the patches were produced by one or more of the following mechanisms: the melting of cpx, the melting of cpx and an associated phase, or the interaction of the cpx and a fluid.

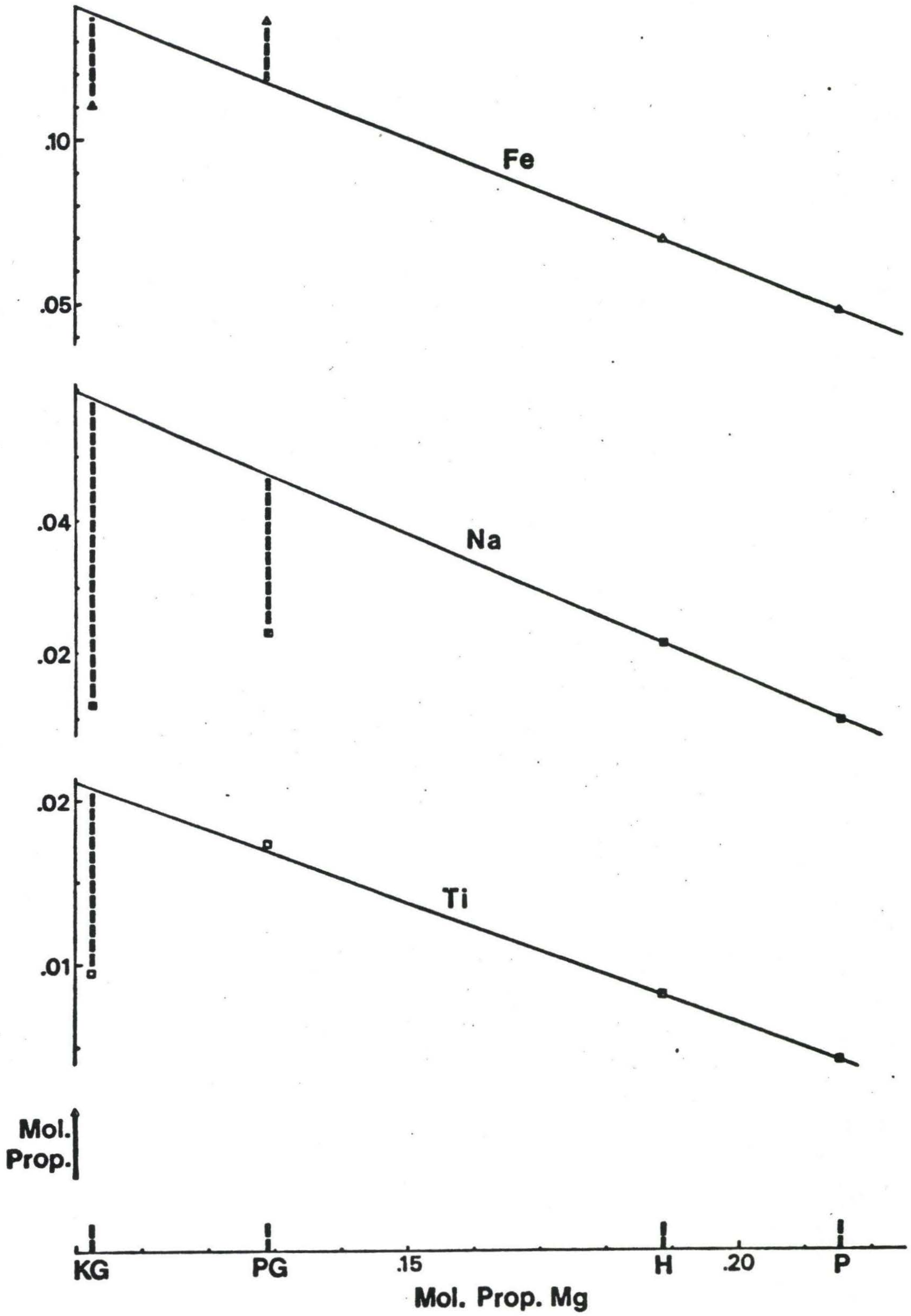
One approach used to support the contention that the cpx patches formed by the melting of cpx host grains was to show that the change in host and patch compositions is consistent with the experimentally observed melting behavior of cpx. The melting of cpx should produce a residual cpx which is enriched in the refractory elements Ca and Mg, and a liquid which is enriched in the magmaphile elements Fe, Na, and Al (as depicted on phase diagrams of diopside-hedenbergite (Deer et al., 1966) and jadeite-diopside (Bell et al., 1969)). The cpx patch compositions display a shift toward increasing Ca and Mg contents with a concomitant loss in Fe, Na, and Al, relative to the cpx host grains (Figures 5 and 7). This is consistent with the predicted behavior of cpx melting.

Another aspect of the cpx melting model requires consideration of the liquid composition (glass) produced in the melting. Two different glass compositions were found in the immediate vicinity of the patches: Glass A, which corresponds to the typical pale brown glass found associated with garnet kelyphitic features, and Glass B, which has a distinct composition. Unfortunately, analyses of the glass immediately surrounding the patch tended to give low totals (see Table 8), probably due to 1) the necessity of using a focused beam because of the small size of the glassy areas, and 2) the partial devitrification and/or alteration of the glass. To test the model in which the glass was produced from the cpx host grain as a consequence of the formation of the cpx patch, a mole proportion mixing line calculation and graphical solution were performed (Figure 10).

Figure 10. -- Mole proportion mixing line graphical solution for the equation Cpx Host Grain --> Cpx Patch + Glass. Mixing line defined by cpx patch and cpx host compositions.

Symbols: P = cpx patch, H = cpx host grain, PG = glass at edges of and within cpx patches, KG = glass associated with kelyphitic intergrowths, Mol. = Mole, Prop. = Proportion. Error bar drawn for KG Si measurement.


.50
.45
Si
Ca
.20
.15
.10
.10
Al
.05
Mol.
Prop.
KG
PG
.15
H
.20
P
Mol. Prop. Mg


.10
.05
Fe
.04
.02
Na
.02
.01
Ti
Mol. Prop.
KG
PG
.15
H
.20
P
Mol. Prop. Mg

Normalized compositions of the two glasses were used, in order to determine which glass composition fit the model best. Glass B resulted in a better fit to the mixing line compared to the fit of Glass A.

However, potassium (K) is present in both glasses, and is not present in the cpx. Therefore, assuming that the glass (Glass B) was produced by melting of the cpx host grain, a potassic phase(s) must also have been involved. Three possible sources for K are phlogopite, some other undefined K(REE)P-type phase, or the host basanitoid. The mixing calculation suggests that the basanitoid cannot be considered as a source for all of the K in the glass; since the basanitoid has a low K content, the amount necessary to provide the observed quantity of K in the glass would substantially increase the abundances of other elements, such as Mg (see Table 9). If host basanitoid was involved, it was present in a small quantity, and another potassic phase must be called upon. Since phlogopite has a very high K content, only a small amount of it would be needed to produce the quantity of K observed in the glass. However, even though trace phlogopite is observed in one Kaula sample (KA 109), the method of supplying K to the remarkably pervasive system of patches where glass formed must have involved a highly penetrative fluid or vapor. It cannot be established if the presence of this fluid was necessary to initiate melting, nor if the fluid might have caused the melting. Fracture control can be seen in the pattern of cpx patches; this suggests that, since fractures provide channelways for a fluid or vapor, the location of the fluid may have affected the location of cpx patches.

TABLE 9

AVERAGE WHOLE-ROCK MAJOR ELEMENT ANALYSIS OF HOST KAULA BASANITOID

Ave. of 6, from Grooms (1980)

Wt.%	
SiO2	40.98
TiO2	2.71
Al2O3	11.78
Fe2O3	4.94
FeO	8.23
MnO	0.24
MgO	12.04
CaO	11.02
Na2O	3.03
K2O	1.26
P2O5	0.82
H2O	2.67
CO2	0.15
-----	------
Total	99.87

Phophorus (P) is also present in both of the glasses. This requires the contribution of either a small amount of host basanitoid or a phosphatic phase (apatite or an undefined K(REE)P-rich phase). Based primarily on the evidence of K in the glass, and possibly supported by the P also present, an episode in which a K(REE)P-rich component was introduced into the xenolith is advocated. However, the time of the introduction of this component cannot be determined. K(REE)P-rich components may have entered the xenolith in a previous history, crystallized, and later melted and remobilized, or may have penetrated the xenolith just prior to incorporation into the host basanitoid.

Causes of melting

There are several possible models which could explain how and why melting occurred in the xenolith or megacryst. These include post-incorporation mechanisms (operative immediately after the xenolith was incorporated into the host basanitoid and during ascent), and pre-incorporation mechanisms.

Presence of the host basanitoid inside a xenolith is one possible post-incorporation mechanism to cause melting. However, the lack of a pronounced chemical signature of the basanitoid on the composition of the glass in the patch areas strongly implies that the basanitoid was not physically present in the patch area and therefore did not directly induce melting or reaction at the time of patch formation. On the other hand, a number of samples display clear evidence of the penetration of host basanitoid into the xenolith: for example, fractures containing host basanitoid extend into the xenolith, with local secondary overgrowths of olivine invading xenolith pyroxene (KA 108 and 107), as described in Salt Lake xenoliths by White (1966). Also, in KA 105, a fracture containing glass can be traced from the host basanitoid 1.5 cm into the xenolith, where it becomes a fracture in garnet along which fibrous intergrowth is present (see Plate IV). Perhaps the most difficult case to reconcile is in a megacryst (KA 38), where small olivine needles are randomly present inside the patch and patchy rim areas. The olivine might be either a by-product of the reaction in which the patch was formed or the result of contamination by a small amount of host basanitoid. However, this phenomenon is observed only in the megacryst. Otherwise, although the basanitoid did penetrate the xenoliths at some time, chemical evidence suggests that cpx patch formation was unrelated to such penetration.

The thermal energy of the host basanitoid provides another potential melting mechanism. However, whether the thermal energy alone could have been sufficient to induce melting in an entrained xenolith cannot be definitively answered. Some considerations are as follows. A 70:30 diopside:hedenbergite mixture (which corresponds to the Mg/Fe ratio in the cpx host) starts to melt at 1275° C at 1 atm pressure (Deer et al., 1966). An omphacitic pyroxene at 30 kbar pressure begins to melt at approximately 1550° C (O´Hara, 1963). The melting point of the host cpx may be expected to lay somewhere within this range. The presence of an additional phase (potassic, phosphatic) in the cpx would lower the melting point. One way to crudely estimate the basanitoid temperature is through reference to textural evidence provided by the presence of a cpx overgrowth on a megacryst patchy rim. The cpx overgrowth has a similar composition to basanitoid groundmass cpx. Hence, the patchy rim must have formed before cpx was crystallizing out of the basanitoid. It can be reasoned that the basanitoid temperature at the time of patchy rim formation was probably greater than the temperature at which cpx was crystallizing out of the basanitoid. The minimum temperature for which cpx experimentally crystallizes out of a basanitoid is approximately 1220^{o} C at 1 atm. pressure (Arculus, 1975), and so the basanitoid temperature was probably greater than 1220^{o} C at the time of patch formation. Due to the inability to constrain these temperatures better, it is not possible to determine if the host basanitoid, by its heat energy alone, would have been capable of melting the cpx and potassic phase.

Another post-incorporation model involves the decompressional melting of the cpx (with a potassic/phosphatic phase) due to the ascent of the xenolith. In a few samples, cpx patches have slightly higher $Al^{iv}:Al^{vi}$ ratios (Wass, 1979) than cpx host grains (eg., 1.2 patch vs. 2.1 cpx host), which can be interpreted as an indication that the patches formed at a lower pressure than the host grains (Table 10). However, these ratios cannot be used to constrain how low the pressure was or how much of a drop in pressure had occurred.

TABLE 10

$AL^{iv}:AL^{vi}$ RATIOS* FOR KAULA XENOLITH AND MEGACRYST CLINOPYROXENES

Sample		CPX host	CPX patch	CPX rim	Other
KA 107		1.1	1.2		
105		1.0	1.3		0.9 inclus. in gt
108	large	1.1			1.2 sm. grain, react.
	host	1.2	2.1	2.1	
109		1.2	1.3		
106	large	1.2	1.4		
	disrpt	1.2			
103		1.1			
110	ave	1.0			1.2 highly exsolved
	host	0.9	1.4		
104	large	0.9			
	mosaic	0.9			
102		0.9		1.1	
101	webst	1.4			
	dun	1.2			
100		1.1			
38megacr		1.3	1.2	1.6	9.3 overgrowth; 19.1 basalt cpx

---

* (Wass, 1979)

Models for patch formation prior to the incorporation of the xenolith into the host basanitoid are as follows:

a) as discussed earlier (p.90), a K(REE)P-rich fluid penetrated the xenolith and caused melting. The fluid could have caused melting either because it was hot or because its presence sufficiently lowered the solidus of the cpx.

b) in situ partial melting of the cpx due to the local influx of magma at depth (perhaps similar to the scenario proposed by Takahashi, 1980).

There is no definitive evidence available in the data collected in this study to indicate which of these models is more likely. The decompressional melting model is favored because although it has not been treated experimentally, it seems likely that the pressure drop due to ascent is a significant driving force for reaction, and it is a commonly invoked model (eg., Ghent et al., 1980). Formed as a response to this (i.e., the melting of phlogopite + phosphatic phase + cpx), or supplied to the xenolith before incorporation into the host basanitoid (K(REE)P-type fluid or vapor), a fluid was presnt in the cpx during this melting and provided the K and P found in the glass. Regardless of whether the melting was a response to increased temperature, decreased pressure, a penetrative fluid, or perhaps a combination of these mechanisms, the quenching of the glass occurred within the plagioclase stability field, based on the occurrence of rare plagioclase microcrystallites in the glass. This indicates lower pressure relative to the time during which the opx + spinel intergrowth was forming (based on plagioclase and spinel stability fields on phase diagram, Arculus, 1975).

In summary, the cpx patches are considered to have formed by the melting of cpx. A penetrative fluid provides a way of supplying K and P to the observed glass. The cause of the melting is believed to be decompression during ascent of the xenolith, possibly aided by the presence of the fluid.

Formation of Garnet Kelyphitic Features

This section addresses the problem of how kelyphitic opx + spinel intergrowths formed. As mentioned earlier, glass is associated with these intergrowths, and they are important because they provide a record of an event in xenolith history. Mass balancing calculations are used to show that the intergrowth is not a simple garnet breakdown. Various possible reactions to produce the intergrowths are discussed, followed by remarks on the mechanism causing the formation of these features.

Petrographically, the opx + spinel fibrous intergrowth appears to have formed from garnet. A least squares mixing calculation made on the simple equation garnet --> opx + spinel shows that this subsolidus reaction is not balanced, because a very high residuals total (15.4) results (Table 11). Particularly, Mg, Ca, and Si pose problems. Lessening of Ca and Mg residuals would be expected if cpx formed with opx and spinel. However, silica residual would remain high. While it is possible that cpx may be difficult to distinguish from opx in the fibrous intergrowth, the grain size is large enough in the coarse

TABLE 11

MASS BALANCING CALCULATIONS USING A LEAST SQUARES APPROXIMATION*

Equation 1. Garnet = OPX + Spinel
OPX factor: 0.81101
Spinel factor: 0.18331

Residues:

SiO2	2.6754
TiO2	0.090155
Al2O3	2.0005
Cr2O3	-0.018762
FeO	-0.83731
MnO	-0.2207
MgO	-6.0973
CaO	3.4391
Na2O	-0.0024404
K2O	0

Total sum of residues: 15.3816674

Analyses used: KA 107

	Garnet (Gr.3)	=	OPX (Gr.1c)	+	Spinel (Gr.4)
Wt. %					
SiO2	41.02		47.28		--
TiO2	0.44		0.35		0.36
Al2O3	23.36		12.26		62.28
Cr2O3	0.11		0.10		0.26
FeO	13.56		13.39		19.30
MnO	0.38		0.70		0.18
MgO	16.61		23.98		17.78
CaO	4.98		1.90		--
Na2O	0.03		0.04		--
Total	100.49		100.00		100.16

---

* by S. Maaloe, 1982, using Wright and Doherty (1970) procedure

TABLE 11., (Continued) MASS BALANCING CALCULATIONS

Equation 2. Garnet = OPX + Spinel + Glass
OPX factor: 0.38406
Spinel factor: 0.19362
Glass factor: 0.4497

Residues:

SiO2	0.3506
TiO2	-0.21071
Al2O3	0.28702
FeO	-0.66425
MnO	0.053358
MgO	-0.34254
CaO	-0.84357
Na2O	-0.39506
K2O	0
Free	0.016797

Total Sum of Residues: 3.163905

Analyses used: KA 107

Wt.%	Garnet (Gr.4) =	OPX (Gr.3) +	Spinel (Gr.9) +	Glass (Loc.4A)
SiO2	40.43	51.35	—	45.27
TiO2	0.44	0.27	0.34	1.07
Al2O3	23.38	5.75	63.34	19.17
Cr2O3	0.04	0.01	0.10	—
FeO	13.81	13.12	17.33	13.52
MnO	0.33	0.29	0.18	0.29
MgO	16.46	26.26	19.34	6.61
CaO	5.09	2.23	—	11.29
Na2O	0.07	0.04	—	1.00
K2O	n.d.	n.d.	n.d.	0.54
P2O5	n.d.	n.d.	n.d.	0.43
Total	100.05	99.32	100.63	99.19

TABLE 11., (Continued) MASS BALANCING CALCULATIONS

Equation 3. Garnet = OPX + Spinel + Glass - CPX

OPX patch factor:	0.40021
Spinel factor:	0.18484
Glass factor:	0.50779
CPX factor:	-0.068928

Residues:

SiO2	0.27524
TiO2	-0.19911
Al2O3	0.28737
Cr2O3	0.018203
FeO	-0.9338
MnO	0.043059
MgO	-0.10129
CaO	-0.36984
Na2O	-0.30216
K2O	0

Total sum of residues: 2.530072

Analyses used: same as in Equation 2, with:

Wt. %	CPX (Gr.4,2)
SiO2	49.09
TiO2	1.09
Al2O3	9.44
Cr2O3	0.01
FeO	8.35
MnO	0.14
MgO	12.76
CaO	16.91
Na2O	2.20
------	------
Total	99.99

kelyphitic rim to be certain that only opx is present. Kuno (1969) proposed the following equations to express the reaction: 1. garnet ($CaMg_2Al_2Si_3O_{12}$) —>diopside ($CaMgSi_2O_6$) + spinel ($MgAl_2O_4$) + SiO_2, a 2. garnet ($Mg_3Al_2Si_3O_{12}$) —> enstatite ($2MgSiO_3$) + spinel ($MgAl_2O_4$) + SiO_2. In both cases, Kuno suggested that the excess silica reacts with olivine to produce enstatite. In garnet peridotites from Itinome-gata, Japan, where Kuno observed this feature, enstatite is present along the boundary between the intergrowth and olivine. (Note that by requiring olivine, the reaction is, in reverse, identical to the typical Salt Lake reaction to produce garnet and olivine from cpx, opx, and spinel (for example, see Reid and Eggleton, 1977)). However, olivine is not present in the area of the kelyphitic intergrowths for the case of KA 107. Thus, this explanation is problematic. Also, the trace occurrences of olivine in some of the other Kaula pyroxenites petrographically appear unrelated to this feature.

In order to balance an equation in which opx + spinel intergrowth forms from garnet, two possibilities can be considered:

1) Olivine was totally consumed by reaction with SiO_2 to produce enstatite. However, the only occurrence of opx in this sample is that which was produced in the kelyphitic intergrowth; this places constraints on the earlier distribution of olivine, and renders this suggestion unlikely.

2) Some other phases are involved, as reactants, products, or possibly both. The involvement of a fluid is supported by the intimate association of glass with the garnet kelyphitic feature. The

involvement of cpx is also supported texturally (intergrowth appears to form at the expense of cpx). There are a number of possible reactions which can be considered:

1) garnet --> opx + spinel + liquid (glass)

2) garnet --> liquid 1 --> opx + spinel + liquid 2 (glass)

3) garnet + cpx --> opx + spinel + liquid (glass)

4) garnet + cpx --> liquid 1 --> opx + spinel + liquid 2 (glass)

5) garnet + cpx + phase q --> products of equations 1) or 2).

6) garnet + phase q --> products of equations 1) or 2).

The differences between the first four equations center on two aspects: 1) how the opx + spinel intergrowth formed, especially with respect to the glass that it occurs with, and 2) the possible role of cpx as a reactant. The fifth and sixth equations focus on the role of an undefined reactant, which could be a mineral or a fluid, in addition to garnet or garnet + cpx. In equations 1) and 3), the transition from garnet to opx and spinel occurs in a symplectite-producing reaction. In equations 2) and 4), a liquid is produced by the melting of garnet or garnet + cpx, from which the opx and spinel intergrowth crystallizes out. In Salt Lake pyroxenites, Helz (1979) interpreted second-generation euhedral crystals of highly aluminous pyroxene and spinel as crystallization products from glass.

Petrographically it is difficult to determine whether or not the opx and spinel crystallized out of a fluid, and various considerations in attempting to resolve this are inconclusive. One advantage of the crystallization model is that the formation of the intergrowth in two grain sizes (coarse kelyphitic rim and fibrous intergrowth) plus glass could be explained by variation in nucleation and cooling rate of the liquid. Such a difference in grain size is more problematic with the symplectite model. However, the coarse type tends to occur adjacent to cpx, and the fibrous type and glass occur next to garnet. Perhaps the phase which is undergoing transition to symplectite influences the coarseness of the intergrowth, as the zone in which the transition to symplectite occurs moves inward from grain contacts. How this occurs is uncertain, but maybe it reflects some aspect of the process of symplectite formation (specifically, the mechanics of the transition with respect to each phase involved). Or perhaps it is due to changes in the rate of symplectite formation. A major objection to the crystallization model stems from the observed general uniformity in glass composition in the kelyphitic intergrowths. The proportion of intergrowth to glass varies considerably from one location to another within a sample; presumably, this would reflect variation in the extent of crystallization. Since the extent of crystallization apparently is variable, the composition of the remaining fluid is expected to be variable. The general uniformity in glass composition observed in the kelyphitic areas is believed to make the crystallization model less attractive than the symplectite model (see Table 8). The results of mass-balancing calculations indicate that a high proportion of glass should be produced in the reaction forming the intergrowth (45-51%, see Table 11). The average of the amount of glass relative to the amount of intergrowth is visually estimated to be about 20:80, substantially less than the predicted amount. However, petrographic evidence indicates that some fluid had migrated; rare glass veinlets cross-cutting cpx are observed. On the assumption that fluid had migrated, the discrepancy between the amount of glass expected and the amount observed is not considered sufficient to invalidate the symplectite model. Therefore, although there is no conclusive positive evidence, the symplectite model is favored because the crystallization model has difficulties which are harder to explain.

Evaluation of the possible involvement of cpx as a reactant can be made by comparing mixing calculation results; the equation garnet + cpx --> opx + spinel + glass gives a lower residuals total (2.5) compared with the equation garnet --> opx + spinel + glass (residuals total = 3.2). Based on the improvement in the results of the calculation and petrographic evidence, cpx involvement is considered favorable.

Although it is not possible to document the participation of Phase Q, (equations #5 and #6), a reactant phase in addition to garnet or cpx + garnet is required. This is dictated by the presence of K and P in glass associated with garnet kelyphitic features, as in the case of cpx patches (discussed above). A K- and P- bearing phase(s) is necessary in the formation of glass associated with the kelyphitic features, and could be either a) phlogopite + phosphatic phase, or b) a K(REE)P-rich fluid.

Evaluating between a) and b) above cannot be done conclusively. However, variation in the alkali contents and alkali ratios of glass is observed from sample to sample, and within a sample. This might lend support to the melting of phlogopite in differing quantities.

