THE CLASSIFICATION AND RECONNAISANCE PETROGRAPHY OF BASALTIC ACHONDRITES FROM THE YAMATO 1979 COLLECTION INCLUDING PIGEONITE CUMULATE EUCRITES, A NEW GROUP

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Abstract: Eighteen Yamato basaltic achondrites have been examined and preliminary descriptions are given. They include eucrites, polymict eucrites, howardites and a new group of pyroxene-rich meteorites here described as pigeonite cumulate eucrites. Most of these meteorites are similar to previously known basaltic achondrites. The pigeonite cumulate eucrites contain more feldspar and glass than the diogenites and more pigeonitic pyroxene than the previously known pyroxene-rich cumulate Binda. They may be similar to the pyroxene-rich Y-75032. The achondrites studied sample almost all the types of basaltic achondrites known and deserve further study to constrain models of parent body genesis.

1. Introduction

Many basaltic achondrites have been identified among the 3000+ meteorite specimens collected at Yamato Mountains during the 1979 collecting season. Sixteen new specimens from the 1979 collection and two samples from the 1974 collection were examined and classified using petrographic and electron microprobe techniques. These specimens sample several subgroups within the basaltic achondrite suite and include a new subgroup of pyroxene-rich meteorites that had not been previously recognized.

2. Modal Analyses

Modal compositions of all the thin sections studied were determined using an automated electron microprobe (ARL-SEMQ) (Table 1). Details of the technique have been given by PRINZ *et al.* (1980) and DELANEY *et al.* (1983c). The assignment of three pyroxene types does *not* imply that three pyroxene polymorphs were recognized by crystallographic study. Orthopyroxene is taken to be any pyroxene with wollastonite less than 5% mol; pigeonite has wollastonite between 5% and 20% mol and augite has more than 20% mol wollastonite component. As a result of overlaps under the electron beam, specimens containing very fine augite lamellae in an orthopyroxene host appear

Table 1. Modes of new Yamato basaltic achondrites in order of decreasing feldspar content.

	791195,91-1 E	792510 E	74356 E	791960 PE	791201 PCE[a]	791192,91-1 PE	791186 PE	791074 H	791492 H[b]	791073 PCE	791573 H[b]
Olivine	—	—	—	0.1	—	—	—	1.65	2.5	—	5.1
Orthopyroxene	32.2	27.8	8.5	15.7	43.6	30.6	34.2	38.2	49.0	44.5	52.8
Pigeonite	6.7	11.2	40.9	32.6	8.2	21.8	12.8	25.4	17.0	12.4	14.5
Augite	9.2	12.0	5.7	9.2	10.0	11.3	13.1	5.8	5.8	13.2	4.9
Feldspar	46.5	43.2	42.9	38.7	36.4	32.5	32.3	25.5	23.2	21.5	19.7
Silica	4.9	4.1	1.1	2.7	0.9	2.6	6.5	2.0	1.3	6.3	1.2
Ilmenite	0.1	1.1	0.8	0.3	0.1	0.2	0.5	tr	0.2	—	0.5
Chromite	0.3	0.2	0.2	0.1	0.3	0.5	0.3	1.1	0.5	0.5	0.9
Phosphate	—	0.1	—	tr	tr	0.2	—	—	—	—	0.4
Troilite	—	0.4	tr	0.7	0.4	0.1	0.3	0.3	0.5	1.0	0.1
Kamacite	—	—	—	—	—	0.1	—	—	—	—	—
Area mm^2	110.1	50.8	47.6	67.9	64.4	53.7	42.0	22.8	52.2	12.6	55.8
# points	912	909	898	1017	759	903	923	972	930	579	934

