Pyroxene–ilmenite intergrowths in garnet pyroxenite xenoliths from a New York kimberlite and Arizona latites

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Abstract

Lamellar pyroxene–ilmenite intergrowths in garnet pyroxenite xenoliths from a kimberlite in Ithaca, New York, and from Tertiary latites near Prescott, Arizona, may represent a link between exsolution intergrowths in pyroxenes from layered basic intrusions and intergrowths in pyroxene xenocrysts from kimberlites presently interpreted to result from eutectic crystallization.

Introduction

Nodules of pyroxene–ilmenite intergrowths from kimberlites have received much attention because many investigators believe them to be unique to these rocks. They have also been thought to be possible indicators of the depth of origin of kimberlites. Such intergrowths are best known from African pipes (for reviews, see Gurney *et al.*, 1973; Boyd and Nixon, 1973), but have also been described from the Mir pipe in Yakutia (Ilupin *et al.*, 1973), and two North American localities: the Stockdale pipe, Kansas (Brookins, 1971; Gurney *et al.*, 1973; McCallister *et al.*, 1975), and kimberlites in the southern Laramie Range, Wyoming (McCallum *et al.*, 1975; Smith *et al.*, 1976).

The origin of these intergrowths is still uncertain. The proposed mechanisms of formation are eutectoid transformation of garnet (Ringwood and Lovering, 1970), exsolution from an ilmenite-structured pyroxene (Dawson and Reid, 1970), eutectic crystallization (Williams, 1932; MacGregor and Wittkop, 1970; Gurney *et al.*, 1973; Boyd and Nixon, 1973; Smith *et al.*, 1976; Wyatt, 1977; and others), and cotectic crystallization (Frick, 1973). Although the intergrowth textures are compatible with all of these mechanisms, an origin by eutectic crystallization is currently fa-

vored (see references above) for four reasons: (1) textural similarities to alloys formed by eutectic crystallization (Boyd, 1971); (2) restricted compositional range of the intergrown phases; (3) an apparent low solubility of TiO_2 in pyroxenes at high pressures (Akella and Boyd, 1973); and (4) experimental production of texturally similar intergrowths by eutectic crystallization (Wyatt *et al.*, 1975; Wyatt, 1977).

Natural terrestrial pyroxene–ilmenite intergrowths are not restricted to kimberlites, but are also common in pyroxenes from cumulates in layered basic intrusions (Morse, 1969; Deer and Abbott, 1965; Haselton and Nash, 1975). As noted by Gurney *et al.* (1973), these intergrowths have a strong textural resemblance to the kimberlitic intergrowths, yet their origin by subsolidus exsolution is generally accepted.

In this paper we intend to demonstrate that pyroxene–ilmenite intergrowths in kimberlites may also originate by exsolution. Two new intergrowth occurrences are described, one from a kimberlite dike in Ithaca, New York, and the other from Tertiary latites near Prescott, Arizona. As in other kimberlitic intergrowths, textural evidence for an origin by exsolution is ambiguous in the Ithaca sample. However, unlike most kimberlitic occurrences, the intergrowth-bearing clinopyroxene from Ithaca is not a xenocryst, but occurs as grains in a garnet pyroxenite xenolith which compositionally resembles garnet pyroxenite xenoliths from the Arizona latites. Ilmenite lamellae in

clino- and orthopyroxenes of the Arizona xenoliths resemble those found in pyroxenes from layered intrusions and can be shown to have originated by exsolution. From the compositional similarity of the Ithaca and Arizona xenoliths we propose that an exsolution origin of the intergrowth from the Ithaca kimberlite is a distinct possibility.

Garnet clinopyroxenite from Ithaca, New York

A small garnet clinopyroxenite xenolith containing clinopyroxene–ilmenite intergrowths was collected in October 1976 from a 3-foot wide kimberlite dike outcropping in the Cascadilla Gorge on the campus of Cornell University, Ithaca, New York. Eighty-two such dikes and several small diatremes are known from 24 localities in the central Finger Lakes region, New York. They are thought to be of Late Jurassic or Early Cretaceous age, and their geologic setting has been described by Martens (1924), Sheldon (1927), and Foster (1970). The host rocks and a variety of xenocrysts, including garnets, clinopyroxenes, chromites, and ilmenites were studied by Foster (1970). Foster and Reitan (1972) concluded that the host rocks are kimberlites on the basis of textures, mineralogy, and chemical composition. Ultramafic xenoliths have not been reported previously, though Foster (1970) mentioned the rare occurrence of a dark-green diopside attached to garnets.