Frey and Green (1974) used the amounts of K_2O and Na_2O and the ratio K_2O/Na_2O in glass to decipher the influence of amphibole and/or phlogopite melting on the composition of glasses in Victorian lherzolites. They found that glass near amphibole has low $\%K_2O$ (0.1 wt%) and low ratio of K_2O/Na_2O (0.02). Glass derived from phlogopite would be expected to have high K_2O content, fairly low Na_2O content, and a high ratio. However, in the Victorian lherzolites, glass near phlogopite has high $\%K_2O$ (approx. 6 wt%) and high ratio of K_2O/Na_2O (1.3-1.7). Because the $\%Na_2O$ is too high to be derived from phlogopite (3-4 wt%), they concluded that either amphibole was present, or else Na was added to the glass by the recrystallization of primary cpx with 1.6 wt% Na_2O to secondary cpx with 0.8 wt% Na_2O. In another case, very alkali-rich glasses (K_2O 6-7 wt%, Na_2O 7-8 wt%) with K_2O/Na_2O ratio of about unity, were attributed to the melting of both phlogopite and amphibole.

Kaula glasses do not contain as much Na and K as the Victorian glasses (see Table 8), and amphibole has not yet been observed in any Kaula pyroxenites. However, some of the alkali contents, and particularly their alkali ratios, suggest that some of the Kaula melt involves trace phlogopite, despite the rarity of phlogopite in the Kaula pyroxenites. For example, in KA 109, the K_2O/Na_2O ratio is high (0.97-1.49), and trace phlogopite is present. Also, the contribution of slightly differing amounts of phlogopite to the melting provides a convenient explanation for the variability in some glass compositions.

Variation in the alkali ratio (0.4-1.0) in KA 110 may be due to varying amounts of phlogopite having contributed to the melt.

One of two possible mechanisms is implied by the formation of the opx + spinel intergrowth from garnet. All six reactions could have occurred in response to either an increase in temperature or a decrease in pressure (based on experimental work of Arculus, 1975). Green (1966) and other authors favored the latter mechanism. Also, Helz (1979) pointed out that the difference in composition between primary and second-generation pyroxene and the lack of secondary garnet imply a decrease in pressure relative to earlier stages in xenolith history.

In summary, the reaction involving garnet, cpx, and a K- and P-bearing phase(s) to produce the opx + spinel intergrowth and glass implies melting. Since a decrease in pressure is inferred, the model of decompressional melting is favored for kelyphitic intergrowth features.

Formation of Skeletal Olivine and Glass Association

The formation of skeletal olivine + glass is enigmatic, especially since there is no petrographic clue as to what phases this feature formed from. Yet it is important since it is texturally related to the other features. Considerations regarding its formation are discussed.

Various attempts to decipher what may have contributed to the formation of this glass have met with limited success. The glass associated with skeletal olivine cannot be derived from the glass which occurs with opx + spinel intergrowth. Two lines of evidence which demonstrate this are: a) alumina and CaO contents in glass associated with skeletal olivine do not show increases relative to the glass from which they were to be derived, and b) the glass with skeletal olivine has higher K_2O (1.9 wt%) and Na_2O (2.2 wt%) contents than the glasses in kelyphitic intergrowth areas (K_2O 0.5-0.9 wt%, Na_2O 1.0-1.5 wt%), but also has a higher K_2O/Na_2O ratio (0.85 vs. 0.4-0.6). Although the increases in K_2O and Na_2O are consistent with olivine having crystallized out, the alkali ratio should have remained unchanged (see Table 8). Therefore, if the glass associated with skeletal olivine was related to the intergrowth-related glass, then the composition of the fluid was changed in some way prior to olivine crystallization. The K_2O% is higher in the glass associated with skeletal olivine than in any of the analyzed host basanitoids (K_2O 1.2-1.5%); this suggests that there may have been a contribution of K from phlogopite. However, phlogopite melting can provide only part of the discrepancy. A reconstructed liquid composition for the skeletal olivine + glass (assuming approximate proportions of 50/50) shows that the fluid from which skeletal olivine + glass formed was particularly high in Mg, while the glass which occurs with the opx + spinel intergrowth is rich in Si, Ca, and Al. This is not easily explained.

Three possible explanations for the high-Mg nature of this glass (before olivine crystallized) are a) host basanitoid contaminated this glass, b) pyroxene was undergoing incongruent melting to form olivine and liquid, or c) melting did not proceed along the same compositional path in different areas of the rock (disequilibrium melting occurred) or changed at some time. The skeletal olivine with glass bears a strong resemblance in appearance to some of the olivine which invades pyroxene at the xenolith/ host basanitoid contact. However, olivine which crystallized out of the host basanitoid commonly is similar in appearance to the skeletal olivine with glass. Therefore, petrographic observations are not suggestive of the more likely explanation.

Disequilibrium growth may be suggested by the comparison of predicted versus observed olivine forsterite content based on the FeO and MgO contents of the glass from which the olivine appeared to have formed (Roedder et al., 1970). The predicted equilibrium Fo% is approximately 72; the observed is 83. The skeletal habit of olivine suggests that undercooling is occurring, and so supports the evidence for disequilibrium growth. However, another possibility is that iron in the glass is more oxidized than assumed (i.e., has a ferric to ferrous iron ratio greater than 0.15). A higher oxygen fugacity would correlate with influence of host basanitoid or influx of melted phlogopite (volatiles) on/into the liquid from which skeletal olivine + glass formed. It is clear, however, that for some reason, conditions were different at the time this liquid formed. It is believed that the host basanitoid, in addition to phlogopite, played a role in locally changing the composition of this fluid.

Relative Timing of the Formation of Cpx Patches, Kelyphitic Intergrowths, and Skeletal Olivine + Glass Association

Textures, although notoriously ambiguous, commonly provide the only available means by which to deduce the relative timing of the formation of features of interest. Several textural observations are important in Kaula pyroxenites. 1) The cpx patches and kelyphitic intergrowths are both widespread, with cpx patches occurring in cpx grains and kelyphitic intergrowths occurring at garnet/cpx boundaries. 2) The skeletal olivine + glass association is localized and sporadic in distribution. 3) Pockets of skeletal olivine + glass cross-cut cpx patches and so have formed later than the cpx patches. 4) Opx + spinel intergrowth and glass is not observed to cross-cut cpx patches. However, kelyphitic intergrowth-type glass compositions were found in the thin glassy area surrounding the cpx patches. 5) The skeletal olivine + glass association tends to form discrete pockets; skeletal olivine does not occur in areas of opx + spinel intergrowths. However, there are places where these two associations are in physical contact. A thin zone of fine, dusty opaques (oxides?) in glass occurs at the contact between the two, as if oxide precipitation occurred where the two liquids came into contact. These textures seem to be indicating that a) the cpx patches formed earliest, b) the kelyphitic intergrowths formed next, and c) the skeletal olivine + glass appear to have formed latest, with overlap in time between each step. Perhaps since a higher percentage of melt probably was present in the the opx + spinel intergrowth + glass feature compared with melt from cpx patch areas, it remained fluid longer and persisted into the time when the skeletal olivine + glass areas were forming. These observations also support the contention that the skeletal olivine + glass association was a modified or intrinsically different fluid that reflects different conditions at the time of its emplacement into the xenolith.

Xenolith History

A generalized sequence of "events" in the history of Kaula pyroxenite xenoliths is summarized in this section. The events, which were deduced from observed features, will be discussed in reverse chronologic order, beginning with the most recent. The events to be considered, and constrained relative to one another, where possible, are: xenolith/ host basanitoid reactions, pre-incorporation reactions, including exsolution, deformation, and recrystallization history in pyroxene, and formation of the primary xenolith.

Xenolith/ Host Basanitoid Reactions

The effect of the enclosing basaltic melt on an entrained xenolith depends on a number of factors: the permeability of the xenolith (how fractured it is and its grain size) and the compositions and proportions of the phases in the xenolith. In addition, pressure, temperature and composition of the melt, including volatile content, are important factors. Potential mechanical disaggregation and abrasion of the xenolith, and the duration of the interaction between the xenolith and the host, are also important. Most of the xenoliths are now encased in tuff. Unfortunately, the tuff is thoroughly palagonitized, so it is not possible to determine the original host composition. However, several xenoliths have a thin rim of a host lava which is mineralogically similar to the basanitoid inclusions found in the Kaula tuff, and probably represents the composition of the magma shortly before eruption. The degree to which a xenolith is affected by the host basalt is quite variable. In some cases, such as the Victorian lherzolites mentioned above, only the outer 200 microns of the xenolith shows any influence of the host (Frey and Green, 1974). On the other hand, White (1966) found widespread evidence of reaction between Hawaiian xenoliths of a variety of rock types and host basalts. Some of the features observed in Kaula xenoliths are similar to those discussed by White, as mentioned earlier. Some of the effects produced by the host may not be evident (or only a trace may remain) because of xenolith disruption. Ringwood (1975) pointed out that contamination by components derived from a host basanite could distort trace element behavior by as much as three orders of magnitude. This could present a serious problem in trace element studies. Therefore, careful petrographic and perhaps chemical inspection of a xenolith and its contact with host basalt (if available) should be made prior to such a study.

Although it is difficult to positively determine the time at which initiation of melting took place, as discussed above, decompressional melting is favored. Therefore, it is suggested that both the cpx patches and the kelyphtic opx + spinel intergrowths formed during the upward transport of the xenolith, but their formations were possibly initiated at different depths. The pockets of skeletal olivine and glass probably represent the most recent of the glass-bearing features.

Pre-incorporation Reactions in the Xenolith

The reaction in which garnet was produced at the expense of spinel and cpx is probably the next earlier reaction. The spinel to garnet reaction is problematic in the case of KA 107 (garnet-spinel clinopyroxenite); as with Dish Hill clinopyroxenite (Shervais et al., 1973), there is no olivine by-product which is necessary for mass-balancing the reaction. Olivine abundance is not more than a trace in any of the samples which bear garnet, and does not occur near the garnet as in Salt Lake pyroxenites (Jackson and Wright, 1970). This is equivalent to the reverse problem of forming the opx + spinel intergrowth from garnet. The reaction of cpx and spinel to produce garnet either requires increased pressure or a decrease in temperature (Kushiro and Yoder, 1966). Most authors (eg., Green, 1966) favor the latter mechanism. However, due to mass-balancing constraints indicated by the reverse reaction discussed earlier, it appears to have required a fluid. Since the reaction producing garnet probably involves cooling, it seems unlikely that the fluid necessary to balance the reaction would have been a product of the reaction. Therefore, as a reactant, the equation dictates that it was a high silica fluid or phase. There are perhaps other possibilities, but all are speculative. One possibility is that garnet exsolved from a primary clinopyroxene and was later recrystallized. This explanation is problematic where spinel is present as cores to garnet coronas, and also, there is no textural evidence of garnet exsolution in cpx. A more plausible explanation is that spinel was on the liquidus at high pressure; it later reacted with the magma to form garnet. Cpx came on the liquidus and poikilitically enclosed the spinel-garnet clusters. This alternative hypothesis is supported by the experimental results of O'Hara and Yoder (1967). Regardless of the mechanism, the transition from spinel to garnet is constrained to a specific pressure range, depending on bulk composition; 13-18 kb for an alkali basalt (Green, 1966), or 25-30 kb for a basanitoid composition (Arculus, 1975).

Events Involving Pyroxene Exsolution, Deformation, and Recrystallization

A lack of deformation texture is noted in Salt Lake pyroxenites by White (1966), Green (1966), and Sen (1981). This is important because it implies that directed stress either was not significantly operative on, or was not manifested in, those xenoliths. On the other hand, deformational features have been reported in other pyroxenite xenoliths (eg., Wass, 1979). The subparallel banding of cpx described earlier (in KA 110) in a Kaula pyroxenite provides evidence that deformation of pyroxene occurs in some rocks. Also, the disrupted cpx observed in several of the pyroxenites could possibly represent one step of a deformational/ recrystallizational history, of which KA 104, which has porphyroclastic texture, represents a more advanced state.

Pressure effects on Al content in cpx from peridotites in coastal SW Oregon (see Medaris, 1972) have been documented. Smaller, recrystallized pyroxenes have lower alumina contents than larger relict grains. Cpx in KA 104 websterite show a similar compositional/ grain size trend. For the peridotites in Oregon, Medaris interprets this behavior as a high temperature recrystallization at a lower pressure due to the movement of the peridotite upward in the mantle. Another possible explanation for lower alumina contents in the smaller, recrystallized grains is decreasing temperature (Macgregor, 1974).

The exsolution history of pyroxenes in some Kaula pyroxenites is complicated. Nevertheless, a history of exsolution of opx and spinel in cpx can be deduced from the optical continuity, the convoluted grain boundaries, and cross-cutting relationships of exsolution lamellae. In some Kaula samples, deformed cpx grains have opx exsolution which cross-cuts grain boundaries; this may suggest that cpx grains were in the process of being deformed as exsolution was occurring. Other cases involve several types and orientations of exsolution lamellae in the same grain; more than one period of exsolution growth may be suggested. This might imply interruptions in the cooling history of the pyroxenes. Sen (1981) deduced two thermal events in some Salt Lake pyroxenites, based on exsolution texture in pyroxene.

Considerations of Reconstructing Cpx and Bulk Pyroxenite Compositions

The exsolved phases in pyroxene can be useful in reconstructing original pyroxene composition. However, the apparent amount of exsolved phases was found to vary markedly within grains and from grain to grain in Kaula pyroxenites. KA 38megacryst has no exsolution; is is a primary calcic cpx. In KA 107 (gt-sp cpxite) the trace opx and spinel exsolution observed would be insufficient to affect its bulk cpx composition; it is also a calcic cpx. Salt Lake cpx has a subcalcic reconstructed primary composition (Green, 1966). Irving (1980) points out that it is conceivable, based on experimental work, to produce the successive precipitation of opx, through subcalcic cpx, to more calcic cpx, and finally to olivine as pressure decreases from approximately 25 to 20 kb in a basanite melt with water present. The cpx in Kaula pyroxenites is generally Ne- and Ol- normative, which suggests an alkalic basalt affinity (Coombs, 1963); however, this does not exclude a basanitic variety of alkalic basalt.

The presence of spinel exsolution in some pyroxenes indicates that the original pyroxene was higher in Al. Based on experimental work, Chapman (1975) estimated that primary cpx in spinel clinopyroxenite xenoliths from Scotland were formed at P > or = 18 kbar and T between 1450-1350^{o} C, followed by spinel exsolution at T <1290^{o} C. Chapman points out that at higher pressures (>20 kb) garnet may be expected to have exsolved instead of spinel. Although alumina values are similar for the two, Kaula cpx (e.g., KA 107) is higher in Fe and lower in Mg and Ca compared with the cpx in a spinel clinopyroxenite from Scotland (Wo 38.5, En 54.1, Fs 7.4; Chapman, 1975). Kaula spinel (in KA 107) is higher in Fe and lower in Mg relative to the spinel in a spinel clinopyroxenite from Scotland. Because of these compositional differences, and because the amounts of jadeite and Ca-Tschermaks components in cpx, as well as pressure, are important in determining whether garnet or spinel exsolves from clinopyroxene (Chapman, 1975), conclusions cannot be reached in attempting to apply this consideration to Kaula pyroxenites.

The primary pyroxenite assemblage is thought to have been aluminous, subcalcic to calcic cpx +,- spinel +,- garnet. At least one sample (KA 104) also probably had primary opx.

Kaula pyroxenite minerals tend to contain more Fe and Al relative to Salt Lake Crater pyroxenites. It is interesting that cpx patches and kelyphtitic intergrowths are more frequent and better developed in Kaula samples than in Salt Lake samples. The higher abundance of olivine in Salt Lake pyroxenites and the observation that a Salt Lake sample that has well developed kelyphitic intergrowth also contains no olivine makes it tempting to suggest a that there is a relationship between the melting behavior of the xenolith and the amount of olivine present, and therefore, overall Mg number. Another possible variable is the ascent rate of the host, since this could affect the rate and extent of melting and formation of the kelyphitic features and cpx patches (to some extent this may even be implied within the Kaula collection, since there is variation in the extent of development of these features). A bulk compositional difference between Salt Lake and Kaula pyroxenites is indicated, based on the differences in their mineral compositions. These differences may be related to 1) a difference in the veining density in the mantle underneath Salt Lake compared to Kaula (i.e., more olivine left intact upon intrusion of the pyroxenite in the case of Salt Lake), 2) a difference in the primary magma from which the crystallization of the pyroxenite occurred, and/or 3) differences in the early crystallization history of the magmas from which the pyroxenites were derived.

VIII. SUMMARY

1. The textures and chemistry of Kaula pyroxenites chronicle numerous events in the history of the xenoliths; deformation in the mantle, exsolution in pyroxene, initiation of melting within the xenolith (presumably due to decompression), and finally, disaggregation and invasion by the host magma.

2. Glass is intimately associated with several mineral/textural features in Kaula pyroxenites. These features include cpx patches and kelyphitic intergrowths, and may record a temperature and/or pressure change that produced melting in the xenolith. The melting mechanism is thought to be decompression during ascent. The role of a K(REE)P-rich phase(s) is implicated in these events, to account for K and P present in the glasses. A third glass association, skeletal olivine + glass, occurs in discrete pockets. Its origin is problematic; a combination of host basanitoid and phlogopite influence is considered likely in its

formation.

3. Among Kaula pyroxenites, variation in the amount of pyroxene exsolution and deformation as well as in the frequency and degree of cpx patch and kelyphitic intergrowth development suggest some differences in pre-incorporation and transport histories.

4. Comparison of pyroxenite xenoliths from Kaula Island and Salt Lake Crater show differences in the extent of development and frequency of cpx patches and kelyphitic intergrowths, as well as in modal and mineral compositions. These may reflect differences in transport history as well as in conditions of formation and original composition.

APPENDIX A

PROGRAMS OF STANDARD CALIBRATIONS

Below are listings of the natural and synthetic minerals used for microprobe standardization.

Clinopyroxene and orthopyroxene: SiO2, Na2O = omphacite; FeO, MgO = Johnstown hypersthene; CaO, Al2O3 = anorthite 137041; Cr2O3 = chromite 117075; MnO = Rockport fayalite; TiO2 = ilmenite; K2O = orthoclase Or-1.

Garnet: SiO2, Al2O3, MgO = Kakanui pyrope; CaO, FeO = garnet 87375; Cr2O3 = chromite 117075.

Spinel: Al2O3 = synthetic alumina; TiO2 = synthetic TiO2; FeO, MnO = Rockport fayalite; MgO = San Carlos olivine; Cr2O3 = chromite 117075.

Olivine: SiO2, MgO = San Carlos olivine; CaO = anorthite 137041; FeO, MnO = Rockport fayalite; Ni = doped diopside glass.

Glass: SiO2, FeO, MgO, CaO, TiO2, Na2O, P2O5 = Makaopuhi glass; Al2O3 = STG-56 glass; K2O = CAM 112 glass; MnO = Juan de Fuca glass.

APPENDIX B

PETROGRAPHIC DESCRIPTION OF KAULA ISLAND PYROXENITE AND DUNITE XENOLITHS

KA 107: Garnet spinel clinopyroxenite

Texture: allotriomorphic-granular, subpoikilitic to poikilitic. CPX: (46%), pale green color, pos. sign, has patches where extinction behavior and birefringence are slightly different compared to host grain but is also cpx (gives same figure and sign as host grain); these areas are outlined by thin, partly to totally devitrified glass rims and are speckled with the same material, some micro-blebs (melt material?) along healed fractures present; these patches give the cpx a diagnostic feature which can be seen in other slides. Rare, thin lamellar opx exsolution and rare spinel exsolution as small platelets. Fractures are exaggerated by trains of micro-bubbles and blebs of black opaque material (healed fractures). Large, optically continuous grain (2 cm length) and several smaller (5 mm diam.) grains; optical continuity of cpx on either side of garnet, spinel, and/or kelyphitic intergrowths suggests originally larger size of cpx reduced due to reaction. OPX: (5%), occurs with spinel as part of kelyphitic intergrowths (coarse rim and fibrous type) and as rare exsolution in cpx. GARNET: (19%), very pale straw-yellow color in thin section, fractured. Has fibrous px + spinel along grain borders, in some fractures, and as scattered occurrences within grains. SPINEL : dark gray-green (11%), lobate shape, up to 5 mm length (1.5 mm length); light gray-green (5%), < 0.2 mm length present in reaction zone. GARNET KELYPHITIC INTERGROWTHS: composed of "coarse" opx + spinel, brown glass, and fibrous intergrowth of px + spinel where near garnet; occurs in fractures in cpx and where garnet and cpx are in contact. The coarse opx + spinel has optically continuous opx grains up to 1 mm length at or near cpx grain margins, otherwise usually smaller; opx grains include subhedral gray-green to gray spinel <0.2 mm length. Fibrous intergrowth: (7%), consists of fibers of px and spinel 0.1 to 0.2 mm length in radial sprays or clumps, has light gray color, gray to yellow birefringence, and parallel extinction. In several places, kelyphitic intergrowths in fractures grade into partially crystallized melt - this melt is different in two pockets: a) has brown glass + skeletal olivine (0.2 to 1.4 mm optically continuous length and includes rare small gray spinel), and b) has brown to black color opaque material (devitrified glass?) with microcrystallites (px, olivine, spinel?) showing preferred orientations (i.e., forms X´s) and several opx phenocrysts up to 0.4 mm length. A thin rim of fibrous intergrowth also occurs where spinel is included in garnet, where cpx is included in garnet, and in fractures and scattered occurrences in garnet; fibers are not as well developed and are shorter than in reaction areas. GLASS: (2%), pale brown, some microcrystallites, some vesicles (<0.2 mm diam.) with rims of gold-orange non-opaque material. SULFIDES: (trace), approx. 1 mm diam. nearly round inclusion in garnet, rare smaller (<0.1 mm diam.) blebs in glass. CONTACT WITH TUFF: sharp in most places, patchy rims on cpx in some areas. Hand sample: coarse-grained, gray px with black spinel and brown-red irreg. shaped garnets, spinel up to 3 mm length. Rock dimensions: 5 X 4.5 X 2 cm.

KA 105: Garnet clinopyroxenite

Texture: allotriomorphic-granular, porphyroblastic, some areas subpoikilitic to poikilitic. CPX: (58%), green color, large grains 2-7 mm diam., some grains very large (1.5 cm diam.), one of the larger grains shows twinning, has opx exsolution as irreg.-shaped blebs up to 1 mm diam., rods, and irreg. lamellae, has cpx "patches", has micro-bubble trains and micro-tube patterns scattered throughout cpx grains, some spinel exsolution - commonly random, rarely showing orientation along cleavage planes. OPX: (7%), strongly pleochroic, pale straw yellow to yellow-tan, occurs as discrete grains up to approx. 2 mm length (ave. = 1 mm length) as well as exsolution in cpx GARNET: (19%), colorless in thin section, fractured, with kelyphitic rims and intergrowths along fractures and grain boundaries, has rare spinel exsolution, 1.4 cm diam. grain and smaller (1-2 mm length) grains. Kelyphitic rims = rims around garnet composed of black dusty or grainy opaque + opx + fine-grained gray-green spinel +,- large black spinel grains +,- fibrous intergrowth. Inside kelyphitic rim = brown, splotchy, turbid material, with splotchy to parallel-fibrous extinction (garnet alteration?). SPINEL: (4%), black to gray-green color, included in garnet and cpx, commonly has reaction rim consisting of short fibrous intergrowth + a dusty black opaque, irreg. to round shape, variable size up to 1 mm diam. OLIVINE: (tr.), one grain 3 mm length and a few smaller grains 0.2-1 mm length, included in cpx and occurs interstitially. CONTACT WITH HOST: cpx at contact has wide, dusty opaque- porous rims; rare penetrative cracks where host material permeated xenolith. Two hosts preserved in one slide: 1) host nearest xenolith = fine-grained black opaque groundmass with small olivine phenocrysts and rare large subhedral olivine fragment; host has fritted the olivine; rare areas of zeolite, and 2) outermost host = gold-brown to brown partly devitrified glass with areas of inner host material and an area with microxllites; has partly resorbed cpx megacrysts, large fragments of kink-banded olivine, opx megacryst, spinel megacryst, and a two-grain dunite xenolith; calcite common. Hand sample: coarse-grained, gray px with black spinels and red-brown garnets, indiviual px grains 1-2 cm diam. can be distinguished, large garnet 1 cm diam. and smaller garnets 3-6 mm diam., spinel 1-3 mm length, spinel not distributed uniformly (two main areas of spinel concentration). Rock dimensions: 6 X 3 X 1 cm.