	791208 H[b]	791200 PCE[a]	791072 PCE[c]	791199 PCE	791422 PCE[c]	791000 PCE[c]	74097 D	Polymict eucrite means Yamato	EET	ALH
Olivine	3.3	—	—	—	—	—		0.7	—	tr
Orthopyroxene	53.2	65.0	65.3	79.0	61.9	65.7	96.7	8.2	24.4	12.1
Pigeonite	17.3	15.5	15.8	8.1	29.0	26.7	—	34.4	23.3	27.1
Augite	4.1	6.5	5.1	5.3	4.0	3.7	—	12.4	7.8	13.1
Feldspar	19.5	10.4	5.7	4.9	4.2	2.7	0.1	38.8	40.8	43.0
Silica	1.2	0.9	5.6	1.4	—	0.9	0.7	3.5	3.7	3.6
Ilmenite	0.1	tr	0.2	—	—	—	—	0.8	0.7	0.5
Chromite	0.7	1.12	0.3	0.5	0.4	0.2	1.1	0.2	0.1	0.2
Phosphate	tr	—	0.3	0.1	—	—	—	0.2	—	0.1
Troilite	0.6	0.1	1.5	0.3	0.1	0.2	1.6	0.5	0.1	0.1
Kamacite	tr	—	0.2	—	—	—	—	—	tr	0.1
Area mm^2	118.6	72.7	26	46.3	17.8	96.2	85.2	—	—	—
# points	1012	762	584	968	558	752	554	—	—	—

Note for Table 1.

1. E=eucrite; PE=polymict eucrite; PCE=pigeonite cumulate eucrite; H=howardite; D=diogenite.
2. a, b, c superscripts identify sections paired provisionally on the basis of modal, mineralogical and textural data.
3. Use of "pigeonite" includes both true pigeonite and orthopyroxene-clinopyroxene overlaps and, hence, represent a systematic *overestimate* of pigeonite abundance.

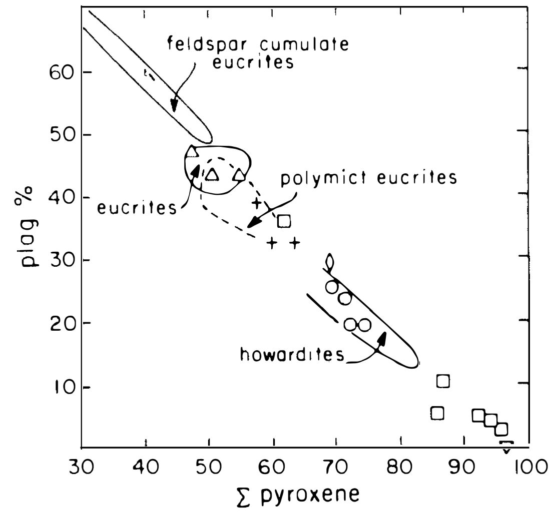

Fig. 1. Total modal pyroxene vs. plagioclase contents of Yamato basaltic achondrites for comparison with previously studied meteorites. Symbols are: triangles=eucrites; crosses=polymict eucrites; circles=howardites; squares=pigeonite cumulate eucrites; inverted triangle=Y-74097; diamond=Binda.

to contain more modal "pigeonite" and less modal orthopyroxene and augite than would be recognized by other methods.

The modes of the studied thin sections vary from typically eucritic (43–46% feldspar+48–53% pyroxene) to diogenitic (>95% orthopyroxene) and reflect the modal diversity of the basaltic achondrites as a group. In Fig. 1 the modal pyroxene/plagioclase abundances of these specimens are compared to previously determined basaltic achondrite modes from Antarctica and elsewhere (DELANEY *et al.*, 1984c). Note that several specimens fall between the most pyroxenite-rich howardite (Y-7308) and the diogenites. To permit very rapid analysis, the modal program used does not perform ZAF corrections and mineral identifications are based on uncorrected raw count rates. When the BENCE and ALBEE (1968) correction procedures are applied to the modal data, there is very little change in the relative proportions of the three pyroxene components and, in general, excellent agreement is found between the analyses of the mode (2 seconds count time) and conventional microprobe analyses using longer count times and more precise operating conditions.