The intergrowth-bearing garnet clinopyroxenite occurs in a kimberlite sample containing several smaller phlogopite-bearing and garnet-bearing xenoliths as well as inclusions of a chrome-rich spinel with diopside. The ovoid xenolith has the approximate dimensions of $1.5 \times 0.75 \times 1.0$ cm, and consists of a relatively large almandine-rich garnet with several equant clinopyroxene grains approximately 3 mm in diameter. Chemical analyses of the mineral phases are presented in Table 1. The clinopyroxene contains fine discontinuous ilmenite lamellae (Fig. 1a) which have partly altered to sphene.

Grains of ilmenite which differ in composition from the lamellae occur interstitially and as inclusions in the garnet. The garnet also has small inclusions of clinopyroxene containing somewhat more TiO_2 than the clinopyroxene host to the ilmenite lamellae (Table 1). Minor granular garnet occurs in the lamellae-bearing clinopyroxene, and (?) secondary amphibole is also present in the xenolith.

Garnet pyroxenites from Chino Valley, Paulden Quadrangle, Arizona

Tertiary latites of the Sullivan Buttes Latite described by Krieger (1965) and Krieger *et al.* (1971) contain a rich variety of ultramafic xenoliths including metamorphic eclogites, garnet clinopyroxenites, garnet websterites, phlogopite-bearing websterite, and garnet–amphibole rocks. Most of the xenoliths belonging to the garnet pyroxenite family come from two of the latite units sampled. The xenoliths in this group have angular to rounded shapes and range in diameter from a few mm to 5 cm. They are very fresh and appear to have reacted slightly or not at all with the host magma. Of more than 15 garnet pyroxenite specimens examined in thin section, 4 garnet clinopyroxenites and 2 garnet websterites were found to contain pyroxenes with "ilmenite" intergrowths.

Garnet clinopyroxenites

These xenoliths consist of relatively coarse clinopyroxene porphyroclasts (up to 2 cm in diameter) set

Table 1. Mineral analyses from Ithaca garnet clinopyroxenite (62-5)

Average of n	1 n=14	2 n=1	3 n=1	4 n=4	5 n=5	6 n=7	7 n=5
Na_2O^X	0.1	0.3	0.4	0.4	1.3	1.6	2.3
MgO	9.2	2.2	1.7	5.6	14.0	12.9	12.2
Al_2O_3	21.8	0.3	0.5	0.8	2.2	4.4	12.9
SiO_2	39.0	0.2	0.5	0.5	52.5	51.2	41.2
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	1.8
CaO	5.7	0.0	0.0	0.1	22.1	21.0	11.5
TiO_2**	0.1	41.3	37.9	46.1	0.2	0.5	2.6
Cr_2O_3	0.1	0.3	0.3	0.3	0.1	0.1	0.1
MnO	0.6	0.0	0.0	0.7	0.1	0.2	0.1
FeO*	24.2	54.2	57.9	45.5	7.9	8.3	12.6
Anhydrous total	100.8	98.8	99.2	100.0	100.4	100.2	97.3