KA 108 A,B Websterite/ Garnet-spinel websterite

Has two areas: websterite area and gt-sp websterite area; point-counted websterite area only because other area is mostly garnet and spinel. Websterite area: texture: allotriomorphic-granular, poikilitic, some areas equigranular-mosaic. Grain boundaries form rare triple points. CPX (108A: 60%, 108B: 55%): pale green color, has opx exsol´n as rods and blebs, has spinel exsol´n along regular planes, has rare grains with cpx patches, size up to 9 mm length. OPX (108A: 27%, 108B: 32%): pleochroic pale green to straw yellow, discrete grains with cpx exsol´n, has spinel exsol´n, size up to approx. 2-3 mm length. SPINEL: (108A: 2%, 108B: 1%): gray-green.

Garnet-spinel websterite area: CPX: up to 5 mm length. OPX: up to 5 mm length, as discrete grains and as part of kelyphitic features (coarse form and fibrous intergrowth). GARNET: colorless, large grain up to 7 mm length; has extensive, well-developed kelyphitic intergrowths (fibrous intergrowth and coarse form; fibers of fibrous intergrowth up to 0.5 mm length). SPINEL: black, lobate to irreg. shape, up to 4 mm length; also, as part of kelyphitic features: gray to gray-green, small, subhedral. OLIVINE: rare grains in garnet-spinel websterite area, invading pyroxene (partly includes pyroxene), lobate shape, approx. 1.5-2 mm length. GLASS: brown color; part of kelyphitic features; has vesicles 0.2-0.4 mm diam., infilled with colorless, gray birefring. mineral with undulatory extinction, (zeolite?), with common black opaque specks in center of infilled vesicle. Hand sample: coarse-grained, one half of the sample = gray px, red-brown garnet, and black spinel (spinel clusters); other half = area where indiv. grains can be seen, mostly px of variable size, some px up to 5 mm length, has more broken-up appearance. Rock dimensions: 3.5 X 5.5 X 2 cm.

KA 109: Garnet websterite

Texture: allotriomorphic-granular, porphyroblastic. Black dusty opaques on grain borders and in fractures (melt along healed fractures?). CPX:

(64%), pale green color, has much opx exsolution as irreg. lamellae, blebs, and as myrmekitic exsol´n; some of the larger grains (size up to approx. 7 mm diam.) have "patches" as well as rare opx exsol´n, and have micro-bubble trains and micro-tube patterns; larger grains located in a band near garnet. OPX: (19%), pleochroic pale green to straw yellow, has small blebs and short lamellae of cpx exsol´n, irreg. to round shape, variable size up to approx. 2 mm length. Opx in kelyphitic features : pale tan color, slightly pleochroic. GARNET: (9%), colorless in thin section, up to 15 mm length, has fibrous intergrowth (2%) in fractures and as scattered occurrences in garnet. SPINEL: (2%), gray-green to gray color, occurs primarily in kelyphitic features. GLASS: (tr.), brown with micro-crystallites, includes some very small round blebs of sulfide. PHLOGOPITE: (tr.), pleochroic gold to reddish gold, has thin brown fritted rim, occurs in area of opx + spinel intergrowths, has lamellae of brown microinclusions, one grain 2 mm length, several grains approx.1 mm length. SULFIDE: (tr.), deep purple-black color, included in fibrous intergrowth in fractures in garnet, in kelyphitic rim between cpx and garnet, and interstitially between px grains. Hand sample: coarse-grained, gray px with rare black spinel on cut surface, green-gray px with black opx or spinel on weathered surface, rare red-brown garnet visible, px = up to 8 mm diam., spinel cluster on one surface, spinel up to 4 mm length, some interstitial alteration/reaction (?) visible. Rock dimensions: 5 X 6.5 X 3.5 cm.

KA 106: Spinel websterite

Texture: allotriomorphic-granular, some areas subpoikilitic. Black opaque along grain margins and fractures, partic. around spinel grains. CPX: (64%), pale green color, rare twinning, opx exsol´n as irreg. lamellae and blebs, and rarely extensive and chaotic; some exsol´n of olive-green spinel in cpx, rare cpx "patches", some grains have gray dusty appearance, px grains have trains of black speckly opaque material (some = micro-bubbles), variable size up to approx. 9 mm diam. (ave. = 2-3 mm diam.). OPX: (20%), pleochroic pale green to straw yellow, grains irreg. to round shape, var. size up to approx. 2 mm length. SPINEL: (5%), green-gray to black color, lobate to irreg. shape, interstitial, up to 2 mm diam. GARNET: (tr.), colorless in thin section, rare small grains <1 mm length, commonly located near the larger spinel grains. OLIVINE: (tr.), several small equant to irreg.-shaped grains, <2 mm diam. FIBROUS INTERGROWTH: (3%), near spinel and garnet, composed of fibrous intergrowth + dusty opaque + gold-orange non-opaque + very small sulfide blebs.

KA 103: Spinel websterite

Texture: allotriomorphic-granular, poikilitic. CPX: (64%), pale gray-green color, pos. sign, has inclusions of olivine that within the same cpx grain are in optical continuity which are sometimes enclosed by opx (see Figure A), occurs as large grains up to 2.3 cm diam., has exsol´n of opx as irregular areas up to approx. 4 mm length (ave. approx. 1 mm length), blebs, and lamellae, has black speckly opaque material (some = micro-bubble trains and patterns), has some spinel exsolution along cleavage planes. OPX: (13%), as an exsolution in cpx, also present as a few discrete grains 1-2 mm length; pleochroic pale green to straw yellow. SPINEL: (7%), gray-green color, included by cpx, some occurs interstitially, ave. size = 0.3 mm diam., up to 2 mm length. SPINEL REACTION RIM: (14%), composed of fine grains of gray-green spinel + colorless gray to gold birefring. mineral (opx) + black dusty opaque, accompanied by brown non-opaque (2%) with brown splotchy birefringence. Hand sample: gray px with black spinel (spinel up to 3 mm length), coarse-grained. Rock dimensions: 5.5 X 8 X 8 cm. (Other notes: The occurrence of spinel exsol´n in cpx may suggest that the abundant larger grains of spinel in the cpx are inclusions, not exsol´n.)

KA 110 A,B: Websterite (Cpxite w/ exsolved opx)

Texture: allotriomorphic granular. Rarely, grains show signs of deformation: twins dislocated within a grain, grains bent and broken (shown by optical behavior and exsolution lamellae). CPX (110A: 71%, 110B: 69%): pale green, has twinning, has opx exsol´n (small blebs, rods, large irreg. blebs, and myrmekitic exsol´n); several grains in 110B have cpx patches; some have micro-bubble and sulfide bleb trains and patterns. OPX (110A: 25%, 110B: 23%): slightly pleochroic pale green to pale straw yellow, as exsol´n in cpx and as rare discrete grains. GARNET (110A: tr., 110B: 1%): has kelyphitic rim; 110A only has inner brown turbid rim, as described for KA 105. SPINEL (110A: 1%, 110B: tr.): green-gray to dark gray color, lobate shape. Also present as intergrowth with opx as kelyphitic features (coarse rim and fibrous intergrowth). OLIVINE (110A: tr., 110B: 0%): occurs in veins and in one triangle-shaped pocket (approx. 2 mm diam.); subhedral grains 0.2 - 0.4 mm length with brown to black opaque material (altered glass?) interstitially; rare brown non-opaqwe alteration (clay?) in some areas of olivine grains; olivine includes black opaque blebs. GLASS (110A: 0%, 110B: tr.): very pale brown color with microxllites and small black blebs. CONTACT WITH TUFF (in KA 110A): cpx grain boundaries: jagged in places, has cpx overgrowth: color change to straw yellow along thin rim at edges of the grains, rare fine-grained dusty opaque rim near grain edge. Hand sample: coarse-grained, green and black px and rare black spinel. Rock dimensions: 4.5 X 7 X 3.5 cm.

KA 104: Websterite

Texture: allotriomorphic-granular; equigranular mosaic areas with rare triple points; porphyroclastic. Large grains 1-2 mm length of opx and cpx surrounded by mosaic of smaller <<1 mm length grains; mosaic grains commonly look like exsol´n blebs. CPX (55%): pale green color, pos. sign, has opx exsol´n as irreg. blebs and rods. OPX (43%): pleochroic pale green to straw yellow, neg. sign, has cpx exsol´n as blebs and lamellae. Rare opx have exsol´n lamellae on different planes resulting in "woven fabric" appearance when grain is near extinction angle. Amount of exsol´n varies from grain to grain; commonly, the exsol´n is so extensive that the grain consists entirely of closely spaced lamellae and blebs. Some micro-bleb trains and patterns present (healed fractures), esp. in larger grains. Hand sample: coarse-grained, in approx. 50/50 proportion: black px grains of 1-2 mm diam. with physical relief (opx) distributed amongst green-gray px grains appearing fine-grained and crumbly. Rock dimensions: 3.5 X 6 X 6 cm.

KA 102: Olivine websterite

Texture: allotriomorphic granular. Two areas distinguishable: 1) area of large 4-5 mm diam. cpx and 2) area of variable px grain size (ranging from <1 mm to approx. 2 mm diam.) with 1-2 mm diam. olivine grains. Opx, cpx, ol anhedral; curvilinear to irreg. grain boundaries; ol grain boundaries tend to curve outward just slightly more frequently than do px grain boundaries. CPX: (34%), pale gray color, has opx exsol´n as thin lamellae and blebs, some grains have irreg. patterns of fine-grained black opaque and black dusty opaque rims on borders (some = micro-bubbles or micro-blebs), has some gray-green spinel exsol´n as nearly round blebs to irreg. blebs and lamellae. OPX: (25%), pleochroic pale green to pale straw yellow, occas. includes olivine. OLIVINE: (24%), has weak kink-banding, some has thin dusty opaque rim at ol/cpx grain contact. SPINEL: (5%), gray-green color, irreg. to round shape, occas. includes olivine, some are enclosed by rxn rims similar to those described in KA 103; both rxn rims are not always present, but usually at least one is present; material of reaction rims can also be found in between px grains and along fractures, spinel grains up to 1 mm diam. (ave. = approx. 0.4 mm diam.). Hand sample: coarse-grained, gray px, black spinel, and olive-green olivine. Distribution of olivine not uniform: areas of mostly px occur. Rock dimensions: 4.5 X 5.5 X 3 cm.

KA 101: Composite xenolith: dunite/websterite

Dunite/websterite contact: marked by a "line" of spinels approx. 0.2 mm dunite side of the actual contact. At the contact, ol grains tend to curve outward slightly more frequently than do px grains. A brown dusty opaque rim occurs at many grain boundaries and varies in thickness; rims are thin to non-existent on the dunite side; at the dunite/websterite contact, olivine and px generally both lack rims; on the websterite side, the rims are thick, are often accompanied by a rust-colored non-opaque, and the birefring. of the grain (px) is often altered slightly in the rim area.

Dunite: texture: allotriomorphic-granular, equigranular. Grain boundaries curvilinear, with some triple points. OLIVINE: (90%), has weak kink-banding, includes spinel, var. size up to 3 mm diam. (ave. = 1.5 to 2 mm diam.). CPX: (1%), pale green color, has rounded to irregularly shaped blebs of opx exsol´n, var. size up to 1.5 mm length. OPX: (6%), pleochroic pale green to pale straw yellow, has some lamellar exsol´n of cpx, var. size up tp 2 mm length. SPINEL: (3%), gray-green color, anhedral to subhedral, occurs as inclusions in olivine and px and interstitially, ave. grain size approx. 0.2 mm diam.

Websterite: texture: allotriomorphic-granular. CPX: (50%), very pale green color, has irreg. to round exsol´n blebs of opx, some grains have small amount of gray-green spinel exsol´n along cleavage planes, var.

size up to 6 mm length, some of the larger grains have cpx patches. OPX: (pleochroic pale green to straw yellow, has some rods of cpx exsol´n, some have rounded shapes, var. size up to 5 mm length. SPINEL: (2%), gray-green color, included in cpx and opx, also occurs interstitially and a small amount as exsol´n in cpx, var. size up to 2 mm length. PHLOGOPITE: (tr.), one small, pleochroic pale brown to brown grain included in opx near contact. Hand sample: 1/3 = black px, 2/3 = black px + olive-green olivine, coarse-grained. Rock dimensions: 4 X 6 X 1.5 cm.

KA 100: Spinel dunite

Texture: allotriomorphic-granular, equigranular with weak foliation. Grain boundaries irreg. to curvilinear with some triple points. OLIVINE: (89%), unaltered, pos. sign, kink-banded, some grains show blocky extinction (effect of subgrain boundaries), some grains have parting, rarely includes cpx, some have trains of micro-bubble or micro-bleb inclusions, vapor bubbles inside fluid inclusions seen, var. size up to 4 mm diam. (many grains 3-4 mm diam.). CPX: (3%), vary pale gray color, pos. sign, no exsol´n, var. size up to approx. 3 mm length. SPINEL: (8%), deep red-brown color, lobate shape, includes ol and cpx and occurs interstitially, grains up to 4 mm length. Hand sample: coarse-grained; light olive-green olivine up to 3-4 mm diam., emerald-green cpx approx. 1 mm length, and black spinel up to 4 mm length; spinel defines weak foliation; cpx has non-uniform distribution. Rock dimensions: 6 X 8 X 4.5 cm.

APPENDIX C

KAULA XENOLITH CLINOPYROXENE ANALYSES

KA 107 GARNET SPINEL CLINOPYROXENITE

	107 11	107 11	107 12	107 2	107 2R	107 3	107 3R	107 41
SiO2	48.73	48.44	48.91	49.26	48.18	48.65	48.55	49.08
TiO2	0.99	1.27	1.21	0.97	1.22	1.26	1.31	1.05
Al2O3	9.58	9.88	9.66	9.58	9.84	9.74	9.71	9.63
Cr2O3	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.04
FeO	8.36	8.36	8.14	8.29	8.55	8.48	8.50	8.77
MnO	0.10	0.15	0.09	0.10	0.11	0.11	0.14	0.14
MgO	13.09	12.66	12.88	12.81	12.85	12.87	12.88	12.86
CaO	16.81	16.63	16.85	17.01	16.78	16.82	16.83	15.96
Na2O	2.27	2.17	2.42	2.34	2.13	2.25	2.01	2.44
SUM	99.95	99.59	100.18	100.38	99.69	100.21	99.95	99.97
Fe2O3	5.22	3.76	4.92	4.55	4.70	4.67	3.61	4.40
FeO	3.67	4.98	3.72	4.20	4.32	4.27	5.25	4.81
SUM	100.47	99.97	100.67	100.84	100.16	100.68	100.31	100.41

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.776	1.776	1.778	1.789	1.764	1.771	1.776	1.790
Alz	0.224	0.224	0.222	0.211	0.236	0.229	0.224	0.210
Aly	0.187	0.203	0.192	0.198	0.189	0.189	0.195	0.203
Ti	0.027	0.035	0.033	0.026	0.034	0.035	0.036	0.029
Cr	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Fe3	0.143	0.104	0.134	0.124	0.130	0.128	0.099	0.121
Fe2	0.112	0.153	0.113	0.128	0.132	0.130	0.161	0.147
Mn	0.003	0.005	0.003	0.003	0.003	0.003	0.004	0.004
Mg	0.711	0.692	0.698	0.693	0.701	0.699	0.702	0.699
Ca	0.656	0.653	0.656	0.662	0.658	0.656	0.660	0.624
Na	0.160	0.154	0.171	0.165	0.151	0.159	0.143	0.172
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	73.6	73.0	73.8	73.4	72.8	73.0	73.0	72.3
Ca	0.404	0.407	0.409	0.411	0.405	0.406	0.406	0.391
Mg	0.437	0.431	0.435	0.431	0.432	0.432	0.432	0.438
Fe	0.159	0.162	0.156	0.158	0.163	0.162	0.163	0.170

CLINOPYROXENE ANALYSES, CONTINUED

KA 107 GARNET SPINEL CLINOPYROXENITE, continued

	107 42	10742R	107 4R
SiO2	48.84	49.09	48.73
TiO2	1.07	1.09	1.13
Al2O3	9.64	9.44	9.84
Cr2O3	0.00	0.01	0.00
FeO	8.81	8.35	8.65
MnO	0.09	0.14	0.00
MgO	12.93	12.76	13.09
CaO	16.20	16.91	16.21
Na2O	2.37	2.20	2.22
SUM	99.95	99.99	99.87
Fe2O3	4.81	3.80	4.18
FeO	4.48	4.93	4.89
SUM	100.43	100.37	100.29

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.781	1.792	1.779
Alz	0.219	0.208	0.221
Aly	0.196	0.199	0.202
Ti	0.029	0.030	0.031
Cr	0.000	0.000	0.000
Fe3	0.132	0.104	0.115
Fe2	0.137	0.151	0.149
Mn	0.003	0.004	0.000
Mg	0.703	0.694	0.712
Ca	0.633	0.662	0.634
Na	0.168	0.156	0.157
Sum	4.000	4.000	4.000
M/M+F	72.3	73.1	73.0
Ca	0.394	0.410	0.394
Mg	0.437	0.430	0.442
Fe	0.169	0.161	0.164

CLINOPYROXENE ANALYSES, CONTINUED

KA 105 GARNET CLINOPYROXENITE

	105 1	105 1R	105 2H	1052HR	105 3H	105 4	105 4R	105 5H
SiO2	49.42	50.17	48.97	50.12	49.46	48.56	50.15	48.83
TiO2	0.82	0.84	0.81	0.87	0.87	0.86	0.87	0.89
Al2O3	9.49	8.99	9.85	9.31	10.12	10.14	9.50	9.50
Cr2O3	0.02	0.01	0.05	0.03	0.04	0.02	0.01	0.02
FeO	6.91	6.85	6.94	6.77	7.19	7.08	6.72	7.43
MnO	0.10	0.13	0.11	0.10	0.16	0.11	0.08	0.13
MgO	14.04	13.96	13.79	13.89	13.94	13.55	13.89	13.99
CaO	16.84	16.42	17.17	16.86	16.78	17.32	17.14	17.27
Na2O	1.92	1.81	1.87	1.89	1.92	1.91	1.89	1.90
SUM	99.56	99.18	99.56	99.84	100.48	99.55	100.25	99.96
Fe2O3	2.98	0.61	3.35	1.42	2.97	3.94	1.70	4.72
FeO	4.23	6.30	3.93	5.49	4.52	3.53	5.19	3.19
SUM	99.86	99.24	99.90	99.98	100.78	99.95	100.42	100.43

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.800	1.839	1.786	1.823	1.787	1.772	1.817	1.774
Alz	0.200	0.161	0.214	0.177	0.213	0.228	0.183	0.226
Aly	0.208	0.227	0.209	0.223	0.218	0.208	0.222	0.181
Ti	0.022	0.023	0.022	0.024	0.024	0.024	0.024	0.024
Cr	0.001	0.000	0.001	0.001	0.001	0.001	0.000	0.001
Fe3	0.082	0.017	0.092	0.039	0.081	0.108	0.046	0.129
Fe2	0.129	0.193	0.120	0.167	0.136	0.108	0.157	0.097
Mn	0.003	0.004	0.003	0.003	0.005	0.003	0.002	0.004
Mg	0.762	0.763	0.749	0.753	0.751	0.737	0.750	0.758
Ca	0.657	0.645	0.671	0.657	0.650	0.677	0.665	0.672
Na	0.136	0.129	0.132	0.133	0.135	0.135	0.133	0.134
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	78.4	78.4	78.0	78.5	77.6	77.3	78.7	77.0
Ca	0.402	0.398	0.410	0.406	0.400	0.415	0.410	0.405
Mg	0.467	0.470	0.458	0.465	0.463	0.451	0.463	0.456
Fe	0.131	0.132	0.131	0.129	0.137	0.134	0.127	0.138

CLINOPYROXENE ANALYSES, CONTINUED

KA 105 GARNET CLINOPYROXENITE, continued

	1055HR	105 6	105 6R	105 7
SiO2	48.91	48.90	49.68	50.41
TiO2	0.88	0.93	0.90	0.83
Al2O3	9.40	9.62	9.48	8.37
Cr2O3	0.04	0.03	0.06	0.04
FeO	7.56	7.38	7.38	6.84
MnO	0.15	0.10	0.14	0.14
MgO	14.15	13.99	14.22	14.42
CaO	16.77	17.15	16.58	17.21
Na2O	1.90	1.91	1.97	1.73
SUM	99.76	100.01	100.41	99.99
Fe2O3	4.39	4.37	3.37	1.92
FeO	3.61	3.44	4.35	5.11
SUM	100.20	100.45	100.75	100.18

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.781	1.776	1.796	1.832
Alz	0.219	0.224	0.204	0.168
Aly	0.184	0.188	0.200	0.191
Ti	0.024	0.025	0.024	0.023
Cr	0.001	0.001	0.002	0.001
Fe3	0.120	0.120	0.092	0.053
Fe2	0.110	0.105	0.132	0.155
Mn	0.005	0.003	0.004	0.004
Mg	0.768	0.757	0.766	0.781
Ca	0.654	0.667	0.642	0.670
Na	0.134	0.134	0.138	0.122
Sum	4.000	4.000	4.000	4.000
M/M+F	76.9	77.2	77.4	79.0
Ca	0.395	0.404	0.393	0.403
Mg	0.463	0.458	0.468	0.470
Fe	0.142	0.138	0.139	0.128

CLINOPYROXENE ANALYSES, CONTINUED

KA 108A,B WEBSTERITE/GARNET SPINEL WEBSTERITE

	108A 1	A 2AH	108A2B	108A31	108A32	108A33	108A 4	A 4CR
SiO_2	48.20	48.23	47.90	48.94	48.53	48.55	48.25	48.13
TiO_2	1.31	0.93	1.33	1.52	1.40	1.45	1.46	1.46
Al_2O_3	10.03	10.05	10.53	9.46	9.46	9.17	9.35	9.44
Cr_2O_3	0.21	0.23	0.21	0.05	0.07	0.09	0.09	0.07
FeO	7.55	7.12	7.44	8.77	8.43	8.45	8.39	8.27
MnO	0.13	0.29	0.14	0.17	0.13	0.17	0.13	0.27
MgO	12.66	13.17	12.57	12.98	12.95	13.12	12.92	12.86
CaO	17.43	17.77	16.92	16.53	16.65	16.69	16.82	16.77
Na_2O	2.02	1.96	2.14	2.11	2.09	2.04	2.08	2.14
SUM	99.54	99.75	99.18	100.53	99.71	99.73	99.49	99.41
Fe_2O_3	3.48	4.71	3.46	3.50	3.75	3.88	4.15	4.45
FeO	4.42	2.89	4.33	5.62	5.05	4.96	4.65	4.26
SUM	99.89	100.22	99.53	100.88	100.09	100.12	99.91	99.86

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.768	1.760	1.761	1.781	1.779	1.780	1.773	1.769
Alz	0.232	0.240	0.239	0.219	0.221	0.220	0.227	0.231
Aly	0.201	0.192	0.217	0.187	0.187	0.176	0.177	0.178
Ti	0.036	0.026	0.037	0.042	0.039	0.040	0.040	0.040
Cr	0.006	0.007	0.006	0.001	0.002	0.003	0.003	0.002
Fe3	0.096	0.129	0.096	0.096	0.103	0.107	0.115	0.123
Fe2	0.136	0.088	0.133	0.171	0.155	0.152	0.143	0.131
Mn	0.004	0.009	0.004	0.005	0.004	0.005	0.004	0.008
Mg	0.692	0.716	0.689	0.704	0.707	0.717	0.707	0.704
Ca	0.685	0.695	0.666	0.645	0.654	0.655	0.662	0.660
Na	0.144	0.139	0.153	0.149	0.149	0.145	0.148	0.152
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	74.9	76.7	75.1	72.5	73.2	73.5	73.3	73.5
Ca	0.425	0.424	0.420	0.398	0.403	0.401	0.406	0.406
Mg	0.429	0.437	0.434	0.434	0.436	0.438	0.434	0.433
Fe	0.146	0.138	0.147	0.168	0.162	0.161	0.160	0.161