The glass phase present in some of the pyroxene-rich samples is not explicitly identified by the modal program and is generally misidentified as pigeonite. It is not yet possible to distinguish all the glass analyses in the mode from analyses of overlaps of pyroxene and feldspar. Estimates of the glass abundance, based on correlation of the modal analyses, the composition range of the glass and optical examination of the thin sections studied suggests that up to half of the pigeonite in some of these modes may be glass and the quoted abundances of orthopyroxene, augite and feldspar are slight overestimates because of misidentification of the glass phase. The relative abundances of orthopyroxene, augite and feldspar appear, however, to be unaffected. The real abundance of intermediate, pigeonitic, pyroxene compositions is probably lower than the quoted values by factors of 1/4 to 1/2 in some modes and these data should, therefore, be treated with caution. The modal data indicate, however, that much of the glass is essentially pigeonite in composition.

3. Eucrites

Three of the specimens studied are eucrites. These are Yamato-74356, -792510 and -791195.

(1) *Y-74356* has been discussed extensively elsewhere (TAKEDA, 1979; TAKEDA *et al.*, 1979a, 1981) and is included here only for comparison with the two other eucrites. Modally Y-74356 is similar to the non Antarctic eucrites (DELANEY *et al.*, 1984c; PRINZ *et al.*, 1980) but has more "pigeonite" than either orthopyroxene or augite relative to the other pyroxene composition ranges (Table 1). Only the rapidly cooled Pasamonte has a comparably high pigeonite content. This section (62-2) of Y-74356 also has remarkably low contents of little quartz or tridymite (1.1%) and other minor phases. It is not clear whether this represents a bias caused by the breccia-rich nature of the sample studied or if it is an intrinsic property of this meteorite.

Y-74356,62-2 contains abundant mineral clasts and no large lithic fragments. Few relicts of the original igneous texture may be seen but those visible suggest that Y-74356 originally crystallized as a coarse subophitic to granular eucritic rock. One large pyroxene clast (Fig. 2) has embayments and cracks filled with recrystallized pyroxene and plagioclase perhaps resulting from shock recrystallization or by reaction between this clast and an interstitial melt phase.

The pyroxene, plagioclase, ilmenite and chromite of Y-74356 were analyzed using the electron microprobe. Pyroxene analyses are identical to data given by TAKEDA *et al.* (1981). One noteworthy feature of the pyroxene, however, is the generally high CaO

Fig. 2. Micrograph of Y-74356,62-2 eucrite showed embayed, partially molten pyroxene clast. Long dimension of photo is 5 mm, plane polarized light.

of the host pigeonite indicating that the modal abundance of "pigeonite" in this section is not an artifact of the modal technique, but approximates the true pigeonite content. Many of the exsolution lamellae present are too fine to be easily analyzed by electron microprobe and data from TAKEDA *et al.* (1981) obtained using ATEM are more useful than the microprobe analyses. Feldspar in Y-74356 is of fairly uniform composition (Mean: $An_{91.6}Or_{0.3}$) ranging from $An_{89}Or_{0.4}$ to $An_{92}Or_{0.2}$ with rare areas having higher alkali contents (Fig. 3). Oxides are prominent in the thin section studied and analyses of ilmenite (Table 2) have higher MgO than many eucrites (*e.g.* BUNCH and KEIL, 1972). The chromite of Y-74356 is also notable for its high TiO_2 content, a feature of chromite in Ibitira (STEELE and SMITH, 1976) and Reckling Peak A80224 (SCORE *et al.*, 1982). Whether this high TiO_2 is present as a Ti-spinel phase or as very fine exsolved ilmenite or rutile requires further study. Most phases are compositionally