X   the effective detectability limit of Na_2O is approximately 0.5 wt %

*   electron microprobe analyses, total Fe reported as FeO

** TiO_2 values are not accurate to more than 5 relative wt %

1. garnet
2. large interstitial granular ilmenite in garnet
3. tiny ilmenite as rods and dots in garnet
4. ilmenite lamellae in clinopyroxene
5. clinopyroxene host to ilmenite lamellae
6. clinopyroxene inclusion in garnet
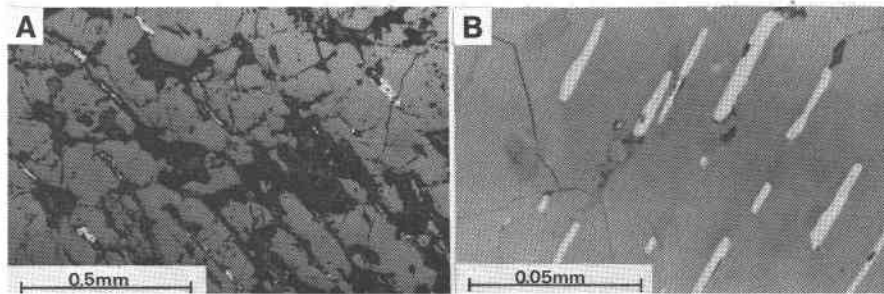7. amphibole (chlorine detected but not analysed)

Fig. 1. (a) Ilmenite lamellae (highly reflective) intergrown with clinopyroxene, from Ithaca, sample 62-5. Dark irregular spots are holes in the section. Reflected light. (b) "Ilmenite" lamellae in clinopyroxene, showing two phases differing in reflectivity. Sample 1-2, Arizona garnet clinopyroxenite. Reflected light.

in a matrix of fine-grained granular clinopyroxene and garnet. Most samples contain secondary amphiboles. Clinopyroxene porphyroclasts with lamellar intergrowths of one or all of the minerals garnet, "ilmenite," and orthopyroxene have been recognized. Due to their narrow width, we have not been able to obtain good chemical analyses of the "ilmenite" lamellae, but calculations from silicate-contaminated

Table 2. Mineral analyses from Arizona garnet clinopyroxenite (1-2)

Average of n	1 n=8	2 n=10	3 n=17	4 n=14	5 n=16	6 n=16
Na_2O^X	1.7	1.4	0.2	0.2	1.3	0.5
MgO	14.6	15.1	9.3	9.2	14.8	27.4
Al_2O_3	2.7	1.9	21.8	21.7	3.0	1.7
SiO_2	53.3	53.7	39.2	39.1	52.7	54.1
K_2O	0.0	0.0	0.0	0.0	0.0	0.0
CaO	21.3	22.1	5.6	5.7	20.3	0.8
TiO_2	0.2	0.1	0.1	0.1	0.2	0.1
Cr_2O_3	0.2	0.2	0.2	0.2	0.2	0.0
MnO	0.1	0.1	0.8	0.8	0.1	0.2
FeO*	6.3	5.5	23.6	22.9	7.2	15.3
Anhydrous total	100.4	100.1	100.8	99.9	99.8	100.1

X   the effective detectability limit of Na_2O is
     approximately 0.5 wt %

*   electron microprobe analyses, total Fe reported
     as FeO

1.   lamellae-free clinopyroxene

2.   lamellae-bearing clinopyroxene

3.   granular garnet

4.   lamellar garnet

5.   clinopyroxene intergrown with orthopyroxene

6.   orthopyroxene intergrown with clinopyroxene

analyses show that they are Fe–Ti oxides with TiO_2 contents ranging from less than 5 to slightly above 40 weight percent. Under reflected light, most of the lamellae are seen to consist of two phases (Fig. 1b), presumably one Fe-rich, the other Ti-rich, that probably originated from the breakdown of an originally homogeneous Fe–Ti oxide. Two-phase lamellae were also noted from kimberlite xenocrysts by MacGregor and Wittkop (1970) and Mitchell et al. (1973). Apart from occasional fine orthopyroxene exsolution lamellae, the fine-grained granular clinopyroxenes are lamellae-free.

Four types of intergrowth relationships can be distinguished (for chemical analyses of different phases, see Table 2):

(1) Clinopyroxene with planar lamellae or bead-like strings of garnet and fine lamellae of "ilmenite" parallel to (100) (determined on the universal stage). Although most clinopyroxene grains show only one set of "ilmenite" lamellae, a second set was recognized in rare cases under reflected light. Some grains show, in addition, very thin orthopyroxene lamellae which are also parallel to (100). Garnet lamellae are many times thicker than the "ilmenite" lamellae (Fig. 2b) which, when viewed perpendicular to the plane of the thin section, have a width of up to 10 microns. Most of the lamellae consist of discontinuous plates, some of which are elongated (Figs. 2a, 2c).