CLINOPYROXENE ANALYSES, CONTINUED

KA 108A,B WEBSTERITE/GARNET SPINEL WEBSTERITE, continued

	A 4ER	108A5H	108A61	108A62	A 7C	A 7E	8 HOST
SiO2	48.55	48.54	49.04	49.19	48.65	48.95	48.25
TiO2	1.29	1.45	1.34	1.33	1.42	1.35	1.41
Al2O3	8.93	10.30	8.67	9.04	9.35	9.09	9.10
Cr2O3	0.07	0.13	0.07	0.10	0.08	0.10	0.06
FeO	8.07	7.75	8.23	8.24	8.55	7.80	8.69
MnO	0.27	0.18	0.13	0.16	0.15	0.09	0.15
MgO	12.97	12.55	13.13	12.93	13.03	12.98	12.98
CaO	17.25	17.06	17.23	17.10	16.75	17.11	16.34
Na2O	2.07	2.17	2.01	2.05	2.07	1.89	2.09
SUM	99.47	100.13	99.85	100.14	100.05	99.36	99.07
Fe2O3	4.38	3.19	3.68	3.16	3.93	2.18	4.04
FeO	4.13	4.88	4.92	5.39	5.02	5.84	5.05
SUM	99.91	100.45	100.22	100.46	100.44	99.58	99.48

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.783	1.770	1.796	1.797	1.778	1.801	1.781
Alz	0.217	0.230	0.204	0.203	0.222	0.199	0.219
Aly	0.170	0.213	0.170	0.186	0.181	0.196	0.177
Ti	0.036	0.040	0.037	0.037	0.039	0.037	0.039
Cr	0.002	0.004	0.002	0.003	0.002	0.003	0.002
Fe3	0.121	0.088	0.101	0.087	0.108	0.060	0.112
Fe2	0.127	0.149	0.151	0.165	0.153	0.180	0.156
Mn	0.008	0.006	0.004	0.005	0.005	0.003	0.005
Mg	0.710	0.682	0.717	0.704	0.710	0.712	0.714
Ca	0.679	0.667	0.676	0.669	0.656	0.675	0.646
Na	0.147	0.153	0.143	0.145	0.147	0.135	0.150
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	74.1	74.3	74.0	73.7	73.1	74.8	72.7
Ca	0.413	0.419	0.410	0.411	0.402	0.414	0.396
Mg	0.432	0.429	0.435	0.432	0.435	0.437	0.437
Fe	0.156	0.152	0.155	0.157	0.163	0.149	0.167

CLINOPYROXENE ANALYSES, CONTINUED

KA 109 GARNET WEBSTERITE

	109 1	109 2C	109 2E	109 2	109 3	109 4	109 6H	109 7H
SiO2	49.91	49.53	49.38	49.46	50.05	49.23	49.08	48.85
TiO2	0.99	0.94	0.87	0.91	0.83	0.86	0.75	0.85
Al2O3	8.44	9.34	9.04	9.21	8.14	9.53	8.45	8.62
Cr2O3	0.13	0.17	0.21	0.16	0.16	0.15	0.15	0.22
FeO	6.95	6.57	6.48	6.53	6.60	6.28	6.59	6.65
MnO	0.18	0.10	0.19	0.14	0.14	0.17	0.08	0.14
MgO	14.42	13.56	13.73	13.63	14.08	13.45	14.14	14.06
CaO	17.37	18.15	18.19	18.16	17.97	18.14	18.42	18.54
Na2O	1.88	1.95	2.02	1.98	1.96	2.05	1.57	1.73
SUM	100.27	100.31	100.11	100.18	99.93	99.86	99.23	99.66
Fe2O3	3.59	3.40	4.43	3.84	3.73	3.92	3.77	4.94
FeO	3.72	3.51	2.49	3.08	3.25	2.75	3.20	2.20
SUM	100.63	100.65	100.55	100.56	100.30	100.25	99.61	100.16

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.808	1.795	1.791	1.793	1.819	1.789	1.799	1.782
Alz	0.192	0.205	0.209	0.207	0.181	0.211	0.201	0.218
Aly	0.168	0.193	0.177	0.187	0.167	0.197	0.163	0.152
Ti	0.027	0.026	0.024	0.025	0.023	0.024	0.021	0.023
Cr	0.004	0.005	0.006	0.005	0.005	0.004	0.004	0.006
Fe3	0.098	0.093	0.121	0.105	0.102	0.107	0.104	0.136
Fe2	0.113	0.106	0.076	0.093	0.099	0.084	0.098	0.067
Mn	0.006	0.003	0.006	0.004	0.004	0.005	0.002	0.004
Mg	0.779	0.732	0.742	0.737	0.763	0.728	0.772	0.764
Ca	0.674	0.705	0.707	0.706	0.700	0.706	0.723	0.724
Na	0.132	0.137	0.142	0.139	0.138	0.144	0.112	0.122
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	78.7	78.6	79.1	78.8	79.2	79.2	79.3	79.0
Ca	0.404	0.430	0.428	0.429	0.420	0.433	0.425	0.427
Mg	0.467	0.447	0.449	0.448	0.457	0.447	0.454	0.451
Fe	0.129	0.123	0.123	0.123	0.123	0.120	0.120	0.122

CLINOPYROXENE ANALYSES, CONTINUED

KA 109 GARNET WEBSTERITE, continued

	9 HOST	9 1 HO
SiO2	49.25	49.33
TiO2	0.92	0.99
Al2O3	8.63	8.58
Cr2O3	0.17	0.10
FeO	7.16	6.97
MnO	0.12	0.14
MgO	13.91	13.85
CaO	17.10	17.06
Na2O	1.63	1.75
SUM	98.89	98.77
Fe2O3	2.02	2.10
FeO	5.34	5.08
SUM	99.09	98.98

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.815	1.818
Alz	0.185	0.182
Aly	0.190	0.191
Ti	0.025	0.027
Cr	0.005	0.003
Fe3	0.056	0.058
Fe2	0.165	0.157
Mn	0.004	0.004
Mg	0.764	0.761
Ca	0.675	0.674
Na	0.116	0.125
Sum	4.000	4.000
M/M+F	77.6	78.0
Ca	0.406	0.407
Mg	0.459	0.460
Fe	0.135	0.133

CLINOPYROXENE ANALYSES, CONTINUED

KA 106 SPINEL WEBSTERITE

	106 1	106 1R	106 2	106 2R	106 3	106 3R	106 4	106 5
SiO2	48.85	49.36	49.39	49.65	49.44	49.97	49.73	49.48
TiO2	0.71	0.70	0.74	0.74	0.74	0.73	0.72	0.73
Al2O3	9.51	9.77	8.94	9.29	8.22	8.55	8.33	8.39
Cr2O3	0.15	0.13	0.12	0.13	0.17	0.24	0.26	0.33
FeO	6.83	7.07	6.68	7.02	6.84	6.72	6.71	6.74
MnO	0.14	0.12	0.15	0.19	0.14	0.12	0.10	0.13
MgO	14.66	14.16	14.83	14.72	15.15	14.66	14.85	14.61
CaO	17.40	17.29	17.42	17.30	17.45	17.45	17.49	17.52
Na2O	1.81	1.77	1.72	1.76	1.68	1.71	1.69	1.68
SUM	100.06	100.37	99.99	100.80	99.83	100.15	99.88	99.61
Fe2O3	5.26	3.49	4.26	4.15	4.83	3.16	3.79	3.70
FeO	2.10	3.93	2.85	3.28	2.49	3.87	3.30	3.41
SUM	100.59	100.72	100.42	101.22	100.31	100.47	100.26	99.98

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.768	1.785	1.790	1.786	1.795	1.811	1.806	1.804
Alz	0.232	0.215	0.210	0.214	0.205	0.189	0.194	0.196
Aly	0.173	0.202	0.171	0.180	0.146	0.176	0.163	0.164
Ti	0.019	0.019	0.020	0.020	0.020	0.020	0.020	0.020
Cr	0.004	0.004	0.003	0.004	0.005	0.007	0.007	0.010
Fe3	0.143	0.095	0.116	0.112	0.132	0.086	0.104	0.101
Fe2	0.063	0.119	0.086	0.099	0.076	0.117	0.100	0.104
Mn	0.004	0.004	0.005	0.006	0.004	0.004	0.003	0.004
Mg	0.791	0.763	0.801	0.789	0.820	0.792	0.804	0.794
Ca	0.675	0.670	0.676	0.667	0.679	0.678	0.681	0.684
Na	0.127	0.124	0.121	0.123	0.118	0.120	0.119	0.119
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	79.3	78.1	79.8	78.9	79.8	79.5	79.8	79.4
Ca	0.402	0.406	0.402	0.399	0.397	0.404	0.402	0.405
Mg	0.472	0.462	0.476	0.472	0.479	0.472	0.475	0.470
Fe	0.126	0.132	0.123	0.130	0.124	0.124	0.122	0.124

CLINOPYROXENE ANALYSES, CONTINUED

KA 106 SPINEL WEBSTERITE, continued

	106 5R
SiO2	50.28
TiO2	0.72
Al2O3	8.65
Cr2O3	0.27
FeO	6.78
MnO	0.16
MgO	14.64
CaO	17.39
Na2O	1.87
SUM	100.76
Fe2O3	3.57
FeO	3.56
SUM	101.12

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.810
Alz	0.190
Aly	0.177
Ti	0.019
Cr	0.008
Fe3	0.097
Fe2	0.107
Mn	0.005
Mg	0.786
Ca	0.671
Na	0.131
Sum	4.000
M/M+F	79.4
Ca	0.403
Mg	0.472
Fe	0.126

CLINOPYROXENE ANALYSES, CONTINUED

KA 103 SPINEL WEBSTERITE

	103 1	103 2A	103 2B	103 2C	103 2D	103 2E	103 2F	103 3
SiO_2	49.84	49.84	50.17	49.67	49.97	49.83	49.87	49.90
TiO_2	0.77	0.70	0.70	0.77	0.71	0.56	0.71	0.69
Al_2O_3	8.32	8.21	8.15	8.10	8.07	8.58	8.44	7.98
Cr_2O_3	0.04	0.06	0.05	0.06	0.05	0.01	0.04	0.05
FeO	5.90	5.89	5.86	5.95	5.72	5.76	5.93	5.77
MnO	0.11	0.06	0.07	0.13	0.07	0.12	0.12	0.09
MgO	14.16	14.26	14.26	14.21	14.39	14.26	14.14	14.31
CaO	18.69	18.86	18.79	18.63	18.63	18.77	18.76	18.74
Na_2O	1.81	1.73	1.86	1.90	1.84	1.89	1.65	1.83
SUM	99.64	99.61	99.91	99.42	99.45	99.78	99.66	99.36
Fe_2O_3	3.67	3.70	3.81	4.45	3.83	4.47	2.97	3.97
FeO	2.60	2.56	2.44	1.95	2.27	1.74	3.26	2.20
SUM	100.01	99.98	100.29	99.87	99.83	100.23	99.96	99.76

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.814	1.814	1.819	1.810	1.819	1.807	1.816	1.819
Alz	0.186	0.186	0.181	0.190	0.181	0.193	0.184	0.181
Aly	0.170	0.167	0.168	0.158	0.165	0.173	0.179	0.162
Ti	0.021	0.019	0.019	0.021	0.019	0.015	0.019	0.019
Cr	0.001	0.002	0.001	0.002	0.001	0.000	0.001	0.001
Fe3	0.100	0.101	0.104	0.122	0.105	0.122	0.081	0.109
Fe2	0.079	0.078	0.074	0.059	0.069	0.053	0.099	0.067
Mn	0.003	0.002	0.002	0.004	0.002	0.004	0.004	0.003
Mg	0.768	0.774	0.771	0.772	0.781	0.771	0.768	0.778
Ca	0.729	0.736	0.730	0.727	0.727	0.729	0.732	0.732
Na	0.128	0.122	0.131	0.134	0.130	0.133	0.117	0.129
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	81.1	81.2	81.3	81.0	81.8	81.5	81.0	81.6
Ca	0.434	0.435	0.434	0.432	0.432	0.435	0.435	0.434
Mg	0.457	0.458	0.459	0.458	0.464	0.459	0.456	0.461
Fe	0.109	0.107	0.107	0.110	0.105	0.106	0.109	0.106

CLINOPYROXENE ANALYSES, CONTINUED

KA 103 SPINEL WEBSTERITE, continued

	103 4	103 5
SiO2	50.10	50.10
TiO2	0.79	0.72
Al2O3	8.43	8.17
Cr2O3	0.01	0.00
FeO	5.76	5.97
MnO	0.13	0.09
MgO	14.10	14.13
CaO	18.72	18.75
Na2O	1.88	1.85
SUM	99.92	99.78
Fe2O3	3.45	3.66
FeO	2.65	2.68
SUM	100.27	100.15

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.817	1.821
Alz	0.183	0.179
Aly	0.177	0.170
Ti	0.022	0.020
Cr	0.000	0.000
Fe3	0.094	0.100
Fe2	0.081	0.081
Mn	0.004	0.003
Mg	0.762	0.765
Ca	0.727	0.730
Na	0.132	0.130
Sum	4.000	4.000
M/M+F	81.4	80.8
Ca	0.436	0.435
Mg	0.457	0.456
Fe	0.107	0.110

CLINOPYROXENE ANALYSES, CONTINUED

KA 110A,B WEBSTERITE (CPXITE W/ EXSOLVED OPX)

	110A 1	110A 2	110A 3	110A4B	110A 5	110A 6	B 1H	B1HOST
SiO2	49.86	50.13	49.78	49.04	50.27	49.47	49.59	49.29
TiO2	0.66	0.64	0.74	0.66	0.71	0.75	0.76	0.82
Al2O3	7.95	8.22	8.70	9.22	8.08	8.92	9.01	8.97
Cr2O3	0.24	0.16	0.17	0.18	0.13	0.17	0.14	0.18
FeO	6.01	6.05	5.99	6.04	6.14	5.95	6.22	6.22
MnO	0.08	0.12	0.13	0.14	0.14	0.14	0.12	0.10
MgO	13.97	13.77	13.55	13.47	13.72	13.60	13.63	13.46
CaO	18.69	18.43	18.70	18.56	18.60	18.67	17.94	17.80
Na2O	1.85	1.94	1.86	1.89	1.91	1.84	1.82	1.81
SUM	99.31	99.46	99.62	99.20	99.70	99.51	99.23	98.65
Fe2O3	3.67	3.12	2.96	3.89	2.97	3.28	2.31	2.04
FeO	2.71	3.25	3.33	2.54	3.47	3.00	4.14	4.39
SUM	99.68	99.77	99.92	99.59	100.00	99.84	99.46	98.85

CATIONS ON THE BASIS OF 6 OXYGENS

	110A 1	110A 2	110A 3	110A4B	110A 5	110A 6	B 1H	B1HOST
Si	1.822	1.829	1.815	1.794	1.832	1.805	1.815	1.816
Alz	0.178	0.171	0.185	0.206	0.168	0.195	0.185	0.184
Aly	0.165	0.183	0.189	0.192	0.179	0.189	0.204	0.206
Ti	0.018	0.018	0.020	0.018	0.019	0.021	0.021	0.023
Cr	0.007	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Fe3	0.101	0.086	0.081	0.107	0.081	0.090	0.064	0.056
Fe2	0.083	0.099	0.101	0.078	0.106	0.091	0.127	0.135
Mn	0.002	0.004	0.004	0.004	0.004	0.004	0.004	0.003
Mg	0.761	0.749	0.737	0.734	0.745	0.740	0.744	0.739
Ca	0.732	0.721	0.731	0.727	0.726	0.730	0.704	0.703
Na	0.131	0.137	0.132	0.134	0.135	0.130	0.129	0.129
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	80.6	80.2	80.1	79.9	79.9	80.3	79.6	79.4
Ca	0.436	0.435	0.442	0.441	0.437	0.441	0.429	0.429
Mg	0.453	0.452	0.445	0.445	0.448	0.447	0.453	0.452
Fe	0.111	0.114	0.113	0.115	0.115	0.112	0.118	0.119

CLINOPYROXENE ANALYSES, CONTINUED

KA 110A,B WEBSTERITE (CPXITE W/ EXSOLVED OPX), continued

	B 2I C	B 2I E	B7HOST
SiO2	49.72	49.69	49.12
TiO2	0.69	0.61	0.87
Al2O3	9.66	8.98	8.86
Cr2O3	0.20	0.21	0.13
FeO	6.08	6.19	6.29
MnO	0.10	0.12	0.10
MgO	13.48	13.71	13.53
CaO	18.06	18.20	17.77
Na2O	1.79	1.72	1.74
SUM	99.78	99.43	98.41
Fe2O3	1.75	2.31	2.03
FeO	4.51	4.12	4.47
SUM	99.95	99.66	98.61

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.810	1.816	1.815
Alz	0.190	0.184	0.185
Aly	0.225	0.203	0.201
Ti	0.019	0.017	0.024
Cr	0.006	0.006	0.004
Fe3	0.048	0.063	0.056
Fe2	0.137	0.126	0.138
Mn	0.003	0.004	0.003
Mg	0.732	0.747	0.745
Ca	0.705	0.713	0.704
Na	0.126	0.122	0.125
Sum	4.000	4.000	4.000
M/M+F	79.8	79.8	79.3
Ca	0.434	0.431	0.427
Mg	0.450	0.452	0.453
Fe	0.116	0.117	0.120

CLINOPYROXENE ANALYSES, CONTINUED

KA 104 WEBSTERITE

	104 1	104 2	104 3
SiO2	50.44	50.59	49.83
TiO2	0.52	0.42	0.55
Al2O3	8.51	8.22	9.24
Cr2O3	0.51	0.55	0.36
FeO	5.15	5.17	5.12
MnO	0.13	0.15	0.17
MgO	14.02	14.23	13.70
CaO	18.93	19.03	18.99
Na2O	1.70	1.71	1.73
SUM	99.91	100.07	99.69
Fe2O3	1.80	2.36	2.20
FeO	3.53	3.05	3.14
SUM	100.09	100.31	99.91

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.832	1.833	1.813
Alz	0.168	0.167	0.187
Aly	0.196	0.184	0.209
Ti	0.014	0.011	0.015
Cr	0.015	0.016	0.010
Fe3	0.049	0.064	0.060
Fe2	0.107	0.092	0.095
Mn	0.004	0.005	0.005
Mg	0.759	0.769	0.743
Ca	0.736	0.739	0.740
Na	0.120	0.120	0.122
Sum	4.000	4.000	4.000
M/M+F	82.9	83.1	82.7
Ca	0.445	0.443	0.450
Mg	0.458	0.461	0.452
Fe	0.097	0.097	0.098

CLINOPYROXENE ANALYSES, CONTINUED

KA 102 OLIVINE WEBSTERITE

	102 1	102 2	102 3	102 4A	102 4B	102 5	102 6	SC GR
SiO2	49.73	49.84	49.98	49.81	50.12	49.97	49.26	49.78
TiO2	1.11	1.11	1.11	1.18	1.18	1.17	1.14	1.07
Al2O3	8.69	9.00	8.94	8.29	8.53	8.34	8.99	8.67
Cr2O3	0.05	0.06	0.08	0.06	0.17	0.11	0.03	0.04
FeO	6.40	6.57	6.52	6.45	6.59	6.69	6.75	6.38
MnO	0.13	0.15	0.12	0.12	0.08	0.11	0.16	0.09
MgO	13.68	13.66	13.58	13.56	13.67	13.52	13.79	13.82
CaO	18.03	17.97	17.93	18.16	18.04	18.00	17.89	17.84
Na2O	1.71	1.80	1.75	1.65	1.65	1.78	1.78	1.98
SUM	99.53	100.16	100.01	99.28	100.03	99.69	99.79	99.67
Fe2O3	1.64	2.05	1.30	1.15	0.90	1.57	3.04	2.95
FeO	4.92	4.73	5.35	5.41	5.78	5.28	4.01	3.73
SUM	99.69	100.37	100.14	99.40	100.12	99.85	100.09	99.97

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.819	1.811	1.821	1.830	1.828	1.828	1.796	1.813
Alz	0.181	0.189	0.179	0.170	0.172	0.172	0.204	0.187
Aly	0.194	0.197	0.204	0.189	0.195	0.188	0.183	0.186
Ti	0.031	0.030	0.030	0.033	0.032	0.032	0.031	0.029
Cr	0.001	0.002	0.002	0.002	0.005	0.003	0.001	0.001
Fe3	0.045	0.056	0.036	0.032	0.025	0.043	0.083	0.081
Fe2	0.151	0.144	0.163	0.166	0.176	0.162	0.122	0.114
Mn	0.004	0.005	0.004	0.004	0.002	0.003	0.005	0.003
Mg	0.746	0.740	0.737	0.743	0.743	0.737	0.750	0.750
Ca	0.707	0.700	0.700	0.715	0.705	0.706	0.699	0.696
Na	0.121	0.127	0.124	0.118	0.117	0.126	0.126	0.140
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	79.2	78.7	78.8	78.9	78.7	78.3	78.5	79.4
Ca	0.428	0.426	0.427	0.431	0.427	0.427	0.421	0.424
Mg	0.451	0.450	0.450	0.448	0.450	0.447	0.452	0.456
Fe	0.121	0.124	0.123	0.122	0.123	0.126	0.127	0.120

CLINOPYROXENE ANALYSES, CONTINUED

KA 101 COMPOSITE: DUNITE/WEBSTERITE

	101 W1	101W3A	101W3B	101W6B	101 D
SiO2	48.19	48.23	48.52	47.96	49.08
TiO2	1.89	1.75	1.53	1.77	1.32
Al2O3	9.83	9.58	9.80	9.83	8.66
Cr2O3	0.02	0.01	0.00	0.05	0.39
FeO	8.37	6.04	7.04	8.19	5.54
MnO	0.14	0.14	0.10	0.16	0.14
MgO	13.84	14.73	14.05	13.58	14.52
CaO	16.02	17.84	17.06	16.48	17.75
Na2O	1.94	1.75	1.86	1.91	1.69
SUM	100.24	100.07	99.96	99.93	99.09
Fe2O3	3.75	4.62	3.63	3.99	2.52
FeO	4.99	1.88	3.77	4.60	3.28
SUM	100.62	100.53	100.32	100.33	99.34

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.754	1.746	1.764	1.752	1.797
Alz	0.246	0.254	0.236	0.248	0.203
Aly	0.176	0.155	0.184	0.175	0.170
Ti	0.052	0.048	0.042	0.049	0.036
Cr	0.001	0.000	0.000	0.001	0.011
Fe3	0.103	0.126	0.099	0.110	0.069
Fe2	0.152	0.057	0.115	0.141	0.100
Mn	0.004	0.004	0.003	0.005	0.004
Mg	0.751	0.795	0.761	0.739	0.792
Ca	0.625	0.692	0.665	0.645	0.696
Na	0.137	0.123	0.131	0.135	0.120
Sum	4.000	4.000	4.000	4.000	4.000
M/M+F	74.7	81.3	78.1	74.7	82.4
Ca	0.382	0.413	0.404	0.393	0.419
Mg	0.459	0.475	0.463	0.451	0.477
Fe	0.158	0.112	0.132	0.156	0.105

CLINOPYROXENE ANALYSES, CONTINUED

KA 100 SPINEL DUNITE

	100 1C	100 1E	100 2	100 3	100 4	100 5A	100 5B
SiO2	52.15	51.87	52.09	52.42	52.20	51.98	52.30
TiO2	0.49	0.52	0.50	0.49	0.47	0.44	0.52
Al2O3	4.51	4.70	4.82	4.74	4.66	4.77	4.78
Cr2O3	1.32	1.57	1.52	1.43	1.32	1.45	1.32
FeO	3.16	3.23	3.13	3.16	3.12	3.19	3.00
MnO	0.08	0.11	0.04	0.07	0.10	0.11	0.08
MgO	15.95	15.99	15.89	15.91	15.90	15.91	15.75
CaO	20.39	20.22	20.31	20.26	20.08	20.30	20.52
Na2O	1.37	1.47	1.50	1.45	1.52	1.44	1.41
SUM	99.42	99.68	99.80	99.93	99.37	99.59	99.68
Fe2O3	1.50	2.30	1.92	1.27	1.66	1.99	1.08
FeO	1.81	1.16	1.40	2.01	1.63	1.40	2.03
SUM	99.57	99.91	99.99	100.06	99.54	99.79	99.79