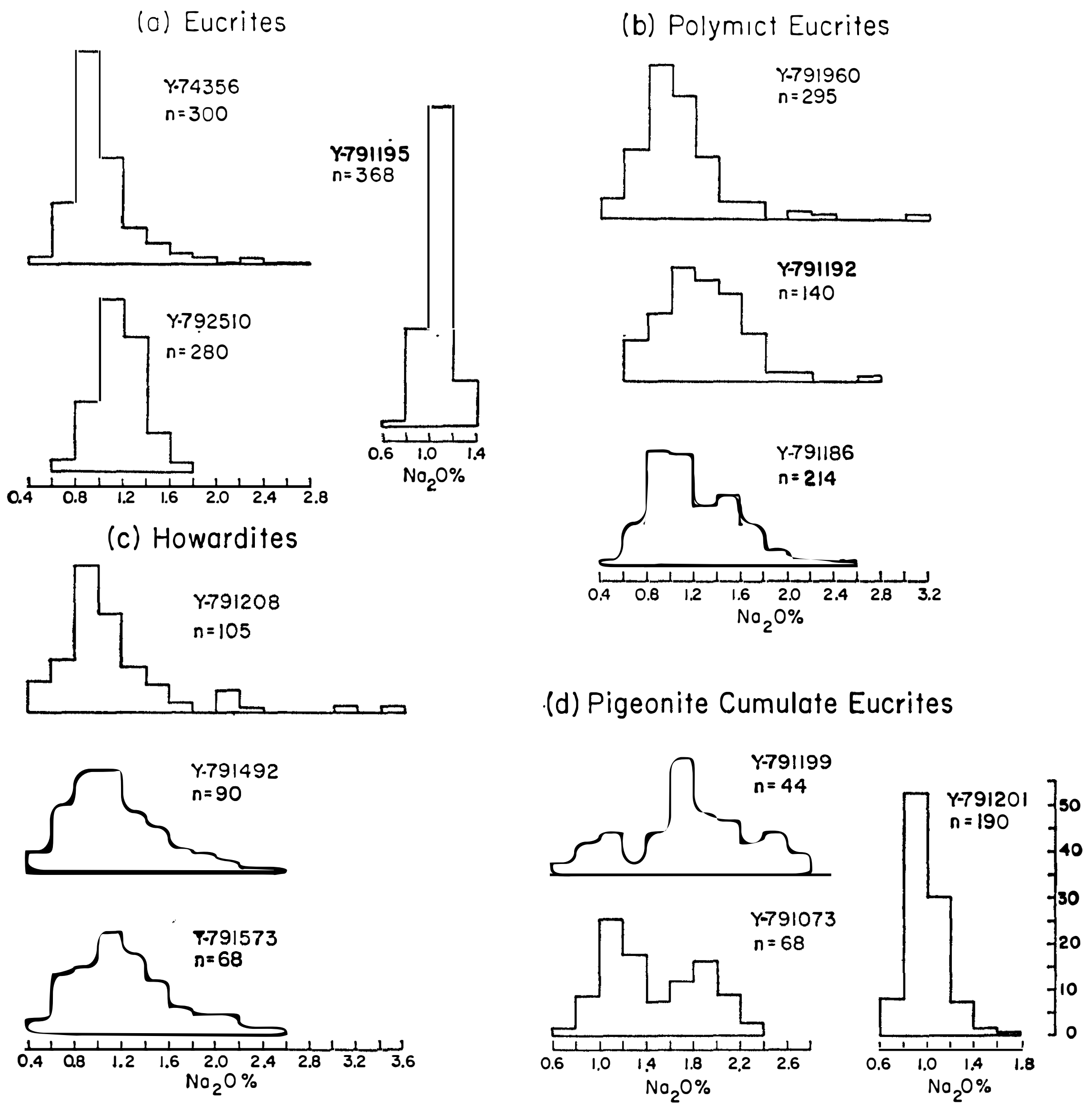

Fig. 3. Histograms of feldspar Na_2O content for 12 Yamato achondrite specimens.

Table 2. Mineral composition data for eucrites.