As most sections are oblique to the plane of the lamellae, the proportion of lamellar "ilmenite" can easily be over-estimated. From sections normal to the lamellae it can be seen, however, that the modal content of the intergrown phase rarely exceeds 5 percent.

Host pyroxenes and lamellae have been deformed together, as seen by bent lamellae, undulatory extinction, and kinkbands in the host grains. All stages between undulatory extinction and complete recrystallization of the clinopyroxene hosts can be ob-
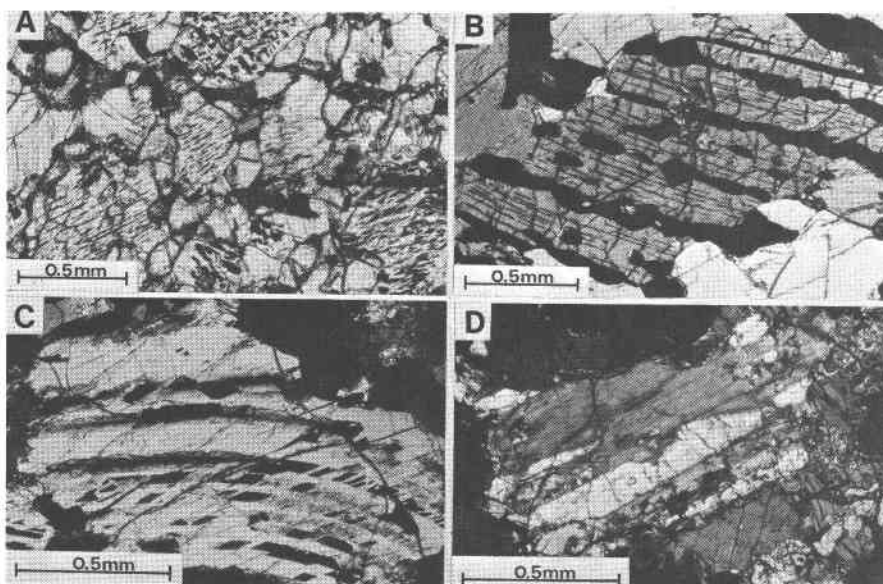
Fig. 2. (a) Sample 1-2, showing granular nature of the xenolith. Clinopyroxene is present with no exsolution lamellae, "ilmenite" lamellae only, and both "ilmenite" and garnet lamellae. Granular garnet, oxides and minor amphibole are also present. Plane polarized transmitted light. (b) Clinopyroxene porphyroclast with "ilmenite" lamellae (narrow and almost vertical) surrounded by granular garnet and lamellae-free clinopyroxene. From clinopyroxene-rich portion of Arizona garnet websterite 54-17. Transmitted light, crossed nicols. (c) Bent exsolution lamellae of "ilmenite" (black parallelograms) and garnet (grey to black, depending on thickness) in orthopyroxene porphyroclast from orthopyroxene-rich portion of Arizona garnet websterite 54-17. Transmitted light, crossed nicols. (d) Lamellar intergrowth of orthopyroxene and clinopyroxene from Arizona xenolith 50-1. Orthopyroxene is lighter than clinopyroxene, and shows fracturing approximately perpendicular to length of the lamellae. Transmitted light, crossed nicols.

served. In the latter case, remnants of garnet lamellae are the only indication that larger clinopyroxenes existed previously. Some xenoliths show evidence of complete recrystallization of all minerals. Chemical compositions of host grains and recrystallized clinopyroxenes are compared in Table 2.

(2) Clinopyroxene with garnet lamellae only. Except for the absence of "ilmenite" lamellae, host grains and garnet lamellae resemble Type 1 in terms of chemical composition and all aspects of deformation and recrystallization.

(3) Clinopyroxene with "ilmenite" lamellae only. These grains are smaller than Types 1 and 2, but may also be strained and partly recrystallized. Lamellae are generally confined to the centers of grains and resemble in all aspects the "ilmenite" lamellae of Type 1. Under transmitted light some obliquely-cut grains give the impression that two sets of lamellae are common (Fig. 2a). However, all such grains which were examined under the universal stage and in reflected light revealed only one set.