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.899	1.883	1.888	1.899	1.899	1.889	1.899
Alz	0.101	0.117	0.112	0.101	0.101	0.111	0.101
Aly	0.092	0.084	0.094	0.101	0.099	0.093	0.104
Ti	0.013	0.014	0.014	0.013	0.013	0.012	0.014
Cr	0.038	0.045	0.044	0.041	0.038	0.042	0.038
Fe3	0.041	0.063	0.052	0.035	0.045	0.054	0.030
Fe2	0.055	0.035	0.042	0.061	0.050	0.042	0.062
Mn	0.002	0.003	0.001	0.002	0.003	0.003	0.002
Mg	0.866	0.865	0.858	0.859	0.862	0.862	0.853
Ca	0.795	0.786	0.789	0.786	0.783	0.790	0.798
Na	0.097	0.103	0.105	0.102	0.107	0.101	0.099
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	90.0	89.8	90.0	90.0	90.1	89.9	90.3
Ca	0.452	0.449	0.452	0.451	0.449	0.451	0.458
Mg	0.492	0.494	0.492	0.493	0.495	0.492	0.489
Fe	0.056	0.058	0.055	0.056	0.056	0.057	0.054

CLINOPYROXENE ANALYSES, CONTINUED

KA 38 MEGACRYST

	38 HOS	38 HOS	38 HOS
SiO2	48.22	48.02	47.99
TiO2	1.70	1.72	1.74
Al2O3	9.33	9.58	9.55
Cr2O3	0.00	0.01	0.03
FeO	8.85	8.91	9.01
MnO	0.14	0.13	0.13
MgO	13.07	13.07	13.02
CaO	16.13	15.94	15.86
Na2O	2.10	2.03	2.08
SUM	99.54	99.41	99.41
Fe2O3	3.89	3.56	3.74
FeO	5.35	5.71	5.65
SUM	99.93	99.77	99.78

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.772	1.768	1.767
Alz	0.228	0.232	0.233
Aly	0.176	0.183	0.181
Ti	0.047	0.048	0.048
Cr	0.000	0.000	0.001
Fe3	0.108	0.099	0.104
Fe2	0.164	0.176	0.174
Mn	0.004	0.004	0.004
Mg	0.716	0.717	0.714
Ca	0.635	0.629	0.626
Na	0.150	0.145	0.148
Sum	4.000	4.000	4.000
M/M+F	72.5	72.3	72.0
Ca	0.390	0.387	0.386
Mg	0.440	0.442	0.441
Fe	0.170	0.171	0.174

APPENDIX D

KAULA XENOLITH SPECIAL CLINOPYROXENE ANALYSES: PATCHES, PATCHY RIMS, AND OTHERS

KAULA XENOLITH CPX PATCHES AND PATCHY RIMS

	107 2P	107R2P	105 6P	108 P	108 PR	109 P	109 1P	106 1P
SiO2	51.03	50.84	49.34	48.45	48.47	49.45	51.03	49.45
TiO2	0.60	0.64	0.58	1.23	1.21	0.72	0.54	0.61
Al2O3	6.22	6.52	8.24	7.01	6.50	7.40	5.35	7.80
Cr2O3	0.10	0.06	0.12	0.02	0.03	0.22	0.19	0.14
FeO	5.88	6.19	5.89	7.38	6.91	6.49	5.33	6.45
MnO	0.06	0.10	0.15	0.14	0.11	0.12	0.12	0.12
MgO	15.27	15.16	15.95	15.61	14.52	15.57	16.30	15.82
CaO	19.85	19.80	18.06	17.90	19.86	18.60	19.27	18.11
Na2O	1.10	1.05	1.02	0.85	0.76	0.71	0.82	1.30
SUM	100.11	100.36	99.35	98.59	98.37	99.28	98.95	99.80
Fe2O3	2.37	2.42	3.13	3.53	3.14	1.90	1.65	4.80
FeO	3.75	4.01	3.07	4.20	4.09	4.78	3.84	2.13
SUM	100.35	100.60	99.66	98.94	98.68	99.47	99.12	100.28

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.855	1.846	1.798	1.794	1.806	1.816	1.873	1.795
Alz	0.145	0.154	0.202	0.206	0.194	0.184	0.127	0.205
Aly	0.122	0.125	0.152	0.100	0.092	0.136	0.104	0.128
Ti	0.016	0.017	0.016	0.034	0.034	0.020	0.015	0.017
Cr	0.003	0.002	0.003	0.001	0.001	0.006	0.006	0.004
Fe3	0.065	0.066	0.086	0.098	0.088	0.052	0.046	0.131
Fe2	0.114	0.122	0.094	0.130	0.127	0.147	0.118	0.065
Mn	0.002	0.003	0.005	0.004	0.003	0.004	0.004	0.004
Mg	0.827	0.820	0.867	0.861	0.807	0.852	0.892	0.856
Ca	0.773	0.770	0.705	0.710	0.793	0.732	0.758	0.704
Na	0.078	0.074	0.072	0.061	0.055	0.051	0.058	0.091
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	82.2	81.4	82.8	79.0	78.9	81.0	84.5	81.4
Ca	0.434	0.432	0.402	0.394	0.436	0.410	0.417	0.400
Mg	0.465	0.460	0.493	0.477	0.444	0.477	0.491	0.486
Fe	0.101	0.107	0.105	0.129	0.120	0.114	0.092	0.113

SPECIAL CLINOPYROXENE ANALYSES, CONTINUED

KAULA XENOLITH CPX PATCHES AND PATCHY RIMS, continued

	106R1P	110A4A	110B1P	110B7P	102PR1	102PR2
SiO2	50.01	50.68	50.65	50.13	48.39	48.67
TiO2	0.65	0.33	0.79	0.71	0.49	0.40
Al2O3	8.17	7.81	5.93	6.59	11.02	10.88
Cr2O3	0.18	0.20	0.22	0.24	0.00	0.01
FeO	6.39	7.87	4.54	4.69	7.89	7.62
MnO	0.17	0.12	0.12	0.05	0.21	0.14
MgO	15.34	19.44	18.44	17.34	16.64	17.24
CaO	18.06	12.30	17.75	18.27	14.47	13.91
Na2O	1.27	1.19	0.48	0.51	0.75	0.71
SUM	100.24	99.94	98.92	98.53	99.86	99.58
Fe2O3	2.83	3.35	1.35	0.93	1.64	1.16
FeO	3.84	4.85	3.32	3.85	6.42	6.57
SUM	100.52	100.28	99.06	98.62	100.02	99.70

CATIONS ON THE BASIS OF 6 OXYGENS

	106R1P	110A4A	110B1P	110B7P	102PR1	102PR2
Si	1.811	1.819	1.846	1.840	1.755	1.765
Alz	0.189	0.181	0.154	0.160	0.245	0.235
Aly	0.160	0.150	0.101	0.125	0.226	0.231
Ti	0.018	0.009	0.022	0.020	0.013	0.011
Cr	0.005	0.006	0.006	0.007	0.000	0.000
Fe3	0.077	0.091	0.037	0.026	0.045	0.032
Fe2	0.116	0.146	0.101	0.118	0.195	0.199
Mn	0.005	0.004	0.004	0.002	0.006	0.004
Mg	0.828	1.040	1.002	0.949	0.900	0.932
Ca	0.701	0.473	0.693	0.718	0.562	0.541
Na	0.089	0.083	0.034	0.036	0.053	0.050
Sum	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	81.1	81.5	87.9	86.8	79.0	80.1
Ca	0.406	0.270	0.377	0.396	0.329	0.316
Mg	0.479	0.593	0.545	0.523	0.527	0.546
Fe	0.115	0.137	0.077	0.080	0.144	0.138

SPECIAL CLINOPYROXENE ANALYSES, CONTINUED

KA 38 MEGACRYST

	38 PA	38 PA	38 RIM	380VGR	BAS GM
SiO2	49.78	49.63	48.73	43.03	41.66
TiO2	1.07	1.02	1.26	3.46	4.47
Al2O3	7.57	7.82	7.96	9.56	9.92
Cr2O3	0.01	0.00	0.03	0.10	0.04
FeO	7.25	6.96	6.65	8.09	8.10
MnO	0.17	0.14	0.15	0.08	0.10
MgO	14.42	14.70	14.67	11.40	11.07
CaO	18.04	17.91	19.17	22.98	22.96
Na2O	1.28	1.32	0.97	0.50	0.44
SUM	99.59	99.50	99.59	99.20	98.76
Fe2O3	1.87	2.34	2.89	6.32	6.17
FeO	5.57	4.85	4.05	2.41	2.55
SUM	99.78	99.73	99.88	99.83	99.38

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.826	1.818	1.787	1.618	1.579
Alz	0.174	0.182	0.213	0.382	0.421
Aly	0.154	0.155	0.131	0.041	0.022
Ti	0.030	0.028	0.035	0.098	0.127
Cr	0.000	0.000	0.001	0.003	0.001
Fe3	0.052	0.065	0.080	0.179	0.176
Fe2	0.171	0.149	0.124	0.076	0.081
Mn	0.005	0.004	0.005	0.003	0.003
Mg	0.789	0.803	0.802	0.639	0.625
Ca	0.709	0.703	0.753	0.926	0.932
Na	0.091	0.094	0.069	0.036	0.032
Sum	4.000	4.000	4.000	4.000	4.000
M/M+F	78.0	79.0	79.7	71.5	70.9
Ca	0.411	0.408	0.427	0.508	0.513
Mg	0.457	0.466	0.455	0.351	0.344
Fe	0.132	0.126	0.118	0.141	0.143

APPENDIX E

KAULA XENOLITH ORTHOPYROXENE ANALYSES

KA 107 GARNET SPINEL CLINOPYROXENITE

	107 1	107 2	107 3	107 4
SiO_2	49.78	48.60	51.35	51.37
TiO_2	0.12	0.29	0.27	0.60
Al_2O_3	9.95	10.85	5.75	7.58
Cr_2O_3	0.04	0.03	0.01	0.03
FeO	12.74	13.72	13.12	9.22
MnO	0.31	0.28	0.29	0.18
MgO	25.56	24.12	26.26	28.31
CaO	2.01	2.07	2.23	1.99
Na_2O	0.09	0.09	0.04	0.11
SUM	100.60	100.05	99.32	99.39
Fe_2O_3	2.19	1.88	1.80	1.06
FeO	10.77	12.03	11.50	8.27
SUM	100.82	100.24	99.50	99.50

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.763	1.741	1.848	1.815
Alz	0.237	0.259	0.152	0.185
Aly	0.178	0.199	0.092	0.131
Ti	0.003	0.008	0.007	0.016
Cr	0.001	0.001	0.000	0.001
Fe3	0.058	0.051	0.049	0.028
Fe2	0.319	0.360	0.346	0.244
Mn	0.009	0.008	0.009	0.005
Mg	1.349	1.288	1.408	1.491
Ca	0.076	0.079	0.086	0.075
Na	0.006	0.006	0.003	0.008
Sum	4.000	4.000	4.000	4.000
M/M+F	78.1	75.8	78.1	84.6
Ca	0.042	0.044	0.045	0.041
Mg	0.745	0.721	0.742	0.808
Fe	0.213	0.235	0.213	0.151

ORTHOPYROXENE ANALYSES, CONTINUED

KA 105 GARNET CLINOPYROXENITE

	105 1	5 2A1X	5 2A2X	5 2BX	105 3X	105 5X
SiO2	50.70	50.53	50.75	50.01	50.80	51.59
TiO2	0.28	0.29	0.27	0.27	0.25	0.26
Al2O3	7.55	8.06	8.06	8.72	8.23	7.14
Cr2O3	0.04	0.05	0.08	0.03	0.03	0.03
FeO	12.13	12.42	12.38	12.27	11.99	12.12
MnO	0.15	0.16	0.22	0.20	0.20	0.11
MgO	27.04	26.73	26.88	26.61	26.60	27.33
CaO	1.19	1.16	1.18	1.15	1.13	1.12
Na2O	0.21	0.21	0.21	0.20	0.20	0.21
SUM	99.29	99.61	100.03	99.46	99.43	99.91
Fe2O3	2.33	2.22	2.30	2.51	1.12	1.59
FeO	10.03	10.42	10.31	10.01	10.98	10.69
SUM	99.52	99.83	100.26	99.71	99.54	100.07

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.809	1.800	1.800	1.782	1.812	1.829
Alz	0.191	0.200	0.200	0.218	0.188	0.171
Aly	0.127	0.138	0.137	0.149	0.158	0.128
Ti	0.008	0.008	0.007	0.007	0.007	0.007
Cr	0.001	0.001	0.002	0.001	0.001	0.001
Fe3	0.063	0.060	0.061	0.067	0.030	0.042
Fe2	0.299	0.310	0.306	0.298	0.328	0.317
Mn	0.005	0.005	0.007	0.006	0.006	0.003
Mg	1.438	1.419	1.421	1.414	1.414	1.445
Ca	0.045	0.044	0.045	0.044	0.043	0.043
Na	0.015	0.015	0.014	0.014	0.014	0.014
Sum	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	79.9	79.3	79.5	79.4	79.8	80.1
Ca	0.025	0.024	0.024	0.024	0.024	0.023
Mg	0.777	0.772	0.772	0.773	0.777	0.781
Fe	0.198	0.204	0.203	0.203	0.200	0.196

ORTHOPYROXENE ANALYSES, CONTINUED

KA 108 A,B WEBSTERITE / GARNET SPINEL WEBSTERITE

	108A1C	108A1E	8A 2AX	108A3C	108A3E	108A4C	108A4E	8A 5XC
SiO2	47.28	46.76	50.12	50.65	50.93	50.94	51.09	50.72
TiO2	0.35	0.32	0.25	0.37	0.36	0.32	0.36	0.35
Al2O3	12.26	13.49	8.23	6.93	6.10	7.10	6.50	7.24
Cr2O3	0.10	0.16	0.17	0.12	0.11	0.18	0.19	0.09
FeO	13.39	13.49	12.27	13.58	13.38	12.94	12.82	12.93
MnO	0.70	0.73	0.26	0.29	0.27	0.33	0.38	0.41
MgO	23.98	23.39	27.04	26.52	26.86	26.81	27.06	26.59
CaO	1.90	1.52	1.01	1.14	1.12	1.10	1.08	1.07
Na2O	0.04	0.03	0.18	0.24	0.20	0.22	0.18	0.21
SUM	100.00	99.89	99.53	99.84	99.33	99.94	99.66	99.61
Fe2O3	2.90	2.00	3.00	3.13	2.96	2.54	2.49	2.35
FeO	10.78	11.69	9.57	10.76	10.71	10.65	10.58	10.81
SUM	100.29	100.09	99.83	100.15	99.63	100.19	99.91	99.85

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.693	1.678	1.784	1.809	1.827	1.813	1.824	1.812
Alz	0.307	0.322	0.216	0.191	0.173	0.187	0.176	0.188
Aly	0.210	0.248	0.130	0.100	0.085	0.111	0.097	0.117
Ti	0.009	0.009	0.007	0.010	0.010	0.009	0.010	0.009
Cr	0.003	0.005	0.005	0.003	0.003	0.005	0.005	0.003
Fe3	0.078	0.054	0.080	0.084	0.080	0.068	0.067	0.063
Fe2	0.323	0.351	0.285	0.321	0.321	0.317	0.316	0.323
Mn	0.021	0.022	0.008	0.009	0.008	0.010	0.011	0.012
Mg	1.280	1.251	1.435	1.412	1.436	1.423	1.440	1.416
Ca	0.073	0.058	0.039	0.044	0.043	0.042	0.041	0.041
Na	0.003	0.002	0.012	0.017	0.014	0.015	0.012	0.015
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	76.1	75.6	79.7	77.7	78.2	78.7	79.0	78.6
Ca	0.041	0.034	0.021	0.023	0.023	0.023	0.022	0.022
Mg	0.721	0.720	0.777	0.755	0.760	0.765	0.768	0.763
Fe	0.238	0.246	0.202	0.222	0.217	0.213	0.210	0.215

ORTHOPYROXENE ANALYSES, CONTINUED

KA 108 A,B WEBSTERITE / GARNET SPINEL WEBSTERITE, continued

	8A 5XE
SiO2	51.21
TiO2	0.30
Al2O3	6.99
Cr2O3	0.05
FeO	13.21
MnO	0.37
MgO	26.75
CaO	1.02
Na2O	0.22
SUM	100.12
Fe2O3	2.32
FeO	11.13
SUM	100.35

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.821
Alz	0.179
Aly	0.114
Ti	0.008
Cr	0.001
Fe3	0.062
Fe2	0.331
Mn	0.011
Mg	1.418
Ca	0.039
Na	0.015
Sum	4.000
M/M+F	78.3
Ca	0.021
Mg	0.762
Fe	0.217

ORTHOPYROXENE ANALYSES, CONTINUED

KA 109 GT WEBSTERITE

	109 1C	109 1E	109 2	109 5C	109 5E	109 6X	109 7X
SiO2	50.32	50.14	50.45	50.09	50.23	50.39	50.63
TiO2	0.21	0.23	0.21	0.21	0.21	0.23	0.23
Al2O3	7.21	7.42	7.35	7.77	7.31	6.43	6.46
Cr2O3	0.11	0.12	0.15	0.13	0.10	0.12	0.16
FeO	12.34	12.49	12.44	12.29	12.37	12.19	12.07
MnO	0.17	0.25	0.19	0.20	0.18	0.17	0.18
MgO	27.71	27.97	27.94	27.99	28.06	28.32	28.21
CaO	1.01	1.02	0.97	0.99	0.99	1.03	1.08
Na2O	0.15	0.18	0.15	0.16	0.15	0.18	0.15
SUM	99.23	99.82	99.85	99.83	99.60	99.06	99.17
Fe2O3	3.92	5.08	4.28	4.79	4.75	5.04	4.29
FeO	8.81	7.92	8.59	7.98	8.09	7.66	8.21
SUM	99.62	100.33	100.28	100.31	100.08	99.56	99.60

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.794	1.776	1.787	1.772	1.782	1.796	1.804
Alz	0.206	0.224	0.213	0.228	0.218	0.204	0.196
Aly	0.097	0.085	0.094	0.096	0.088	0.066	0.075
Ti	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Cr	0.003	0.003	0.004	0.004	0.003	0.003	0.005
Fe3	0.105	0.135	0.114	0.127	0.127	0.135	0.115
Fe2	0.263	0.234	0.254	0.236	0.240	0.228	0.245
Mn	0.005	0.007	0.006	0.006	0.005	0.005	0.005
Mg	1.472	1.477	1.475	1.476	1.484	1.504	1.498
Ca	0.039	0.039	0.037	0.038	0.038	0.039	0.041
Na	0.010	0.012	0.010	0.011	0.010	0.012	0.010
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	80.0	80.0	80.0	80.2	80.2	80.5	80.6
Ca	0.020	0.020	0.020	0.020	0.020	0.021	0.022
Mg	0.782	0.780	0.782	0.784	0.783	0.787	0.787
Fe	0.198	0.199	0.198	0.196	0.197	0.193	0.192

ORTHOPYROXENE ANALYSES, CONTINUED

KA 106 SPINEL WEBSTERITE

	106 1	106 2	106 3	106 4
SiO2	51.78	51.51	51.32	51.18
TiO2	0.26	0.27	0.23	0.24
Al2O3	6.91	6.80	6.67	6.62
Cr2O3	0.04	0.11	0.16	0.16
FeO	11.62	12.01	11.80	11.79
MnO	0.15	0.13	0.20	0.15
MgO	28.04	27.68	27.73	27.90
CaO	1.14	1.17	1.16	1.21
Na2O	0.19	0.19	0.20	0.16
SUM	100.13	99.87	99.47	99.41
Fe2O3	2.16	2.25	2.52	2.83
FeO	9.68	9.99	9.53	9.24
SUM	100.35	100.09	99.72	99.69

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.827	1.826	1.825	1.820
Alz	0.173	0.174	0.175	0.180
Aly	0.114	0.110	0.105	0.098
Ti	0.007	0.007	0.006	0.006
Cr	0.001	0.003	0.004	0.004
Fe3	0.057	0.060	0.067	0.076
Fe2	0.286	0.296	0.284	0.275
Mn	0.004	0.004	0.006	0.005
Mg	1.474	1.462	1.470	1.479
Ca	0.043	0.044	0.044	0.046
Na	0.013	0.013	0.014	0.011
Sum	4.000	4.000	4.000	4.000
M/M+F	81.1	80.4	80.7	80.8
Ca	0.023	0.024	0.024	0.025
Mg	0.791	0.783	0.786	0.787
Fe	0.186	0.193	0.191	0.189

ORTHOPYROXENE ANALYSES, CONTINUED

KA 103 SPINEL WEBSTERITE

	103 1	103 2	103 2U
SiO2	52.56	50.57	51.27
TiO2	0.21	0.21	0.18
Al2O3	6.09	9.06	9.06
Cr2O3	0.07	0.01	0.02
FeO	10.73	10.50	10.37
MnO	0.12	0.12	0.14
MgO	28.94	27.63	26.29
CaO	1.01	1.02	2.29
Na2O	0.12	0.13	0.26
SUM	99.85	99.25	99.88
Fe2O3	1.38	1.24	0.04
FeO	9.49	9.38	10.33
SUM	99.99	99.37	99.88

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.853	1.793	1.814
Alz	0.147	0.207	0.186
Aly	0.106	0.171	0.192
Ti	0.006	0.006	0.005
Cr	0.002	0.000	0.001
Fe3	0.037	0.033	0.001
Fe2	0.280	0.278	0.306
Mn	0.004	0.004	0.004
Mg	1.521	1.460	1.387
Ca	0.038	0.039	0.087
Na	0.008	0.009	0.018
Sum	4.000	4.000	4.000
M/M+F	82.8	82.4	81.9
Ca	0.020	0.021	0.049
Mg	0.809	0.805	0.777
Fe	0.170	0.174	0.174

ORTHOPYROXENE ANALYSES, CONTINUED

KA 110 A,B WEBSTERITE (CPXITE W/ EXSOLVED OPX)

	B1XC,E	B 2C	B 2E	B3XC,E	B 4C	B 4E	B 5X	B 6MYR
SiO2	51.67	50.81	52.87	52.36	52.60	52.57	51.99	52.01
TiO2	0.20	0.18	0.11	0.12	0.19	0.18	0.16	0.16
Al2O3	6.89	8.42	5.39	5.59	5.47	5.34	6.41	6.87
Cr2O3	0.11	0.13	0.08	0.08	0.10	0.09	0.14	0.19
FeO	11.72	11.59	11.06	11.61	11.58	11.36	10.93	11.10
MnO	0.20	0.20	0.19	0.19	0.12	0.22	0.17	0.19
MgO	27.92	27.68	29.01	28.54	28.94	28.97	28.74	28.50
CaO	0.92	0.89	0.96	1.07	0.99	1.01	1.07	1.02
Na2O	0.14	0.14	0.14	0.14	0.16	0.12	0.15	0.16
SUM	99.77	100.04	99.81	99.70	100.15	99.86	99.76	100.20
Fe2O3	1.72	2.22	1.69	2.19	2.47	2.27	2.31	2.00
FeO	10.17	9.59	9.54	9.64	9.36	9.32	8.85	9.30
SUM	99.94	100.26	99.98	99.92	100.40	100.09	99.99	100.40