	(a) Y-74356				(b) Y-792510						
	$feld_1$	$feld_2$	ilm	cm	low Ca host	augite lamellae	$feld_1$	$feld_2$	ilm	cm	$apat^+$
P_2O_5	—	—	—	—	—	—	—	—	—		41.4
SiO_2	45.0	46.0	0.04	0.05	50.3	50.9	47.8	45.5	0.10	0.03	0.3
TiO_2	nd	nd	52.5	9.90	0.17	0.24	nd	nd	52.0	3.29	nd
Al_2O_3	36.8	35.6	nd	6.41	0.19	0.80	34.6	35.4	nd	7.8	1.2
Cr_2O_3	na	na	0.19	43.6	0.13	0.21	na	na	nd	52.8	na
FeO	0.3	0.38	45.5	39.8	34.0	14.5	0.23	0.69	45.9	35.0	1.80
MnO	na	na	0.83	0.64	1.36	0.62	na	na	0.93	0.67	na
MgO	0.1	0.12	1.18	0.95	11.8	10.0	0.10	0.23	0.48	0.40	0.16
CaO	18.4	18.1	bd	bd	0.93	20.6	16.3	17.5	bd	bd	53.2
Na_2O	0.79	1.17	na	na	nd	0.06	1.72	1.18	na	na	0.05
K_2O	0.04	0.07	na	na	na	na	0.19	0.07	na	na	na
Total	101.5	101.3	100.24	101.35	98.9	97.9	101.00	100.64	99.41	99.99	101.8^+
En/An	92.6	89.1	—		37.4	30.3	83.0	88.7	—	—	
Wo/Or	0.25	0.41	—		2.1	45.0	1.15	0.39	—	—	

	(c) Y-791195					
	pyroxene host	pyroxene lamellae	plag	ilm	cm_1	cm_2
SiO_2	49.8	51.0	45.5	0.05	0.08	0.09
TiO_2	0.28	0.37	bd	51.6	10.2	15.9
Al_2O_3	0.16	0.58	34.5	bd	7.4	4.8
Cr_2O_3	0.16	0.26	bd	0.73	44.0	34.5
FeO	32.0	16.1	0.16	45.5	38.2	44.5
MnO	1.12	0.59	bd	0.87	0.65	0.7
MgO	13.4	11.0	bd	1.19	1.05	1.07
CaO	2.28	19.9	18.5	<0.10	<0.1	<0.1
Na_2O	<0.10	<0.10	1.13	na	na	na
K_2O	na	bd	0.07	na	na	na
Total	99.2	99.76	99.96	100.1	101.7	101.7
En/An	40.7	32.1	89.7	—	—	—
Wo/Or	4.97	41.7	0.4	—	—	—

Notes: + includes 3.5% F and 0.17% Cl.
bd: below detection; na: not analyzed.

fairly homogeneous suggesting that they have been thermally annealed, as is also suggested by clouding of both pyroxene and plagioclase (HARLOW and KLIMENTIDIS, 1980).

(2) *Y-792510* is a slightly brecciated eucrite that still shows well developed subophitic textures (Fig. 4). Both pyroxene and plagioclase are coarse grained (up to 3 mm long grains) with variable fracturing and contain minor clouding. The mode of Y-792510 is very similar to a typical eucrite (Table 1). Pyroxene is coarsely exsolved and has beautifully developed "herring-bone" textures (Fig. 5). The number of exsolution lamellae in the host increases toward the edges. The pyroxenes originally crystallized with significant Ca zoning, having pigeonite cores and more augitic rims (*cf.* Stannern,

Fig. 4. Micrograph of Y-792510 eucrite showing general subophitic texture. Long axis is 5 mm, plane polarized light.