(4) Clinopyroxene with coarse orthopyroxene lamellae (Fig. 2d). Clinopyroxene grains with up to 50 percent exsolved orthopyroxene lamellae are smaller than Types 1 and 2. They occur in separate domains interspersed with granular garnet and secondary am-

phibole. In one section (not yet analyzed), numerous grains of this type of pyroxene occur between remnants of garnet exsolution lamellae (Fig. 3), suggesting that these grains recrystallized from an earlier large clinopyroxene which had exsolved garnet. Exsolution of orthopyroxene occurred after the recrystallization of this earlier clinopyroxene. Locally, the present intergrowth has recrystallized, in turn, to form a fine-grained mosaic of clino- and orthopyroxene. A rough reconstruction of the chemical composition, using the composition of the present intergrowth (Table 2) and a clino- to orthopyroxene ratio of 50:50 (based on 27 120-sec electron microprobe traverses approximately perpendicular to the lamellae), indicates that the CaO content of the earlier phase was approximately 10.8 weight percent after garnet exsolution. Considering that the exsolved garnet contains about 5 weight percent CaO (Table 2), this suggests that the CaO content of the original phase must have been somewhat less than 10 weight percent.

Garnet websterites

Garnet websterites have textures similar to those of the garnet clinopyroxenites and contain clinopyroxenes with all intergrowth types described from them.
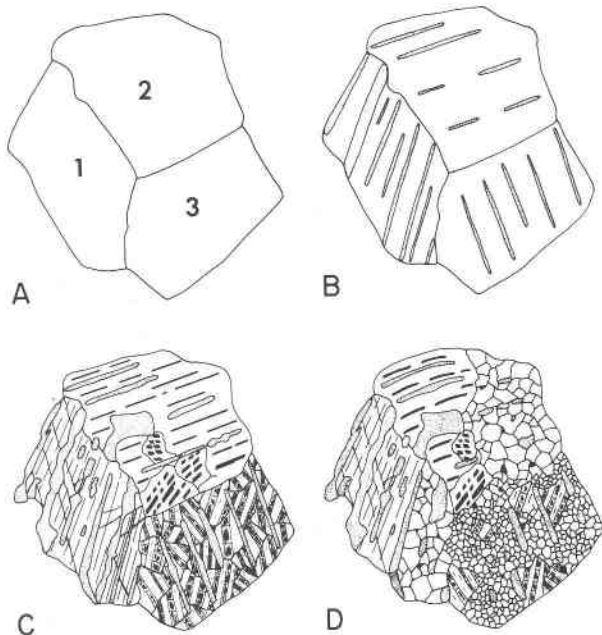
Fig. 3. Schematic drawing of textural evolution of pyroxenes in garnet websterite from Arizona. (Cluster of grains 2–3 mm in diameter.)

A. Three coexisting aluminous pyroxenes: (1) orthopyroxene; (2) calcic clinopyroxene; (3) subcalcic clinopyroxene.

B. Exsolution of lamellar garnet in all pyroxenes.

C. Further exsolution and partial recrystallization.

Orthopyroxene: continuation of garnet exsolution, formation of "ilmenite" lamellae parallel to garnet lamellae. Plane of drawing is perpendicular to lamellae. Lamellae bisect prismatic cleavage.

Calcic clinopyroxenes: continuation of garnet exsolution, partial recrystallization followed by "ilmenite" exsolution. Plane of drawing somewhat oblique to lamellae in original clinopyroxene, but highly oblique to blade-like lamellae in recrystallized grains.

Subcalcic clinopyroxene: continuation of garnet exsolution, recrystallization of pyroxene between garnet lamellae followed by formation of clino- and orthopyroxene intergrowth. Note cross fractures in orthopyroxene. Granular opaques may be recrystallized exsolution lamellae.

D. Deformation and recrystallization.

Orthopyroxene: recrystallization into granular orthopyroxene, garnet, and "ilmenite."

Clinopyroxene: bending of garnet and "ilmenite" lamellae, recrystallization into granular clinopyroxene, garnet, and "ilmenite."