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.831	1.794	1.866	1.855	1.853	1.857	1.835	1.830
Alz	0.169	0.206	0.134	0.145	0.147	0.143	0.165	0.170
Aly	0.119	0.144	0.090	0.088	0.080	0.079	0.102	0.114
Ti	0.005	0.005	0.003	0.003	0.005	0.005	0.004	0.004
Cr	0.003	0.004	0.002	0.002	0.003	0.003	0.004	0.005
Fe3	0.046	0.059	0.045	0.058	0.066	0.060	0.061	0.053
Fe2	0.301	0.283	0.282	0.285	0.276	0.275	0.261	0.274
Mn	0.006	0.006	0.006	0.006	0.004	0.007	0.005	0.006
Mg	1.475	1.456	1.526	1.507	1.519	1.525	1.512	1.494
Ca	0.035	0.034	0.036	0.041	0.037	0.038	0.040	0.038
Na	0.010	0.010	0.010	0.010	0.011	0.008	0.010	0.011
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	80.9	81.0	82.4	81.4	81.7	82.0	82.4	82.1
Ca	0.019	0.018	0.019	0.021	0.020	0.020	0.022	0.021
Mg	0.792	0.792	0.806	0.794	0.799	0.800	0.804	0.801
Fe	0.190	0.189	0.175	0.184	0.181	0.180	0.174	0.178

ORTHOPYROXENE ANALYSES, CONTINUED

KA 110 A,B WEBSTERITE (CPXITE W/ EXSOLVED OPX), continued

	B 7X
SiO2	51.82
TiO2	0.19
Al2O3	6.61
Cr2O3	0.10
FeO	11.66
MnO	0.18
MgO	28.31
CaO	0.94
Na2O	0.16
SUM	99.97
Fe2O3	2.35
FeO	9.55
SUM	100.21

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.830
Alz	0.170
Aly	0.105
Ti	0.005
Cr	0.003
Fe3	0.062
Fe2	0.282
Mn	0.005
Mg	1.490
Ca	0.036
Na	0.011
Sum	4.000
M/M+F	81.2
Ca	0.019
Mg	0.795
Fe	0.186

ORTHOPYROXENE ANALYSES, CONTINUED

KA 104 WEBSTERITE

	104 1	104 1U	104 2	104 3	104 4	104 4U
SiO_2	52.44	52.59	52.24	52.24	52.39	51.44
TiO_2	0.15	0.20	0.15	0.15	0.11	0.16
Al_2O_3	6.42	6.46	6.38	6.65	6.16	6.40
Cr_2O_3	0.40	0.43	0.40	0.41	0.32	0.52
FeO	9.95	9.35	10.07	9.08	9.80	9.34
MnO	0.18	0.20	0.22	0.16	0.16	0.18
MgO	29.38	28.77	29.38	27.53	29.12	26.75
CaO	1.02	2.59	0.90	3.17	1.03	3.99
Na_2O	0.17	0.24	0.14	0.30	0.16	0.44
SUM	100.11	100.83	99.88	99.69	99.25	99.22
Fe_2O_3	1.95	2.44	2.07	1.29	1.31	3.00
FeO	8.20	7.15	8.21	7.92	8.62	6.64
SUM	100.31	101.07	100.09	99.82	99.38	99.52

CATIONS ON THE BASIS OF 6 OXYGENS

	104 1	104 1U	104 2	104 3	104 4	104 4U
Si	1.838	1.832	1.836	1.845	1.852	1.829
Alz	0.162	0.168	0.164	0.155	0.148	0.171
Aly	0.103	0.098	0.100	0.122	0.109	0.098
Ti	0.004	0.005	0.004	0.004	0.003	0.004
Cr	0.011	0.012	0.011	0.011	0.009	0.015
Fe3	0.051	0.064	0.055	0.034	0.035	0.080
Fe2	0.240	0.208	0.241	0.234	0.255	0.198
Mn	0.005	0.006	0.007	0.005	0.005	0.005
Mg	1.535	1.494	1.539	1.449	1.535	1.418
Ca	0.038	0.097	0.034	0.120	0.039	0.152
Na	0.012	0.016	0.010	0.021	0.011	0.030
Sum	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	84.0	84.6	83.9	84.4	84.1	83.6
Ca	0.020	0.052	0.018	0.065	0.021	0.082
Mg	0.821	0.799	0.821	0.787	0.821	0.765
Fe	0.159	0.149	0.161	0.148	0.158	0.153

ORTHOPYROXENE ANALYSES, CONTINUED

KA 102 OLIVINE WEBSTERITE

	1021AC	1021AE	1021BX	102 2C	102 2E	102 3C	102 3E	102 4C
SiO2	52.00	52.09	52.13	52.14	52.21	52.20	52.23	52.23
TiO2	0.27	0.31	0.26	0.26	0.27	0.31	0.30	0.31
Al2O3	6.42	6.28	6.28	5.92	5.89	6.20	5.87	5.92
Cr2O3	0.06	0.03	0.06	0.06	0.08	0.03	0.06	0.04
FeO	11.45	11.69	11.44	11.70	11.55	11.53	11.51	11.33
MnO	0.18	0.16	0.14	0.18	0.18	0.18	0.16	0.15
MgO	28.18	28.44	28.20	28.34	28.31	28.27	28.28	28.30
CaO	0.95	0.91	0.94	0.95	0.99	1.02	0.91	1.03
Na2O	0.17	0.18	0.18	0.19	0.16	0.14	0.14	0.18
SUM	99.68	100.09	99.63	99.74	99.64	99.88	99.46	99.49
Fe2O3	1.60	2.20	1.46	2.12	1.70	1.51	1.30	1.49
FeO	10.01	9.71	10.13	9.79	10.02	10.17	10.34	9.99
SUM	99.84	100.31	99.78	99.95	99.81	100.03	99.59	99.64

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.842	1.838	1.848	1.847	1.851	1.847	1.856	1.854
Alz	0.158	0.162	0.152	0.153	0.149	0.153	0.144	0.146
Aly	0.110	0.099	0.110	0.094	0.098	0.105	0.102	0.101
Ti	0.007	0.008	0.007	0.007	0.007	0.008	0.008	0.008
Cr	0.002	0.001	0.002	0.002	0.002	0.001	0.002	0.001
Fe3	0.043	0.058	0.039	0.057	0.045	0.040	0.035	0.040
Fe2	0.297	0.287	0.300	0.290	0.297	0.301	0.307	0.296
Mn	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005
Mg	1.488	1.496	1.490	1.496	1.496	1.491	1.498	1.497
Ca	0.036	0.034	0.036	0.036	0.038	0.039	0.035	0.039
Na	0.012	0.012	0.012	0.013	0.011	0.010	0.010	0.012
Sum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
M/M+F	81.4	81.3	81.5	81.2	81.4	81.4	81.4	81.7
Ca	0.019	0.018	0.019	0.019	0.020	0.021	0.018	0.021
Mg	0.796	0.796	0.797	0.794	0.795	0.795	0.797	0.798
Fe	0.184	0.186	0.184	0.187	0.185	0.185	0.185	0.182

ORTHOPYROXENE ANALYSES, CONTINUED

KA 102 OLIVINE WEBSTERITE,continued

	102 5	102 6	102 7X	102SCX
SiO2	52.54	52.30	51.95	52.44
TiO2	0.25	0.27	0.33	0.28
Al2O3	5.76	5.96	6.29	5.92
Cr2O3	0.03	0.09	0.04	0.01
FeO	11.55	11.72	11.57	11.30
MnO	0.15	0.19	0.16	0.19
MgO	28.41	28.43	28.22	28.68
CaO	0.97	0.92	0.96	0.93
Na2O	0.18	0.15	0.15	0.14
SUM	99.84	100.03	99.67	99.89
Fe2O3	1.52	1.86	1.71	1.66
FeO	10.18	10.04	10.03	9.81
SUM	99.99	100.22	99.84	100.06

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.859	1.848	1.842	1.852
Alz	0.141	0.152	0.158	0.148
Aly	0.099	0.096	0.104	0.098
Ti	0.007	0.007	0.009	0.007
Cr	0.001	0.003	0.001	0.000
Fe3	0.040	0.050	0.046	0.044
Fe2	0.301	0.297	0.297	0.290
Mn	0.004	0.006	0.005	0.006
Mg	1.498	1.497	1.491	1.510
Ca	0.037	0.035	0.036	0.035
Na	0.012	0.010	0.010	0.010
Sum	4.000	4.000	4.000	4.000
M/M+F	81.4	81.2	81.3	81.9
Ca	0.020	0.018	0.019	0.019
Mg	0.796	0.795	0.795	0.801
Fe	0.184	0.187	0.185	0.180

ORTHOPYROXENE ANALYSES, CONTINUED

KA 101 COMPOSITE: DUNITE/WEBSTERITE

	101W 1	101W2I	101D 2	101D 3	101D 4
SiO2	51.93	50.57	53.23	53.17	52.71
TiO2	0.51	0.52	0.37	0.31	0.44
Al2O3	7.40	7.55	6.34	6.40	6.47
Cr2O3	0.02	0.02	0.24	0.23	0.22
FeO	9.85	13.60	9.23	9.08	9.30
MnO	0.15	0.22	0.16	0.13	0.17
MgO	28.65	26.19	29.06	29.24	28.91
CaO	1.04	1.16	1.09	1.13	1.09
Na2O	0.12	0.21	0.16	0.15	0.18
SUM	99.67	100.04	99.88	99.84	99.49
Fe2O3	0.44	2.25	0.00	0.00	0.00
FeO	9.45	11.58	9.23	9.08	9.30
SUM	99.71	100.27	99.88	99.84	99.49

CATIONS ON THE BASIS OF 6 OXYGENS

Si	1.831	1.804	1.868	1.865	1.859
Alz	0.169	0.196	0.132	0.135	0.141
Aly	0.138	0.122	0.130	0.130	0.128
Ti	0.014	0.014	0.010	0.008	0.012
Cr	0.001	0.001	0.007	0.006	0.006
Fe3	0.012	0.060	0.000	0.000	0.000
Fe2	0.279	0.345	0.271	0.266	0.274
Mn	0.004	0.007	0.005	0.004	0.005
Mg	1.505	1.393	1.520	1.529	1.520
Ca	0.039	0.044	0.041	0.042	0.041
Na	0.008	0.015	0.011	0.010	0.012
Sum	4.000	4.000	3.994	3.996	3.998
M/M+F	83.8	77.4	84.9	85.2	84.7
Ca	0.021	0.024	0.022	0.023	0.022
Mg	0.818	0.753	0.828	0.830	0.826
Fe	0.160	0.223	0.150	0.147	0.152

APPENDIX F

KAULA XENOLITH GARNET ANALYSES

KA 107 GARNET SPINEL CLINOPYROXENITE

	107 1	107 2A	107 2B	107 3	107 4
SiO2	40.61	40.57	40.75	40.56	40.43
TiO2	0.38	0.42	0.35	0.33	0.44
Al2O3	23.67	23.32	23.25	23.49	23.38
Cr2O3	0.03	0.05	0.02	0.03	0.04
FeO	13.42	13.56	13.21	13.55	13.81
MnO	0.34	0.35	0.33	0.35	0.33
MgO	17.00	16.75	17.09	16.79	16.46
CaO	5.10	5.11	5.06	5.13	5.09
Na2O	0.04	0.03	0.01	0.03	0.07
SUM	100.59	100.16	100.07	100.26	100.05

CATIONS ON THE BASIS OF 24 OXYGENS

Si	5.870	5.895	5.913	5.887	5.888
Alz	0.130	0.105	0.087	0.113	0.112
Aly	3.903	3.889	3.890	3.905	3.902
Ti	0.041	0.046	0.038	0.036	0.048
Cr	0.003	0.006	0.002	0.003	0.005
Fe2	1.622	1.648	1.603	1.645	1.682
Mn	0.042	0.043	0.041	0.043	0.041
Mg	3.663	3.628	3.697	3.632	3.573
Ca	0.790	0.796	0.787	0.798	0.794
Na	0.011	0.008	0.003	0.008	0.020
Sum	16.076	16.063	16.060	16.071	16.064
M/M+F	69.3	68.8	69.7	68.8	68.0
Ca	0.129	0.130	0.128	0.130	0.130
Mg	0.599	0.593	0.603	0.594	0.587
Fe	0.272	0.277	0.268	0.276	0.283

GARNET ANALYSES, CONTINUED

KA 105 GARNET CLINOPYROXENITE

	105 1	105 1R	105 2	105 2R	105 3	105 3R	105 4	105 4R
SiO2	41.13	41.16	40.87	40.92	41.22	41.02	40.74	41.08
TiO2	0.38	0.37	0.36	0.35	0.26	0.28	0.27	0.29
Al2O3	23.16	23.70	23.12	23.38	23.31	23.49	23.38	23.64
Cr2O3	0.03	0.05	0.02	0.04	0.04	0.06	0.05	0.03
FeO	11.25	11.29	11.83	12.28	11.40	11.47	11.62	11.84
MnO	0.33	0.28	0.34	0.31	0.37	0.33	0.33	0.31
MgO	18.62	18.04	18.05	17.61	18.51	18.09	18.70	17.95
CaO	5.44	5.34	5.16	5.07	5.31	5.03	5.31	5.05
Na2O	0.02	0.05	0.03	0.04	0.05	0.05	0.05	0.07
SUM	100.36	100.28	99.78	100.00	100.47	99.82	100.45	100.26

CATIONS ON THE BASIS OF 24 OXYGENS

Si	5.907	5.909	5.915	5.916	5.915	5.919	5.859	5.910
Alz	0.093	0.091	0.085	0.084	0.085	0.081	0.141	0.090
Aly	3.828	3.919	3.859	3.900	3.857	3.913	3.822	3.918
Ti	0.041	0.040	0.039	0.038	0.028	0.030	0.029	0.031
Cr	0.003	0.006	0.002	0.005	0.005	0.007	0.006	0.003
Fe2	1.351	1.356	1.432	1.485	1.368	1.384	1.398	1.425
Mn	0.040	0.034	0.042	0.038	0.045	0.040	0.040	0.038
Mg	3.986	3.860	3.894	3.795	3.959	3.891	4.008	3.849
Ca	0.837	0.821	0.800	0.785	0.816	0.778	0.818	0.778
Na	0.006	0.014	0.008	0.011	0.014	0.014	0.014	0.020
Sum	16.092	16.050	16.077	16.057	16.091	16.057	16.135	16.063
M/M+F	74.7	74.0	73.1	71.9	74.3	73.8	74.1	73.0
Ca	0.135	0.135	0.130	0.129	0.132	0.128	0.131	0.128
Mg	0.641	0.636	0.631	0.622	0.640	0.639	0.640	0.632
Fe	0.224	0.229	0.239	0.250	0.228	0.234	0.230	0.240

GARNET ANALYSES, CONTINUED

KA 105 GARNET CLINOPYROXENITE, continued

	105 5	105 5R
SiO2	40.77	41.03
TiO2	0.29	0.36
Al2O3	23.42	23.76
Cr2O3	0.04	0.07
FeO	11.87	11.99
MnO	0.33	0.31
MgO	18.29	17.79
CaO	5.19	4.99
Na2O	0.05	0.01
SUM	100.25	100.31

CATIONS ON THE BASIS OF 24 OXYGENS

Si	5.877	5.902
Alz	0.123	0.098
Aly	3.855	3.930
Ti	0.031	0.039
Cr	0.005	0.008
Fe2	1.431	1.442
Mn	0.040	0.038
Mg	3.930	3.814
Ca	0.802	0.769
Na	0.014	0.003
Sum	16.107	16.043
M/M+F	73.3	72.6
Ca	0.129	0.127
Mg	0.634	0.629
Fe	0.237	0.244

GARNET ANALYSES, CONTINUED

KA 108A WEBSTERITE/GARNET SPINEL WEBSTERITE

	108A 1	108A 2	108A 3	108A 4	108A 5
SiO2	41.20	40.84	41.02	40.86	40.78
TiO2	0.44	0.43	0.44	0.48	0.49
Al2O3	23.30	23.24	23.36	23.18	23.31
Cr2O3	0.08	0.11	0.11	0.12	0.12
FeO	13.81	13.98	13.56	13.91	13.33
MnO	0.41	0.40	0.38	0.39	0.39
MgO	16.59	16.41	16.61	16.58	16.78
CaO	4.86	4.83	4.98	4.78	4.98
Na2O	0.02	0.03	0.03	0.05	0.03
SUM	100.71	100.27	100.49	100.35	100.21

CATIONS ON THE BASIS OF 24 OXYGENS

Si	5.949	5.932	5.934	5.929	5.914
Alz	0.051	0.068	0.066	0.071	0.086
Aly	3.915	3.910	3.916	3.892	3.898
Ti	0.048	0.047	0.048	0.052	0.053
Cr	0.009	0.013	0.013	0.014	0.014
Fe2	1.668	1.698	1.640	1.688	1.617
Mn	0.050	0.049	0.047	0.048	0.048
Mg	3.571	3.553	3.581	3.586	3.627
Ca	0.752	0.752	0.772	0.743	0.774
Na	0.006	0.008	0.008	0.014	0.008
Sum	16.018	16.030	16.025	16.037	16.038
M/M+F	68.2	67.7	68.6	68.0	69.2
Ca	0.124	0.124	0.128	0.123	0.128
Mg	0.591	0.587	0.593	0.591	0.598
Fe	0.284	0.289	0.279	0.286	0.274

GARNET ANALYSES, CONTINUED

KA 109 GARNET WEBSTERITE

	109 11	109 12	109 13	109 14	109 2C	109 2E
SiO2	41.22	41.18	41.26	41.04	41.05	41.53
TiO2	0.33	0.33	0.37	0.39	0.24	0.21
Al2O3	23.79	23.87	23.68	23.61	23.77	23.77
Cr2O3	0.13	0.16	0.14	0.07	0.15	0.16
FeO	12.02	11.54	11.33	12.41	12.86	12.97
MnO	0.35	0.38	0.36	0.35	0.41	0.42
MgO	17.23	17.58	17.64	17.20	16.75	16.22
CaO	5.30	5.30	5.19	5.04	5.06	5.14
Na2O	0.05	0.03	0.07	0.04	0.02	0.01
SUM	100.42	100.37	100.04	100.15	100.31	100.43

CATIONS ON THE BASIS OF 24 OXYGENS

Si	5.927	5.913	5.936	5.925	5.929	5.987
Alz	0.073	0.087	0.064	0.075	0.071	0.013
Aly	3.959	3.953	3.952	3.942	3.975	4.025
Ti	0.036	0.036	0.040	0.042	0.026	0.023
Cr	0.015	0.018	0.016	0.008	0.017	0.018
Fe2	1.445	1.386	1.363	1.498	1.553	1.564
Mn	0.043	0.046	0.044	0.043	0.050	0.051
Mg	3.693	3.763	3.783	3.701	3.606	3.485
Ca	0.817	0.815	0.800	0.780	0.783	0.794
Na	0.014	0.008	0.020	0.011	0.006	0.003
Sum	16.021	16.026	16.018	16.026	16.016	15.963
M/M+F	71.9	73.1	73.5	71.2	69.9	69.0
Ca	0.136	0.136	0.134	0.129	0.131	0.135
Mg	0.616	0.626	0.632	0.615	0.602	0.591
Fe	0.248	0.238	0.235	0.256	0.268	0.274

GARNET ANALYSES, CONTINUED

KA 110B WEBSTERITE (CPXITE W/ EXSOLVED OPX)

	110 1	110 2	110 31	110 32
SiO2	40.84	41.03	41.22	41.17
TiO2	0.29	0.41	0.23	0.23
Al2O3	23.61	23.44	23.42	23.60
Cr2O3	0.09	0.07	0.12	0.14
FeO	12.66	12.53	12.60	12.52
MnO	0.41	0.41	0.44	0.41
MgO	16.83	16.49	16.76	17.02
CaO	5.30	5.34	5.14	5.25
Na2O	0.03	0.04	0.02	0.01
SUM	100.06	99.76	99.95	100.35

CATIONS ON THE BASIS OF 24 OXYGENS

Si	5.916	5.955	5.969	5.938
Alz	0.084	0.045	0.031	0.062
Aly	3.946	3.964	3.965	3.950
Ti	0.032	0.045	0.025	0.025
Cr	0.010	0.008	0.014	0.016
Fe2	1.534	1.521	1.526	1.510
Mn	0.050	0.050	0.054	0.050
Mg	3.634	3.567	3.617	3.659
Ca	0.823	0.830	0.797	0.811
Na	0.008	0.011	0.006	0.003
Sum	16.037	15.997	16.004	16.024
M/M+F	70.3	70.1	70.3	70.8
Ca	0.136	0.139	0.133	0.135
Mg	0.602	0.598	0.603	0.607
Fe	0.262	0.263	0.264	0.259

APPENDIX G

KAULA XENOLITH SPINEL ANALYSES

KA 107 GARNET SPINEL CLINOPYROXENITE

	107 1C	1071CR	107 1E	1071ER	107 2C	107 2E	107 3C	107 3E
TiO2	0.59	0.58	0.57	0.54	0.53	0.58	0.57	0.53
Al2O3	58.57	59.43	58.47	59.30	59.80	59.59	57.51	57.66
Cr2O3	0.23	0.23	0.24	0.20	0.24	0.28	0.26	0.23
FeO	23.62	23.48	23.80	23.39	21.75	21.84	26.03	25.76
MnO	0.05	0.11	0.06	0.09	0.09	0.08	0.06	0.08
MgO	16.56	16.44	16.26	16.60	17.14	17.39	15.47	15.52
SUM	99.62	100.27	99.40	100.12	99.55	99.76	99.90	99.78
Fe2O3	7.96	7.31	7.78	7.57	6.81	7.22	8.88	8.75
FeO	16.46	16.90	16.80	16.58	15.63	15.34	18.04	17.89
SUM	100.42	101.00	100.18	100.88	100.23	100.48	100.79	100.66

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.093	0.091	0.090	0.085	0.083	0.091	0.091	0.084
Al	14.515	14.631	14.543	14.607	14.724	14.639	14.359	14.398
Cr	0.038	0.038	0.040	0.033	0.040	0.046	0.044	0.039
Fe3	1.260	1.149	1.236	1.190	1.070	1.133	1.416	1.395
Fe2	2.894	2.953	2.965	2.898	2.730	2.674	3.195	3.169
Mn	0.009	0.019	0.011	0.016	0.016	0.014	0.011	0.014
Mg	5.190	5.119	5.115	5.171	5.337	5.403	4.885	4.901
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	55.5	55.5	54.9	55.8	58.4	58.7	51.4	51.8

SPINEL ANALYSES, CONTINUED

KA 107 GARNET SPINEL CLINOPYROXENITE, continued

	107 4C	1074CR	107 4E	107 5	107 6	107 7	107 8	107 9
TiO_2	0.55	0.52	0.55	0.09	0.12	0.22	0.16	0.34
Al_2O_3	59.05	57.82	58.96	63.89	63.48	63.67	62.59	63.34
Cr_2O_3	0.24	0.22	0.23	0.12	0.14	0.11	0.10	0.10
FeO	24.36	24.40	24.57	17.51	18.14	17.49	19.85	17.33
MnO	0.05	0.07	0.06	0.17	0.18	0.14	0.20	0.18
MgO	16.20	16.80	16.13	18.51	18.25	19.04	17.56	19.34
SUM	100.45	99.83	100.50	100.29	100.31	100.67	100.46	100.63
Fe_2O_3	7.83	9.36	7.95	4.03	4.32	4.63	5.12	4.96
FeO	17.31	15.98	17.41	13.89	14.25	13.32	15.24	12.87
SUM	101.23	100.77	101.30	100.69	100.74	101.13	100.97	101.13

CATIONS ON THE BASIS OF 32 OXYGENS

	107 4C	1074CR	107 4E	107 5	107 6	107 7	107 8	107 9
Ti	0.086	0.082	0.087	0.014	0.018	0.034	0.025	0.052
Al	14.555	14.319	14.537	15.336	15.276	15.209	15.143	15.125
Cr	0.040	0.037	0.038	0.019	0.023	0.018	0.016	0.016
Fe3	1.233	1.480	1.252	0.617	0.664	0.707	0.791	0.756
Fe2	3.028	2.808	3.046	2.365	2.433	2.258	2.617	2.181
Mn	0.009	0.012	0.011	0.029	0.031	0.024	0.035	0.031
Mg	5.050	5.262	5.030	5.619	5.554	5.752	5.373	5.840
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	54.2	55.1	53.9	65.3	64.2	66.0	61.2	66.5