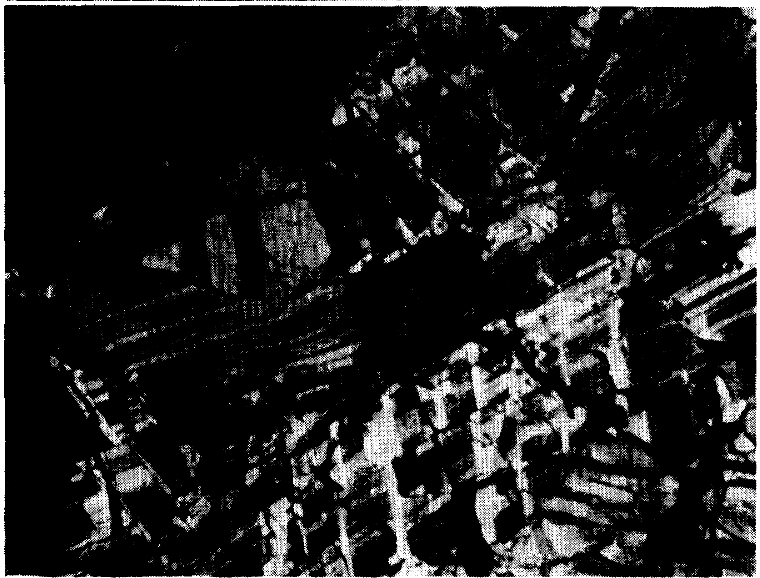

Fig. 5. Micrograph of Y-792510 pyroxene exsolution. Grain core is occupied by plagioclase. Long axis is 0.9 mm, crossed polarizers.

Fig. 6. Micrograph of Y-791195 eucrite showing gabbroic texture. Long axis is 5 mm, plane polarized light.

Fig. 7. Micrograph of Y-791195 simple lamellar exsolution and swarms of oriented inclusions. Long axis is 0.9 mm, crossed polarizers.

Fig. 8. Micrograph of Y-791186 polymict eucrite showing clasts of two contrasting pyroxene types. Long axis is 5 mm, plane polarized light.

Fig. 9. Orthopyroxenite clast in Y-791186 containing three intergrown pyroxene grains. None are exsolved. Long dimension is 1.75 mm, crossed polarizers.

TAKEDA *et al.*, 1983). The pigeonite cores are generally slightly clouded and the augitic rims are clear. The pyroxene presently has uniform Fe/(Fe+Mg) and analyses define a tie line between $En_{36}Wo_2$ and $En_{30}Wo_{45}$ (Table 2b). The pyroxene appears to have exsolved in two stages. Broad ($\sim 10\ \mu m$) exsolution lamellae of augite formed parallel to (001) of the original high temperature pigeonite. With further cooling this exsolved pigeonite then exsolved another set of submicron to micron sized exsolution lamellae parallel to (100) which cross cut the earlier broad lamellae. Some of these late lamellae have optical characteristics suggesting that they are orthopyroxene, but this has not been confirmed by X-ray or microprobe analysis. Careful optical examination indicates that the final host pyroxene remains pigeonite, at least in part, rather than the orthopyroxene originally suggested by DELANEY *et al.* (1984a). This eucrite was, therefore, held at high temperature for an extended period to produce two generations of exsolution lamellae but the rock sampled then cooled rapidly to partially inhibit the pigeonite-orthopyroxene inversion in the host. Some areas in the pyroxene grains also contain patches of micron sized rodlike inclusions of ilmenite and chromite, that appear to have exsolved in the (110) cleavage plane of the pigeonite during cooling.

Feldspar in Y-792510 is compositionally quite distinct from that in Y-74356 (Table 2b). Although zoning is not well developed, a significant range of feldspar compositions from $An_{83}Or_{1.2}$ to $An_{88}Or_{0.5}$ is seen. The mean feldspar composition is $An_{87}Or_{0.6}$, and is, therefore, more sodic than in Y-74356. This feldspar shows pale brown clouding in many areas perhaps produced by exsolution of excess SiO_2 dissolved in the original high temperature feldspar (cf. BEATY and ALBEE, 1980). Occasional grains seem to be reverse zoned. Most of the compositional variation in the feldspar occurs in these grains.

Compositions of other minerals in Y-792510 are given in Table 2b. Both ilmenite and chromite are similar to the eucritic oxides analyzed by BUNCH and KEIL (1972). The MgO content of the ilmenite in 792510 is half that in 74356 despite the similarity of the Mg/(Mg+Fe) ratios of their pyroxenes. Fluorapatite was analyzed and no merrillite was found, but this may reflect the general difficulty of locating this rare phase in the eucrites since almost all eucrites contain the two phosphate minerals (DELANEY *et al.*, 1984b).