Subcalcic clinopyroxene: recrystallization of ortho-clinopyroxene intergrowth into fine-grained mosaic of ortho- and clinopyroxene. Some garnet lamellae survive in recrystallized mosaic.

The chemical compositions of these phases are also reasonably similar (Table 3). Additional phases are deformed orthopyroxene porphyroclasts (Fig. 2c) with garnet and "ilmenite" lamellae parallel to (100) as well as recrystallized orthopyroxene grains without lamellae (Table 3). Orthopyroxene with only "ilme-

nite" lamellae have not been recognized. The different pyroxenes occur in domains which appear to occupy the former positions of coarser porphyroclasts.

Textural history and origin of lamellae in Arizona samples

The subsolidus history outlined on Figure 3 suggests that the pyroxene–"ilmenite" intergrowths formed by exsolution. All calcic clinopyroxene porphyroclasts contain garnet with or without "ilmenite" lamellae, but a number of smaller clinopyroxene grains contain "ilmenite" lamellae only, indicating that garnet exsolution was followed by partial recrystallization of the pyroxene before "ilmenite" exsolution commenced. These recrystallized clinopyroxene grains exsolved "ilmenite" only. No orthopyroxene–"ilmenite" intergrowths lacking garnet lamellae were observed, suggesting that orthopyroxene did not recrystallize prior to exsolution of "ilmenite." Such behavior conforms with commonly observed pyroxene deformation textures indicating that orthopyroxene has a greater resistance to recrystallization than clinopyroxene.

Following "ilmenite" exsolution, both ortho- and clinopyroxene were intensely deformed and recrystallized, leaving only remnants of porphyroclasts. The "ilmenite" probably formed separate grains and most of the garnet lamellae transformed into granular garnet at this stage. Secondary amphibole formed last. The subcalcic clinopyroxene also exsolved garnet first, was deformed, recrystallized, and orthopyroxene exsolved from the recrystallized grains. As no remnants of the original subcalcic clinopyroxene have been observed, it is impossible to definitely determine whether "ilmenite" exsolution ever took place in the subcalcic pyroxene. However, granular ilmenite in the matrix may be the result of recrystallization of lamellar "ilmenite."

Discussion

Considering their derivation from different host rocks at widely separated localities, the ilmenite-bearing clinopyroxenes and accompanying garnets in the garnet clinopyroxenites from Ithaca and Arizona have surprisingly similar chemical compositions (Tables 1–3). The Arizona samples have strong textural resemblances to garnet pyroxenite xenoliths from basalts in Hawaii (Beeson and Jackson, 1970) and at Dish Hill, California (Shervais et al., 1973), but they differ from these rocks by the presence of "ilmenite" lamellae, an inferred additional original pyroxene

Table 3. Mineral analyses from Arizona garnet websterite (54-17)

Average of n	1 n=6	2 n=10	3 n=14	4 n=6	5 n=6	6 n=9	7 n=6	8 n=10	9 n=6	10 n=9	11 n=9
Na_2O^X	0.5	0.5	0.2	0.4	1.3	1.3	0.2	0.2	2.7	1.1	0.5
MgO	27.8	27.8	10.3	10.8	15.5	15.1	10.3	10.4	15.7	15.0	30.3
Al_2O_3	1.1	1.2	21.8	21.9	1.6	2.0	21.8	21.8	11.5	4.0	1.8
SiO_2	54.4	54.3	39.4	39.5	54.3	53.9	39.5	39.4	44.1	52.3	55.9
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0
CaO	0.2	0.2	5.2	5.1	22.3	22.1	5.3	5.3	9.9	20.4	1.1
TiO_2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.5	0.3	0.1
Cr_2O_3	0.1	0.1	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.2	0.1
MnO	0.2	0.2	0.8	0.7	0.1	0.0	0.9	0.7	0.1	0.1	0.1
FeO*	15.7	16.2	22.2	22.1	5.2	5.4	22.1	22.1	9.4	6.5	11.4
Anhydrous total	100.0	100.6	100.4	101.0	100.7	100.2	100.5	100.3	96.6	99.9	101.3

X   the effective detectability limit of Na_2O is approximately 0.5 wt %

*   electron microprobe analyses, total Fe reported as FeO

1. recrystallized lamellae-free orthopyroxene
2. lamellae-bearing orthopyroxene
3. garnet lamellae in orthopyroxene
4. granular garnet around orthopyroxene
5. lamellae-bearing clinopyroxene
6. recrystallized lamellae-free clinopyroxene
7. garnet lamellae in clinopyroxene
8. granular garnet around clinopyroxene
9. amphibole
10. clinopyroxene intergrown with orthopyroxene
11. orthopyroxene intergrown with clinopyroxene

phase, and lower whole-rock Mg/(Mg + Fe) values.