SPINEL ANALYSES, CONTINUED

KA 107 GARNET SPINEL CLINOPYROXENITE, continued

	107 10
TiO2	0.20
Al2O3	63.11
Cr2O3	0.10
FeO	18.15
MnO	0.15
MgO	18.22
SUM	99.93
Fe2O3	4.37
FeO	14.22
SUM	100.37

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.031
Al	15.248
Cr	0.016
Fe3	0.674
Fe2	2.438
Mn	0.026
Mg	5.567
Sum	24.000
M/M+F	64.1

SPINEL ANALYSES, CONTINUED

KA 105 GARNET CLINOPYROXENITE

	105 1C	1051CR	105 1E	105 21	105 22	105 3
TiO2	0.43	0.42	0.47	0.46	0.46	0.46
Al2O3	61.93	61.96	62.20	61.39	61.68	61.04
Cr2O3	0.35	0.32	0.35	0.38	0.37	0.31
FeO	17.96	18.18	17.96	19.71	19.52	19.56
MnO	0.09	0.06	0.05	0.05	0.06	0.06
MgO	19.04	18.81	18.88	18.14	18.14	18.40
SUM	99.80	99.75	99.91	100.13	100.23	99.83
Fe2O3	5.49	5.33	5.05	5.80	5.52	6.25
FeO	13.02	13.38	13.41	14.49	14.56	13.94
SUM	100.35	100.28	100.42	100.71	100.78	100.46

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.066	0.065	0.072	0.071	0.071	0.071
Al	14.964	14.994	15.019	14.897	14.944	14.837
Cr	0.057	0.052	0.057	0.062	0.060	0.051
Fe3	0.847	0.824	0.779	0.898	0.854	0.969
Fe2	2.232	2.298	2.298	2.495	2.502	2.404
Mn	0.016	0.010	0.009	0.009	0.010	0.010
Mg	5.818	5.757	5.766	5.567	5.558	5.656
Sum	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	65.4	64.8	65.2	62.1	62.4	62.6

SPINEL ANALYSES, CONTINUED

KA 108A WEBSTERITE/GARNET SPINEL WEBSTERITE

	108A 1	108A 2	108A 3	108A 4
TiO2	1.10	1.15	1.20	0.36
Al2O3	53.86	54.00	52.66	62.28
Cr2O3	1.04	0.57	0.50	0.26
FeO	28.92	29.52	30.87	19.30
MnO	0.06	0.08	0.10	0.18
MgO	15.08	14.85	14.30	17.78
SUM	100.06	100.17	99.63	100.16
Fe2O3	11.44	11.62	12.56	4.83
FeO	18.63	19.07	19.57	14.96
SUM	101.21	101.33	100.89	100.64

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.178	0.186	0.196	0.056
Al	13.622	13.656	13.471	15.099
Cr	0.176	0.097	0.086	0.042
Fe3	1.847	1.876	2.052	0.747
Fe2	3.343	3.422	3.551	2.573
Mn	0.011	0.015	0.018	0.031
Mg	4.823	4.749	4.626	5.451
Sum	24.000	24.000	24.000	24.000
M/M+F	48.2	47.3	45.2	62.1

SPINEL ANALYSES, CONTINUED

KA 109 GARNET WEBSTERITE

	109 1	109 2	109 3	109 4	109 5	109 6	109 7
TiO2	0.13	0.17	0.12	0.15	0.60	0.63	0.21
Al2O3	64.24	63.27	63.30	64.37	61.36	62.62	64.82
Cr2O3	0.54	0.63	0.87	1.00	1.68	0.58	0.45
FeO	16.49	16.19	15.68	15.16	16.58	16.50	14.47
MnO	0.17	0.08	0.17	0.06	0.07	0.14	0.20
MgO	19.14	19.41	19.82	19.33	19.58	19.13	19.75
SUM	100.71	99.75	99.96	100.07	99.87	99.60	99.90
Fe2O3	3.72	4.21	4.41	2.65	4.77	3.86	2.67
FeO	13.14	12.40	11.72	12.78	12.29	13.03	12.06
SUM	101.08	100.17	100.40	100.34	100.35	99.99	100.17

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.020	0.026	0.018	0.023	0.092	0.097	0.032
Al	15.308	15.201	15.150	15.390	14.808	15.118	15.457
Cr	0.086	0.102	0.140	0.160	0.272	0.094	0.072
Fe3	0.566	0.645	0.673	0.404	0.735	0.594	0.407
Fe2	2.222	2.115	1.990	2.168	2.104	2.232	2.041
Mn	0.029	0.014	0.029	0.010	0.012	0.024	0.034
Mg	5.768	5.898	5.999	5.845	5.976	5.841	5.956
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	67.4	68.1	69.3	69.4	67.8	67.4	70.9

SPINEL ANALYSES, CONTINUED

KA 106 SPINEL WEBSTERITE

	106 1C	106 1E	106 2C	106 2E	106 3C	106 3E	106 41	106 42
TiO2	0.40	0.42	0.38	0.47	0.46	0.43	0.38	0.39
Al2O3	59.25	60.39	59.74	60.32	58.21	57.90	59.62	60.28
Cr2O3	1.78	1.82	1.45	1.46	2.48	2.56	1.45	1.30
FeO	20.58	19.13	20.08	19.94	20.78	20.71	20.18	20.25
MnO	0.01	0.03	0.02	0.04	0.00	0.00	0.00	0.01
MgO	17.64	17.61	18.23	17.72	17.84	17.98	18.21	18.18
SUM	99.66	99.40	99.90	99.95	99.77	99.58	99.84	100.41
Fe2O3	6.46	4.73	6.76	5.57	7.08	7.39	6.86	6.57
FeO	14.77	14.88	14.00	14.92	14.41	14.06	14.01	14.34
SUM	100.31	99.87	100.58	100.51	100.48	100.32	100.53	101.07

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.063	0.066	0.059	0.073	0.072	0.068	0.059	0.060
Al	14.567	14.828	14.590	14.744	14.332	14.278	14.573	14.648
Cr	0.294	0.300	0.238	0.239	0.410	0.423	0.238	0.212
Fe3	1.014	0.741	1.054	0.870	1.113	1.163	1.070	1.020
Fe2	2.576	2.592	2.425	2.589	2.517	2.460	2.430	2.472
Mn	0.002	0.005	0.004	0.007	0.000	0.000	0.000	0.002
Mg	5.485	5.468	5.630	5.478	5.555	5.607	5.629	5.587
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	60.4	62.1	61.8	61.3	60.5	60.7	61.7	61.5

SPINEL ANALYSES, CONTINUED

KA 106 SPINEL WEBSTERITE, continued

	106 43	106 5C	1065E1	1065E2	1066C1	1066C2	106 6E	106 7
TiO2	0.38	0.36	0.29	0.40	0.42	0.43	0.47	0.17
Al2O3	60.91	60.95	62.02	60.91	59.06	59.45	60.18	64.63
Cr2O3	1.27	1.15	1.17	1.14	1.69	1.72	1.65	0.88
FeO	19.93	19.43	17.79	19.22	20.34	20.12	19.33	14.05
MnO	0.03	0.00	0.05	0.01	0.00	0.01	0.03	0.05
MgO	18.11	18.37	18.58	18.20	18.40	18.15	18.20	20.20
SUM	100.63	100.26	99.90	99.88	99.91	99.88	99.86	99.98
Fe2O3	5.95	5.95	4.58	5.55	7.38	6.67	5.75	2.85
FeO	14.57	14.08	13.67	14.23	13.70	14.12	14.15	11.49
SUM	101.23	100.86	100.36	100.44	100.65	100.55	100.44	100.27

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.059	0.056	0.045	0.062	0.066	0.067	0.073	0.026
Al	14.755	14.780	15.013	14.827	14.439	14.542	14.687	15.376
Cr	0.206	0.187	0.190	0.186	0.277	0.282	0.270	0.140
Fe3	0.921	0.921	0.708	0.862	1.152	1.042	0.897	0.432
Fe2	2.505	2.422	2.348	2.457	2.376	2.451	2.451	1.940
Mn	0.005	0.000	0.009	0.002	0.000	0.002	0.005	0.009
Mg	5.548	5.634	5.688	5.603	5.689	5.615	5.617	6.078
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	61.8	62.8	65.1	62.8	61.7	61.7	62.7	71.9

SPINEL ANALYSES, CONTINUED

KA 106 SPINEL WEBSTERITE, continued

	1068C1	1068C2	1068E1	1068E2	106 9
TiO2	0.40	0.37	0.34	0.28	0.26
Al2O3	59.57	61.09	61.49	62.49	64.56
Cr2O3	1.20	1.20	1.22	1.15	0.86
FeO	20.04	19.47	18.35	17.83	13.58
MnO	0.00	0.01	0.04	0.03	0.11
MgO	18.16	18.08	18.31	18.71	20.89
SUM	99.37	100.22	99.75	100.49	100.26
Fe2O3	6.78	5.50	4.82	4.54	3.38
FeO	13.94	14.52	14.01	13.75	10.54
SUM	100.05	100.77	100.23	100.94	100.60

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.063	0.057	0.053	0.043	0.039
Al	14.616	14.837	14.947	15.031	15.275
Cr	0.198	0.196	0.199	0.186	0.136
Fe3	1.061	0.853	0.748	0.697	0.510
Fe2	2.428	2.502	2.417	2.346	1.770
Mn	0.000	0.002	0.007	0.005	0.019
Mg	5.635	5.553	5.629	5.692	6.251
Sum	24.000	24.000	24.000	24.000	24.000
M/M+F	61.8	62.3	64.0	65.2	73.3

SPINEL ANALYSES, CONTINUED

KA 103 SPINEL WEBSTERITE

	103 11	103 12	103 2	103 3	103 4
TiO2	0.22	0.21	0.25	0.30	0.33
Al2O3	62.97	62.79	62.77	62.32	62.12
Cr2O3	0.23	0.24	0.25	0.32	0.29
FeO	17.72	17.68	17.90	18.09	17.98
MnO	0.05	0.02	0.06	0.05	0.04
MgO	19.11	18.93	18.79	18.72	18.72
SUM	100.30	99.87	100.02	99.80	99.48
Fe2O3	5.15	4.97	4.93	5.11	5.10
FeO	13.08	13.21	13.47	13.49	13.39
SUM	100.82	100.37	100.51	100.31	99.99

CATIONS ON THE BASIS OF 32 OXYGENS

	103 11	103 12	103 2	103 3	103 4
Ti	0.034	0.032	0.038	0.046	0.051
Al	15.106	15.132	15.125	15.066	15.061
Cr	0.037	0.039	0.040	0.052	0.047
Fe3	0.789	0.764	0.758	0.789	0.789
Fe2	2.227	2.259	2.302	2.314	2.304
Mn	0.009	0.003	0.010	0.009	0.007
Mg	5.798	5.770	5.726	5.724	5.740
Sum	24.000	24.000	24.000	24.000	24.000
M/M+F	65.8	65.6	65.2	64.8	65.0

SPINEL ANALYSES, CONTINUED

KA 102 OLIVINE WEBSTERITE

	102 1C	102 1E	102 2C	102 2E	102 3C	102 3E	102 4C	1024E1
TiO2	0.52	0.52	0.56	0.55	0.46	0.46	0.49	0.45
Al2O3	60.14	60.21	60.27	60.14	60.53	60.65	60.16	60.63
Cr2O3	1.06	1.02	1.02	1.02	0.16	0.13	0.94	0.91
FeO	20.41	20.38	20.37	20.40	20.44	19.73	20.07	20.13
MnO	0.04	0.02	0.03	0.06	0.12	0.03	0.03	0.05
MgO	18.22	17.95	18.17	17.96	18.20	18.91	18.36	17.88
SUM	100.39	100.10	100.42	100.13	99.91	99.91	100.05	100.05
Fe2O3	6.75	6.33	6.54	6.39	7.00	7.29	6.75	5.99
FeO	14.34	14.68	14.49	14.65	14.14	13.17	14.00	14.74
SUM	101.07	100.73	101.08	100.77	100.61	100.64	100.73	100.65

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.081	0.081	0.087	0.086	0.071	0.071	0.076	0.070
Al	14.618	14.685	14.645	14.667	14.743	14.708	14.646	14.779
Cr	0.173	0.167	0.166	0.167	0.026	0.021	0.154	0.149
Fe3	1.048	0.986	1.015	0.995	1.088	1.129	1.049	0.932
Fe2	2.473	2.541	2.498	2.536	2.444	2.266	2.418	2.549
Mn	0.007	0.004	0.005	0.011	0.021	0.005	0.005	0.009
Mg	5.601	5.537	5.584	5.539	5.606	5.800	5.653	5.512
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	61.4	61.1	61.4	61.1	61.3	63.1	62.0	61.3

SPINEL ANALYSES, CONTINUED

KA 102 OLIVINE WEBSTERITE, continued

	1024E2	102 5C	102 5E	1026C1	1026C2	102 6E	102 63	102 7
TiO_2	0.52	0.52	0.50	0.44	0.49	0.45	0.42	0.12
Al_2O_3	60.38	59.13	60.18	61.04	60.36	61.19	60.83	65.60
Cr_2O_3	0.95	1.48	1.50	0.69	0.72	0.75	0.77	0.31
FeO	20.08	20.47	19.46	19.76	20.02	18.86	20.02	14.64
MnO	0.01	0.02	0.04	0.06	0.05	0.04	0.10	0.10
MgO	17.92	18.16	18.04	18.39	18.21	18.59	18.37	19.57
SUM	99.86	99.78	99.72	100.38	99.85	99.88	100.51	100.34
Fe_2O_3	6.00	7.08	5.66	6.27	6.50	5.74	6.58	2.25
FeO	14.68	14.10	14.37	14.11	14.17	13.69	14.10	12.62
SUM	100.46	100.49	100.29	101.01	100.50	100.46	101.17	100.57

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.081	0.081	0.078	0.068	0.076	0.070	0.065	0.018
Al	14.747	14.487	14.714	14.782	14.718	14.849	14.728	15.574
Cr	0.156	0.243	0.246	0.112	0.118	0.122	0.125	0.049
Fe3	0.936	1.108	0.884	0.970	1.012	0.890	1.017	0.341
Fe2	2.544	2.451	2.493	2.425	2.452	2.358	2.423	2.125
Mn	0.002	0.004	0.007	0.010	0.009	0.007	0.017	0.017
Mg	5.535	5.627	5.578	5.632	5.615	5.705	5.625	5.876
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	61.4	61.3	62.3	62.4	61.8	63.7	62.1	70.4

SPINEL ANALYSES, CONTINUED

KA 102 OLIVINE WEBSTERITE, continued

	102 8	102 9	102 10	102 11	102 12	102 13	102 14
TiO2	0.16	0.22	0.60	0.51	0.52	0.62	0.61
Al2O3	64.47	63.90	59.25	60.27	60.62	59.15	58.97
Cr2O3	0.57	0.26	0.97	1.09	0.36	0.99	1.11
FeO	16.27	18.14	20.84	20.22	20.50	20.75	20.99
MnO	0.05	0.12	0.00	0.03	0.04	0.05	0.04
MgO	18.80	17.50	18.18	17.82	18.29	18.61	18.26
SUM	100.32	100.14	99.84	99.94	100.33	100.17	99.98
Fe2O3	2.85	2.89	7.38	6.01	6.90	7.93	7.71
FeO	13.71	15.54	14.20	14.81	14.29	13.61	14.06
SUM	100.61	100.43	100.58	100.54	101.02	100.96	100.75

CATIONS ON THE BASIS OF 32 OXYGENS

	102 8	102 9	102 10	102 11	102 12	102 13	102 14
Ti	0.024	0.034	0.094	0.080	0.081	0.096	0.095
Al	15.425	15.443	14.501	14.725	14.711	14.411	14.424
Cr	0.091	0.042	0.159	0.179	0.059	0.162	0.182
Fe3	0.435	0.447	1.152	0.937	1.070	1.234	1.203
Fe2	2.327	2.664	2.467	2.568	2.460	2.353	2.440
Mn	0.009	0.021	0.000	0.005	0.007	0.009	0.007
Mg	5.689	5.349	5.627	5.506	5.613	5.734	5.649
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	67.3	63.2	60.9	61.1	61.4	61.5	60.8

SPINEL ANALYSES, CONTINUED

KA 101 COMPOSITE: DUNITE/WEBSTERITE

	101 1	101 21	101 22	101 3	101 4	101 51	101 52	101 6
TiO2	0.69	0.59	0.65	0.66	0.64	0.70	0.79	0.66
Al2O3	57.40	57.18	56.62	58.22	58.48	61.12	60.88	58.75
Cr2O3	5.21	5.68	5.71	4.35	4.03	0.41	0.43	3.84
FeO	17.21	17.43	17.47	17.42	17.18	18.12	18.79	16.97
MnO	0.00	0.00	0.00	0.00	0.00	0.07	0.09	0.00
MgO	19.17	19.07	19.05	19.59	19.25	19.10	18.90	19.30
SUM	99.68	99.95	99.50	100.24	99.58	99.52	99.88	99.52
Fe2O3	5.35	5.47	5.67	5.98	5.35	5.71	5.96	5.16
FeO	12.39	12.51	12.36	12.04	12.36	12.98	13.43	12.32
SUM	100.22	100.50	100.07	100.84	100.12	100.09	100.48	100.04

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.108	0.092	0.102	0.102	0.100	0.108	0.122	0.103
Al	14.087	14.024	13.958	14.158	14.303	14.831	14.763	14.359
Cr	0.858	0.935	0.944	0.710	0.661	0.067	0.070	0.630
Fe3	0.839	0.856	0.893	0.928	0.836	0.885	0.923	0.806
Fe2	2.158	2.177	2.163	2.078	2.146	2.235	2.310	2.137
Mn	0.000	0.000	0.000	0.000	0.000	0.012	0.016	0.000
Mg	5.950	5.915	5.939	6.025	5.954	5.861	5.796	5.966
Sum	24.000	24.000	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	66.5	66.1	66.0	66.7	66.6	65.3	64.2	67.0

SPINEL ANALYSES, CONTINUED

KA 101 COMPOSITE: DUNITE/WEBSTERITE, continued

	101 7	101 8	101 9
TiO2	0.64	0.67	0.58
Al2O3	58.40	58.24	56.94
Cr2O3	4.00	4.10	5.66
FeO	17.43	17.21	17.48
MgO	19.35	19.33	18.82
SUM	99.82	99.55	99.48
Fe2O3	5.72	5.54	5.32
FeO	12.28	12.22	12.69
SUM	100.39	100.11	100.01

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.100	0.105	0.091
Al	14.254	14.252	14.043
Cr	0.655	0.673	0.936
Fe3	0.892	0.866	0.838
Fe2	2.127	2.122	2.221
Mg	5.973	5.982	5.870
Sum	24.000	24.000	24.000
M/M+F	66.4	66.7	65.7

SPINEL ANALYSES, CONTINUED

KA 100 SPINEL DUNITE

	100 1C	100 1E	100 21	100 22	100 3	100 4
TiO2	0.78	0.74	0.76	0.74	0.70	0.75
Al2O3	32.46	32.39	32.47	32.41	32.55	32.37
Cr2O3	33.18	33.17	32.96	33.08	32.82	32.74
FeO	17.32	17.79	17.58	17.94	17.60	17.67
MgO	16.18	16.18	16.46	16.28	16.21	16.31
SUM	99.92	100.27	100.23	100.45	99.88	99.84
Fe2O3	4.59	5.03	5.25	5.30	5.02	5.26
FeO	13.19	13.26	12.85	13.17	13.08	12.93
SUM	100.38	100.77	100.76	100.98	100.38	100.37

CATIONS ON THE BASIS OF 32 OXYGENS

Ti	0.136	0.128	0.132	0.128	0.122	0.131
Al	8.856	8.814	8.820	8.800	8.877	8.830
Cr	6.073	6.055	6.006	6.025	6.004	5.992
Fe3	0.800	0.875	0.911	0.918	0.875	0.917
Fe2	2.553	2.560	2.477	2.538	2.531	2.504
Mg	5.583	5.568	5.654	5.590	5.591	5.627
Sum	24.000	24.000	24.000	24.000	24.000	24.000
M/M+F	62.5	61.8	62.5	61.8	62.1	62.2

APPENDIX H

KAULA XENOLITH OLIVINE ANALYSES

KA 107 GARNET SPINEL CLINOPYROXENITE

	1	2	3	4	5	6	7	8
	107 11	107 12	107 21	107 22	107 3	107 4	107 51	107 52
SiO2	39.54	39.59	39.68	39.27	39.40	39.42	39.43	39.25
FeO	15.40	14.65	15.22	15.93	15.46	14.63	14.95	15.92
MnO	0.17	0.16	0.19	0.24	0.19	0.15	0.16	0.19
MgO	44.71	45.07	44.81	44.16	44.44	45.05	45.20	44.30
CaO	0.20	0.24	0.20	0.25	0.22	0.24	0.24	0.24
NiO	0.17	0.11	0.14	0.13	0.12	0.14	0.02	0.14
SUM	100.19	99.82	100.24	99.98	99.83	99.63	100.00	100.04

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.994	0.995	0.996	0.993	0.995	0.993	0.991	0.991
Fe2	0.324	0.308	0.319	0.337	0.326	0.308	0.314	0.336
Mn	0.004	0.003	0.004	0.005	0.004	0.003	0.003	0.004
Mg	1.676	1.689	1.676	1.664	1.672	1.692	1.693	1.668
Ca	0.005	0.006	0.005	0.007	0.006	0.006	0.006	0.006
Ni	0.003	0.002	0.003	0.003	0.002	0.003	0.000	0.003
Sum	3.006	3.005	3.004	3.007	3.005	3.007	3.009	3.009
M/M+F	83.8	84.6	84.0	83.2	83.7	84.6	84.3	83.2

OLIVINE ANALYSES, CONTINUED

KA 107 GARNET SPINEL CLINOPYROXENITE, continued

	9	10
	107 53	107 6
SiO2	39.63	39.71
FeO	15.40	15.38
MnO	0.17	0.14
MgO	44.86	44.47
CaO	0.21	0.22
NiO	0.17	0.11
SUM	100.44	100.03

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.994	0.999
Fe2	0.323	0.324
Mn	0.004	0.003
Mg	1.677	1.667
Ca	0.006	0.006
Ni	0.003	0.002
Sum	3.006	3.001
M/M+F	83.8	83.7

OLIVINE ANALYSES, CONTINUED

KA 105 GARNET CLINOPYROXENITE

	1	2	3	4
	105 1	105 2	105 3	105 4
SiO2	39.18	38.88	39.21	39.49
FeO	17.97	18.47	17.46	16.85
MnO	0.10	0.14	0.20	0.15
MgO	42.58	42.51	42.24	42.35
CaO	0.19	0.11	0.13	0.16
NiO	0.17	0.14	0.19	0.15
SUM	100.19	100.25	99.43	99.15

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.996	0.991	1.003	1.009
Fe2	0.382	0.394	0.373	0.360
Mn	0.002	0.003	0.004	0.003
Mg	1.614	1.615	1.610	1.612
Ca	0.005	0.003	0.004	0.004
Ni	0.003	0.003	0.004	0.003
Sum	3.004	3.009	2.997	2.991
M/M+F	80.9	80.4	81.2	81.8

OLIVINE ANALYSES, CONTINUED

KA 108A WEBSTERITE/GARNET SPINEL WEBSTERITE

	1	2
	108A1	108A2
SiO2	38.65	38.67
FeO	20.59	20.61
MnO	0.23	0.20
MgO	39.90	39.95
CaO	0.11	0.10
NiO	0.08	0.11
SUM	99.56	99.64

CATIONS ON THE BASIS OF 4 OXYGENS

Si	1.001	1.001
Fe2	0.446	0.446
Mn	0.005	0.004
Mg	1.541	1.542
Ca	0.003	0.003
Ni	0.002	0.002
Sum	2.999	2.999
M/M+F	77.5	77.6