(3) *Y-791195*. The eucrite Y-791195 is unique. It is an unbrecciated pyroxene-plagioclase rock with a granular or microgabbroic texture rather than the ophitic-subophitic texture characteristic of most eucrites (Fig. 6). Superficially Y-791195 resembles feldspar cumulate eucrites like Serra de Magé or Moore County. The grain size of Y-791195 is, however, much smaller (100–200 μm grains) and there is no indication of any preferred orientation of either the plagioclase or the pyroxene in the thin section (91-1) studied. No petrofabric evidence, therefore, exists for describing Y-791195 as a cumulate. Of the monomict basaltic achondrites Medanitos (DELANEY *et al.*, 1983a) is texturally the most similar. Medanitos is, however, much more magnesian and is brecciated. Ibitira is also similar but Y-791195 has no evidence of early brecciation and metamorphism similar to that described by STEELE and SMITH (1976). Modally Y-791195 is slightly more feldspathic than the eucrites average but it does not contain as much feldspar as the feldspar cumulate eucrites. A few eucrites (Sioux

County, Reckling Peak A80204 and Millbillillie) have the same modal feldspar contents as Y-791195 but none of these has a similar texture to it.

Pyroxene in Y-791195 forms equant anhedral grains showing well developed, fairly coarse exsolution on (100). Occasional grains show pigeonite twinning. The compositions of the pyroxene fall in two very tight clusters at $En_{40}Wo_5$ and $En_{34}Wo_{41}$ corresponding to the pigeonite host and augite lamellae. Only the Ibitira eucrite (STEELE and SMITH, 1976) contains such homogeneous pyroxene. Y-791195 appears to have crystallized slowly (or has been annealed) with plenty of time for the pyroxene to homogenize Fe and Mg across several millimeters and also time for the development of beautiful exsolution lamellae. Many grains also contain swarms of well oriented oxide inclusions that appear to lie in a cleavage plane (Fig. 7).

Plagioclase in Y-791195 is very clean, unzoned and contains rare inclusions of pyroxene and silica. Unlike that in most eucrites the composition of the feldspar is extremely uniform at $An_{90}Or_{0.3-0.4}$ (Fig. 3, Table 2). The other major phase in Y-791195 is a silica polymorph showing irregular, undulose extinction perhaps suggesting quartz inverted from tridymite. This silica occurs as large grains filling interstices between pyroxene and plagioclase. In common with many eucrites, this silica is almost pure SiO_2 containing $\sim 0.1\%$ K_2O but with Na_2O below detection (DELANEY, 1983 unpublished data). Both chromite and ilmenite have been analyzed (Table 2c) and show similarities to Y-74356 since the ilmenite has high MgO and the chromite contains a substantial Ti-bearing component.

4. Polymict Eucrites

Three specimens are classified as polymict eucrites. All these specimens are polymict breccias dominated by various eucritic components (DELANEY *et al.*, 1983b, d).

(1) *Y-791186* is a pyroxene-plagioclase breccia containing significantly more pyroxene (60.1%) than most eucrites (48–55%) (Table 1). The sample has abundant shock features that obscure many primary mineralogical and petrographic features, but definite lithic clasts with coarse grained pyroxene and plagioclase are recognized (Fig. 8). The pyroxene of 791186 has a variety of exsolution textures. A few coarse clasts appear to be orthopyroxene (Fig. 9) with no obvious exsolution except of very fine grained opaques. Straight extinction of these grains suggests that they are true orthopyroxene. Shock modification in some cases is, however, severe and further detailed work is necessary to characterize these pyroxenes. Some of the orthopyroxene grains are in lithic fragments with a texture of interfingering of pyroxene grains similar to that seen in some diogenites and orthopyroxenite clasts from howardites (NEHRU *et al.*, 1981). Apart from the orthopyroxene-like fragments in Y-791186, other pyroxene grains show well developed exsolution (Fig. 10). The width of exsolution lamellae and their spacing varies from clast to clast. Detailed study is necessary to determine whether this variability of the exsolution could represent the natural variation within a single rock type. These exsolved pigeonite grains invariably are very heavily clouded. In some cases clouding makes pyroxene grains almost opaque. This contrasts with the orthopyroxene grains which, although heavily clouded in some areas, generally do not contain so many inclusions as the pigeonitic material. The shock features and clouding of the pyroxene