The intergrowth-bearing pyroxenes from the Ithaca and Arizona samples are more calcic and slightly more Fe-rich than intergrowth-bearing kimberlite xenocrysts, which have a relatively restricted compositional range (Fig. 4). The ilmenite lamellae of the Ithaca clinopyroxene (Table 1) are poorer in MgO than lamellae from most previously-described kimberlite xenocrysts, but contain more MgO than ilmenite intergrowths in orthopyroxenes from gabbros (Haselton and Nash, 1975). As the MgO content of the "ilmenite" lamellae appears to be systematically related to that of the orthopyroxene (Haselton and Nash, 1975), we expect that the lamellae of the Arizona samples have an MgO content similar to that of the Ithaca sample. Aside from these differences, our pyroxene–"ilmenite" intergrowths are much smaller than those found as nodules from kimberlites, where they reach several centimeters in diameter. The weight percent ilmenite in our samples is generally lower than for those from other kimberlite nodules,

which have pyroxene–ilmenite ratios ranging from 10:1 to 1:1 (Haggerty et al., 1977). However, ignoring the differences in scale, a definite textural similarity between kimberlitic and the intergrowths in this study exists (see Plate 67A of Gurney et al., 1973).

Haselton and Nash (1975) pointed out that intergrowth textures which are ambiguous by themselves can be properly interpreted only if the geological environment of formation is known. Therefore, it is perhaps not surprising that "ilmenite" lamellae in pyroxenes from gabbroic rocks are explained by exsolution (Morse, 1969; Haselton and Nash, 1975), because enough geological constraints exist to make this explanation most plausible. On the other hand, most intergrowth-bearing nodules from kimberlites are single crystals of clino- or orthopyroxene whose original mineral assemblage and textural history are unknown. Compelling evidence for exsolution does not exist, leaving other modes of origin as viable alternatives (see references in "Introduction"). The wide acceptance of an origin by eutectic recrys-
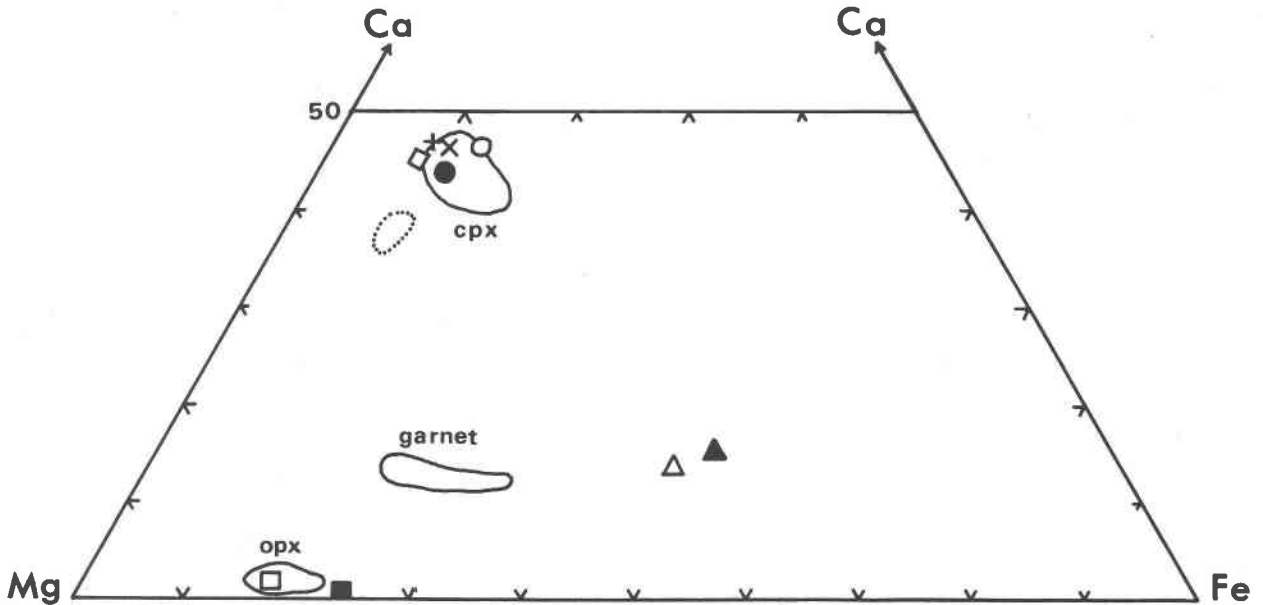
Fig. 4. Lower portion of a Ca–Mg–Fe ternary plot showing distribution of garnets, clinopyroxenes, and orthopyroxenes. Open triangle represents all garnets from 54-17 (lamellar and granular, associated with both opx and cpx); filled triangle represents garnet from 62-5 and both lamellar and granular garnets from 1-2; open square represents the orthopyroxene in the lamellar opx–cpx intergrowth from 54-17; the filled square represents the orthopyroxenes with and without lamellae from 54-17 and from the lamellar opx–cpx intergrowth from 1-2; the open circle represents the clinopyroxene from 62-5 (both inside the garnet and as host to ilmenite lamellae); the X represents the lamellae-bearing clinopyroxene from 1-2, and the cross represents the lamellae-free clinopyroxene from 1-2; the open diamond represents both lamellae-free and lamellae-bearing clinopyroxene from 54-17; the filled circle represents the clinopyroxene from the lamellar cpx–opx intergrowths in 1-2 and 54-17.