OLIVINE ANALYSES, CONTINUED

KA 106 SPINEL WEBSTERITE

	1
	106 1
SiO2	39.12
FeO	18.42
MnO	0.18
MgO	42.58
CaO	0.11
SUM	100.41

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.994
Fe2	0.392
Mn	0.004
Mg	1.613
Ca	0.003
Sum	3.006
M/M+F	80.5

OLIVINE ANALYSES, CONTINUED

KA 103 SPINEL WEBSTERITE

	1	2	3
	103 1	103 2	103 3
SiO2	39.27	39.50	39.51
FeO	15.62	15.32	15.19
MnO	0.07	0.08	0.09
MgO	44.41	44.81	44.90
CaO	0.12	0.12	0.08
NiO	0.18	0.16	0.18
SUM	99.67	99.99	99.95

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.993	0.994	0.994
Fe2	0.330	0.322	0.320
Mn	0.001	0.002	0.002
Mg	1.674	1.681	1.684
Ca	0.003	0.003	0.002
Ni	0.004	0.003	0.004
Sum	3.007	3.006	3.006
M/M+F	83.5	83.9	84.0

OLIVINE ANALYSES, CONTINUED

KA 110A WEBSTERITE (CPXITE W/ EXSOLVED OPX)

	1	2	3	4	5	6
	110A11	110A12	110A 2	110A 3	110A 4	110A 5
SiO2	39.64	39.56	39.74	39.27	39.83	39.79
FeO	15.93	16.35	15.24	16.16	14.49	14.75
MnO	0.24	0.23	0.22	0.23	0.20	0.20
MgO	44.23	44.31	44.58	44.07	45.28	45.29
CaO	0.17	0.19	0.18	0.22	0.22	0.21
NiO	0.16	0.14	0.16	0.11	0.18	0.19
SUM	100.37	100.78	100.12	100.06	100.20	100.43

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.997	0.993	0.999	0.993	0.997	0.995
Fe2	0.335	0.343	0.320	0.342	0.303	0.308
Mn	0.005	0.005	0.005	0.005	0.004	0.004
Mg	1.658	1.658	1.670	1.660	1.689	1.688
Ca	0.005	0.005	0.005	0.006	0.006	0.006
Ni	0.003	0.003	0.003	0.002	0.004	0.004
Sum	3.003	3.007	3.001	3.007	3.003	3.005
M/M+F	83.2	82.8	83.9	82.9	84.8	84.6

OLIVINE ANALYSES, CONTINUED

KA 102 OLIVINE WEBSTERITE

	1	2	3	4	5	6	7
	102 1	1021R	102 2	102 3	102 4	102 5	102 6
SiO2	39.52	39.37	39.31	39.32	39.42	39.30	39.16
FeO	17.42	17.62	17.30	17.34	17.38	17.41	17.36
MnO	0.16	0.18	0.14	0.17	0.15	0.18	0.18
MgO	43.36	43.19	43.58	43.29	42.94	43.08	43.34
CaO	0.10	0.07	0.10	0.07	0.08	0.08	0.10
NiO	0.23	0.23	0.20	0.22	0.25	0.29	0.21
SUM	100.79	100.66	100.63	100.41	100.22	100.34	100.35

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.996	0.995	0.992	0.995	0.999	0.996	0.992
Fe2	0.367	0.372	0.365	0.367	0.368	0.369	0.368
Mn	0.003	0.004	0.003	0.004	0.003	0.004	0.004
Mg	1.629	1.627	1.640	1.633	1.622	1.627	1.637
Ca	0.003	0.002	0.003	0.002	0.002	0.002	0.003
Ni	0.005	0.005	0.004	0.004	0.005	0.006	0.004
Sum	3.004	3.005	3.008	3.005	3.001	3.004	3.008
M/M+F	81.6	81.4	81.8	81.6	81.5	81.5	81.6

OLIVINE ANALYSES, CONTINUED

KA 101 COMPOSITE: DUNITE/WEBSTERITE

	1	2	3	4	5	6	7	8
	101D11	101D12	101D 2	101W 3	101W 4	101D51	101D52	101D53
SiO2	39.61	39.61	39.68	39.39	39.51	39.51	39.81	39.63
FeO	13.64	13.66	13.77	13.78	13.93	13.90	14.03	14.05
MnO	0.20	0.13	0.16	0.15	0.18	0.21	0.14	0.15
MgO	45.67	45.90	45.84	45.64	45.56	45.68	45.69	45.50
CaO	0.10	0.08	0.09	0.10	0.10	0.07	0.11	0.10
NiO	0.20	0.13	0.16	0.34	0.31	0.23	0.33	0.28
SUM	99.42	99.51	99.70	99.40	99.59	99.60	100.11	99.71

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.996	0.994	0.995	0.992	0.993	0.993	0.996	0.995
Fe2	0.287	0.287	0.289	0.290	0.293	0.292	0.293	0.295
Mn	0.004	0.003	0.003	0.003	0.004	0.004	0.003	0.003
Mg	1.711	1.717	1.713	1.713	1.707	1.711	1.703	1.703
Ca	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.003
Ni	0.004	0.003	0.003	0.007	0.006	0.005	0.007	0.006
Sum	3.004	3.006	3.005	3.008	3.007	3.007	3.004	3.005
M/M+F	85.6	85.7	85.6	85.5	85.4	85.4	85.3	85.2

OLIVINE ANALYSES, CONTINUED

KA 100 SPINEL DUNITE

	1	2	3	4	5	6	7	8
	100 1	1001C	1001E	100 2	1002C	1002E	100 3	1003C
SiO2	40.43	40.60	40.18	40.60	40.68	40.29	40.42	40.51
FeO	9.44	9.54	9.28	9.65	9.68	9.52	9.90	9.48
MnO	0.13	0.13	0.14	0.09	0.09	0.10	0.12	0.12
MgO	49.42	49.41	49.44	49.56	49.65	49.18	48.99	49.27
CaO	0.07	0.07	0.07	0.06	0.07	0.04	0.08	0.09
NiO	0.29	0.30	0.27	0.33	0.31	0.39	0.30	0.31
SUM	99.78	100.05	99.38	100.29	100.48	99.52	99.81	99.78

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.993	0.995	0.991	0.993	0.993	0.993	0.995	0.995
Fe2	0.194	0.195	0.191	0.197	0.198	0.196	0.204	0.195
Mn	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.002
Mg	1.809	1.805	1.817	1.807	1.807	1.807	1.797	1.804
Ca	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
Ni	0.006	0.006	0.005	0.006	0.006	0.008	0.006	0.006
Sum	3.007	3.005	3.009	3.007	3.007	3.007	3.005	3.005
M/M+F	90.3	90.2	90.5	90.2	90.1	90.2	89.8	90.3

OLIVINE ANALYSES, CONTINUED

KA 100 SPINEL DUNITE, continued

	9	10
	1003E	100 4
SiO2	40.33	40.60
FeO	10.32	9.55
MnO	0.11	0.06
MgO	48.71	49.34
CaO	0.08	0.07
NiO	0.29	0.27
SUM	99.84	99.89

CATIONS ON THE BASIS OF 4 OXYGENS

Si	0.994	0.996
Fe2	0.213	0.196
Mn	0.002	0.001
Mg	1.789	1.804
Ca	0.002	0.002
Ni	0.006	0.005
Sum	3.006	3.004
M/M+F	89.4	90.2

APPENDIX I

KAULA XENOLITH GLASS ANALYSES

KA 107 GARNET SPINEL CLINOPYROXENITE

	107 1	107 2	7 1,2	7 3A	7 3B	7 4A-1	7 4A-2	7 4A
SiO2	47.51	47.03	46.73	46.60	46.59	45.59	45.69	45.27
TiO2	1.06	1.38	0.96	1.26	1.08	1.18	1.24	1.07
Al2O3	18.78	18.20	18.98	18.79	19.43	19.21	19.34	19.17
Fe2O3	1.61	1.66	1.70	1.75	1.67	1.74	1.71	1.79
FeO	10.72	11.01	11.29	11.65	11.14	11.60	11.38	11.91
MnO	0.00	0.00	0.30	0.31	0.00	0.00	0.00	0.29
MgO	6.24	6.50	6.05	6.10	6.59	6.68	6.31	6.61
CaO	11.22	10.82	11.49	11.44	11.09	11.44	11.62	11.29
Na2O	1.46	1.47	1.02	1.15	1.15	1.06	1.11	1.00
K2O	0.74	0.94	0.51	0.61	0.51	0.55	0.56	0.54
P2O5	0.24	0.26	0.22	0.32	0.29	0.46	0.44	0.43
Sum	99.58	99.27	99.24	99.98	99.54	99.51	99.40	99.37
CIPW Norms								
Or	4.4	5.6	3.0	3.6	3.0	3.3	3.3	3.2
Ab	12.4	12.5	8.7	9.7	9.8	9.0	9.4	8.5
An	42.7	40.6	46.1	44.3	46.6	46.3	46.4	46.5
Pl	55.1	53.1	54.7	54.0	56.3	55.3	55.9	55.0
Di	9.7	9.8	8.3	8.6	5.6	6.4	7.2	5.8
Hy	11.2	9.8	15.4	13.4	13.5	11.7	11.5	12.2
Ol	4.3	6.4	1.1	3.6	3.4	6.6	5.8	7.6
Mt	2.3	2.4	2.5	2.5	2.4	2.5	2.5	2.6
Il	2.0	2.6	1.8	2.4	2.1	2.3	2.4	2.0
Ap	0.6	0.6	0.5	0.8	0.7	1.1	1.0	1.0
DI	16.8	18.1	11.7	13.3	12.8	12.3	12.8	11.7
An	77.5	76.4	84.1	82.0	82.6	83.7	83.1	84.5
Mg No	47.7	48.1	45.7	45.1	48.2	47.5	46.5	46.6

GLASS ANALYSES, CONTINUED

KA 107 GARNET SPINEL CLINOPYROXENITE, continued

	7 4B	7 PBR1	7 PBR2	7 P BR	7 ORAN	7 ORAN	7PBR1N	7PBR2N
SiO2	45.89	40.64	40.64	45.81	43.13	47.40	43.21	42.16
TiO2	1.26	2.04	2.07	1.25	1.38	1.23	2.17	2.15
Al2O3	18.86	15.72	15.83	18.51	9.01	9.13	16.71	16.42
Fe2O3	1.75	1.80	1.97	1.56	2.64	2.46	1.92	2.05
FeO	11.65	11.99	13.12	10.40	17.58	16.37	12.75	13.61
MnO	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	5.93	7.50	7.88	6.54	0.35	0.20	7.97	8.18
CaO	11.84	11.12	11.47	10.63	1.61	1.43	11.82	11.90
Na2O	1.00	2.04	2.19	1.87	0.30	0.24	2.17	2.27
K2O	0.46	0.72	0.61	0.89	0.87	0.81	0.77	0.63
P2O5	0.32	0.48	0.61	0.02	0.00	0.00	0.51	0.63
Sum	99.24	94.05	96.39	97.48	76.87	79.27	99.99	99.99
CIPW Norms								
Q	0.0	0.0	0.0	0.0	27.9	34.9	0.0	0.0
Cd	0.0	0.0	0.0	0.0	6.0	6.6	0.0	0.0
Or	2.7	4.5	3.7	5.4	6.7	6.0	4.6	3.7
Ab	8.5	9.7	7.5	16.2	3.3	2.6	9.7	7.5
An	46.0	33.6	32.7	40.5	10.4	8.9	33.6	32.8
Ne	0.0	4.7	6.4	0.0	0.0	0.0	4.7	6.3
Pl	54.5	43.3	40.2	56.7	13.7	11.5	43.2	40.2
Di	9.3	17.9	18.3	11.1	0.0	0.0	17.9	18.3
Hy	13.9	0.0	0.0	3.4	36.2	32.8	0.0	0.0
Ol	2.8	21.5	22.9	15.1	0.0	0.0	21.5	22.9
Mt	2.6	2.8	3.0	2.3	5.0	4.5	2.8	3.0
Il	2.4	4.1	4.1	2.4	3.4	2.9	4.1	4.1
Ap	0.8	1.2	1.5	0.0	0.0	0.0	1.2	1.5
DI	11.3	18.9	17.6	21.6	37.9	43.5	18.9	17.6
An	84.4	77.7	81.4	71.4	75.9	77.7	77.7	81.4
Mg No	44.4	49.5	48.5	49.7	3.0	1.9	49.5	48.6

GLASS ANALYSES, CONTINUED

KA 108A,B WEBSTERITE/ GARNET SPINEL WEBSTERITE

	108B1A	8B 1B	8B 1C	8B 2A	8B 2B	8B 3A	8B 3B
SiO2	47.54	47.66	47.97	47.71	47.39	47.92	47.56
TiO2	0.94	0.88	0.78	0.77	0.90	0.70	0.96
Al2O3	19.01	18.55	19.14	19.33	19.31	19.29	18.55
Fe2O3	1.68	1.58	1.66	1.70	1.75	1.70	1.65
FeO	11.19	10.49	11.06	11.30	11.62	11.29	10.99
MnO	0.40	0.37	0.34	0.37	0.38	0.38	0.37
MgO	6.08	6.14	5.89	5.83	5.98	5.95	6.05
CaO	12.14	12.31	12.49	12.31	12.16	12.21	12.00
Na2O	0.42	0.55	0.39	0.22	0.23	0.18	0.56
K2O	0.09	0.14	0.08	0.06	0.07	0.05	0.19
P2O5	0.29	0.24	0.27	0.25	0.25	0.24	0.26
Sum	99.78	98.90	100.07	99.85	100.04	99.90	99.14
CIPW Norms							
Q	4.0	3.8	4.4	5.0	4.4	5.3	3.7
Or	0.5	0.8	0.5	0.4	0.4	0.3	1.1
Ab	3.6	4.7	3.3	1.9	1.9	1.5	4.8
An	49.8	48.3	50.2	51.7	51.4	51.7	48.0
Pl	53.4	53.0	53.5	53.5	53.4	53.3	52.7
Di	7.2	9.9	8.3	6.6	6.0	6.1	8.6
Hy	16.4	14.8	16.0	16.9	17.4	17.2	15.7
Mt	2.4	2.3	2.4	2.5	2.5	2.5	2.4
Il	1.8	1.7	1.5	1.5	1.7	1.3	1.8
Ap	0.7	0.6	0.6	0.6	0.6	0.6	0.6
DI	8.1	9.4	8.2	7.2	6.7	7.1	9.6
An	93.3	91.1	93.8	96.5	96.4	97.1	90.9
Mg No	46.0	47.9	45.5	44.7	44.7	45.3	46.4

GLASS ANALYSES, CONTINUED

KA 109 GARNET WEBSTERITE

	109 1	109 2	109 3
SiO2	48.24	47.32	48.74
TiO2	1.17	1.14	1.30
Al2O3	19.59	20.31	18.97
Fe2O3	1.46	1.44	1.34
FeO	9.74	9.59	8.91
MnO	0.35	0.27	0.32
MgO	5.46	5.91	5.32
CaO	11.03	11.00	10.67
Na2O	1.00	0.90	1.58
K2O	1.49	1.27	1.53
P2O5	0.25	0.23	0.31
Sum	99.78	99.38	98.99
CIPW Norms			
Q	0.5	0.0	0.0
Or	8.8	7.6	9.1
Ab	8.5	7.7	13.5
An	44.7	47.9	40.6
Pl	53.1	55.6	54.1
Di	7.1	4.5	9.0
Hy	13.5	13.7	11.3
Ol	0.0	0.5	0.4
Mt	2.1	2.1	2.0
Il	2.2	2.2	2.5
Ap	0.6	0.5	0.7
DI	17.8	15.2	22.6
An	84.0	86.2	75.0
Mg No	46.8	49.2	48.4

GLASS ANALYSES, CONTINUED

KA 110 A,B WEBSTERITE (CLINOPYROXENITE W/ EXSOLVED OPX)

	B 2	B 3	B 4
SiO2	48.86	48.50	49.24
TiO2	0.54	0.62	0.72
Al2O3	19.72	19.54	19.36
Fe2O3	1.38	1.37	1.37
FeO	9.19	9.15	9.14
MnO	0.33	0.34	0.34
MgO	5.43	5.43	5.24
CaO	11.94	11.78	11.48
Na2O	0.86	0.90	1.11
K2O	0.86	0.89	1.09
P2O5	0.35	0.33	0.31
Sum	99.46	98.85	99.40
CIPW Norms			
Q	2.9	2.6	2.5
Or	5.1	5.3	6.5
Ab	7.3	7.7	9.4
An	47.7	47.2	44.9
Pl	55.0	54.9	54.3
Di	8.0	8.1	8.6
Hy	13.4	13.3	12.9
Mt	2.0	2.0	2.0
Il	1.0	1.2	1.4
Ap	0.8	0.8	0.7
DI	15.3	15.6	18.4
An	86.7	86.0	82.6
Mg No	48.1	48.2	47.4

REFERENCES

Arculus, R.J., 1975, Melting behavior of two basanites in the range 10-35 kbar and the effect of TiO2 on the olivine-diopside reactions at high pressures: Carneg. Inst. Wash. Yrbk, v.74, p.512-515

Beeson, M.H. and Jackson, E.D., 1970, Origin of the garnet pyroxenite xenoliths at Salt Lake Crater, Oahu: Min. Soc. Amer. Spec. Paper 3, p.95-112

Bell. P.M. and Davis, B.T.C., 1969, Melting relations in the system jadeite- diopside at 30 and 40 kilobars: Am. J. Sci., p.17-32

Chapman, N.A., 1975, An experimental study of spinel clinopyroxenite xenoliths from the Duncansby Ness Vent, Caithness, Scotland: Contrib. Min. Petrol., v.51, p.223-230

Coombs, D.S., 1963, Trends and affinities of basaltic magmas and pyroxenes as illustrated on the diopside-olivine-silica diagrams: Min. Soc. Amer. Spec. Paper 1, p.227-250

Dawson, J.B., 1981, The nature of the upper mantle: Mineral. Mag., v.44, p.1-18

Deer, W.A., Howie, R.A., and Zussman, J., 1966, An introduction to the rock forming minerals: Longman Group Limited, London, 528 p.

Faerseth, R.B., 1978, Mantle-derived lherzolite xenoliths and megacrysts from Permo-Triassic dykes, Sunnhordland, western Norway: Lithos, v.11, p.23-35

Frey, F.A., 1980, The origin of pyroxenites and garnet pyroxenites from Salt Lake Crater, Oahu, Hawaii: trace element evidence: Am. J. Sci., v.280-A, pt.2, p.427-449

Frey, F.A. and Green, D.H., 1974, The mineralogy, geochemistry, and origin of lherzolite inclusions in Victorian basanites: Geochim. Cosmochim. Acta, v.38, p.1023-1059

Ghent, E.D., Coleman, R.G., and Hadley, D.G., 1980, Ultramafic inclusions and host alkali olivine basalts of the southern coastal plain of the Red Sea, Saudi Arabia: Am. J. Sci., v.280-A, pt.2, p.499-527

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

Grooms, D.G., 1980, Contributions to the petrography, geochemistry, and geochronology of volcanic rocks from along and near the western Hawaiian ridge and Kaula Island, Hawaiian chain: M.S. Thesis, Univ. Hawaii, 97 p.

Haggerty, S.E., 1979, Spinels in high pressure regimes: The Mantle Sample: Inclusions in Kimberlites and Other Volcanics, Amer. Geophy. Union, Washington, D.C., p.183-196

Helz, R.T., 1979, Glass-bearing pyroxenites from Salt Lake Crater, Oahu: Hawaii Symposium on Intraplate Volcanism and Submarine Volcanism, Abstract Volume, p.87

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: Contrib. Min. Petrol., v.66, p.375-382

Irving, A.J., 1980, Petrology and geochemistry of composite ultramafic xenoliths in alkalic basalts and implications for magmatic processes within the mantle: Amer. Jour. Sci., v.280-A, p.389-426

Jackson, E.D., 1966, Eclogite in Hawaiian basalts: USGS Prof. Paper 550-D, p.D151-D157

Jackson, E.D. and Wright, T.L., 1970, Xenoliths in the Honolulu Volcanic Series, Hawaii: J. Petrol., v.11, pt.2, p.405-430

Kuno, H., 1969, Mafic and ultramafic nodules in basaltic rocks of Hawaii: Geol. Soc. Am. Memoir 115, p. 189-234

Kuno, H., 1969, Mafic and ultramafic nodules from Itinome-gata, Japan, in: Ultramafic and Related Rocks, ed. P.J. Wyllie, R.E. Krieger Publ. Co., N.Y., p.337-342

Kushiro, I. and Yoder, H.S. Jr., 1966, Anorthite-forsterite and anorthite-enstatite reactions and their bearing on the basalt-eclogite transformation: J. Petrol., v.7, p.337-62

Macdonald, G.A. and Abbott, A.T., 1977, Volcanoes in the Sea, The Geology of Hawaii: The University of Hawaii Press, Honolulu, 441 p.

Macgregor, I.D., 1974, The system MgO-Al2O3-SiO2: solubility of Al2O3 in enstatite for spinel and garnet peridotite compositions: Am. Mineral., v.59, p. 110-119

Medaris, L.G. Jr., 1972, High-pressure peridotites in southwestern Oregon: G.S.A. Bull., v.83, p.41-58

O´Hara, M.J., 1963, Melting of bimineralic eclogite at 30 kilobars: Carneg. Inst. Wash. Yrbk v.62, p.76-77

O´Hara, M.J. and Yoder, H.S. Jr., 1967, Formation and fractionation of basic magmas at high pressures: Scott. J. Geol., p.67-117

Palmer, H.S., 1927, Geology of Kaula, Nihoa, Necker, and Gardner Islands, amd French Frigate Shoal: B.P. Bishop Museum Bull. 35, 35 p.

Palmer, H.S., 1936, Geology of Lehua and Kaula Islands: B.P. Museum Occas. Papers, v.12, no.13, p.3-36

Pike, J.E.N. and Schwarzman, E.C., 1977, Classification of textures in ultramafic xenoliths: J. Geol., v.85, p.49-61

Reid, J.B. Jr. and Eggleton, M., 1977, The detailed chemistry of the reaction sp + px = gt + ol in pyroxenite inclusions from Salt Lake Crater, Hawaii: Second Internat´l Kimberlite Conference, Extended Abstracts, no page number

Ringwood, A.E., 1975, Composition and petrology of the Earth´s mantle: McGraw-Hill, Inc., San Francisco, 618 p.

Roeder, P.L. and Emslie, R.F., 1970, Olivine-liquid equilibrium: Contrib. Min. Petrol., v.29, p.275-289

Sen, G., 1981, Petrology of the ultramafic xenoliths on the Koolau Shield: Part 1 of PhD Dissertation, Univ. Texas Dallas, 166p.

Shervais, J.W., Wilshire, H.G., and Schwarzman, E.C., 1973, Garnet clinopyroxenite xenolith from Dish Hill, California: Earth Planet. Sci. Lett., v.19, p.120-130

Simkin, T. and Smith, J.V., 1970, Minor-element distribution in olivine: J. Geol., v.78, p.304-325

Takahashi, E., 1980, Thermal history of lherzolite xenoliths- I. Petrology of lherzolite xenoliths from the Ichinomegata crater, Oga peninsula, northeast Japan, Geochim. Cosmochim. Acta, v.44, p.1643-1658

Wass, S., 1979, Multiple origins of clinopyroxenes in alkalic basaltic rocks: Lithos, v.12, p.115-132

White, R.W., 1966, Ultramafic inclusions in basaltic rocks from Hawaii: Contrib. Min. Petrol., v.12, p.245-314

Wilkinson, J.F.G., 1976, Some subcalcic clinopyroxenites from Salt Lake Crater, Oahu, and their petrogenetic significance: Contrib. Min. Petrol., v.58, p.181-201

Wright,T.L. and Doherty, P.C., 1970, A linear programming and least squares computer method for solving petrologic mixing problems: G.S.A. Bull., v.81, p.1995-2008