The solid lines enclose the fields of opx, cpx, and garnet from garnet pyroxenite xenoliths from Oahu, Hawaii (Beeson and Jackson, 1970) and Dish Hill, California (Shervais et al., 1973). The dotted line encloses the field of clinopyroxenes intergrown with ilmenite lamellae from kimberlites in Yakutia (Ilupin et al., 1973), South Africa (Boyd, 1971), and Wyoming (Smith et al., 1976).

62-5: Ithaca, New York garnet clinopyroxenite
1-2: Arizona garnet clinopyroxenite
54-17: Arizona garnet websterite.

tallization for kimberlitic intergrowths (see "Introduction") has led to the impression that exsolution of ilmenite is restricted to pyroxenes from shallow intrusions, whereas eutectic crystallization leading to pyroxene–ilmenite intergrowth is a high-pressure phenomenon.

Although we have not yet obtained satisfactory P–T estimates, our Arizona samples certainly show that exsolution of ilmenite occurs in pyroxenes from deep-seated rocks. Lacking definite textural constraints, we cannot prove an exsolution origin of the lamellae in the kimberlite xenolith from Ithaca. Such an origin is nevertheless suggested by the similarity in mineral compositions of the Arizona and Ithaca xenoliths.

Exsolution should not be rejected as a possible mechanism of formation of other kimberlitic intergrowths. As noted before, Haselton and Nash (1975) found that in pyroxene–ilmenite intergrowths the MgO content of the ilmenite is systematically related to that of the orthopyroxene. The intergrowths described here conform to this systematic distribution, and are intermediate between the more iron-rich intergrowths from the Skaergaard intrusion and the more magnesian pyroxene–ilmenite pairs from a lunar breccia and kimberlites. Whereas estimates of equilibration temperatures based on pyroxene compositions yield values of 1150–1165°C for kimberlitic intergrowths (Smith et al., 1976), estimates based on the distribution of magnesium between coexisting ilmenite and pyroxene (Anderson et al., 1972) are 930–950°C and 720°C for the kimberlitic and Skaergaard intergrowths, respectively (Haselton and Nash, 1975). These latter temperatures are consistently lower than expected crystallization temperatures of the pyroxenes, implying that the intergrowths may not be the result of eutectic crystallization, but of subsolidus equilibration.

Acknowledgments

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