Fig. 10. Exsolved clinopyroxene clast and fragment of a basaltic clast in Y-791186. Long dimension is 1.75 mm, crossed polarizers.

in Y-791186, therefore, do not prevent the recognition of at least two distinct populations of pyroxene, indicating that this meteorite is probably polymict.

A remarkable feature of Y-791186 is its remarkable compositional uniformity. Most analyses fall on a tie line between $En_{37}Wo_2$ and $En_{30}Wo_{45}$. These analyses are similar to the pyroxenes in the Y-792510 and -74356 eucrites. In addition, one large clouded orthopyroxenite clast has more magnesian ($En_{43}Wo_2$) compositions. Very similar features were described in pyroxene from Elephant Moraine A79004 (DELANEY *et al.*, 1982b) which is a polymict breccia that has been homogenized with respect to Fe and Mg (in pyroxene) by a metamorphic overprint. The large orthopyroxenite clast observed in Y-791186 is texturally most like the magnesian orthopyroxenites (En_{70-75} Wo_{1-2}) in howardites and diogenites. Compositionally it is only very slightly more magnesian than the pigeonitic pyroxene in this meteorite. The presence of features such as planar fractures and mosaicism in some pyroxene grains and undulose extinction, unrelated to composition, in the plagioclase suggest that this specimen was severely shocked. In addition, both pyroxene and plagioclase are clouded, a feature interpreted by HARLOW and KLIMENTIDIS (1980) to be the result of annealing after the shock event. The mode of Y-791186 contains only 32% feldspar, much below the mean for eucrites (43.3% : S.D. $\pm$2.2%). This modal feldspar content is typical of howardites, or pyroxene-rich polymict eucrites. The modal pyroxene of this section of Y-791186 is mainly low calcium pyroxene (orthopyroxene in Table 1), a feature of many howardites, whereas most eucrites have more abundant pigeonite (DELANEY *et al.*, 1984c). The modal distribution of pyroxene compositions in Y-791186 is similar to that in Y-792510 which has exsolved and inverted pigeonite, but has higher orthopyroxene relative to the more calcic pyroxenes. These modal features and the difference between pyroxene compositions in the large orthopyroxenite clast and the matrix pyroxene in Y-791186 are features seen in Elephant Moraine A79004, a metamorphosed polymict breccia (DELANEY

Table 3a. Representative mineral compositions in polymict eucrites.

	Y-791186						
	opx	pigeonite host	pigeonite lamellae	$plag_1$	$plag_2$	ilm	cm
SiO_2	50.1	49.5	51.5	50.7	46.5	0.05	0.12
TiO_2	0.24	0.16	0.20	bd	bd	52.2	3.9
Al_2O_3	0.12	bd	0.34	31.9	35.3	bd	8.4
Cr_2O_3	0.16	0.26	0.20	na	na	0.07	49.8
FeO	31.9	34.3	16.3	0.82	0.24	46.1	35.0
MnO	1.09	1.29	0.61	na	na	0.88	0.60
MgO	13.9	12.5	11.3	0.11	<0.1	0.59	0.58
CaO	1.07	1.02	19.0	14.0	17.5	<0.1	<0.1
Na_2O	<0.05	bd	0.07	2.70	1.24	na	na
K_2O	na	na	na	0.42	0.10	na	na
Total	98.7	99.0	99.4	100.8	101.70	99.99	97.9
En/An	42.7	38.4	33.1	72.1	88.1	—	—
Wo/Or	2.4	2.27	40.1	2.6	0.58	—	—

et al., 1982b). It is, therefore, possible that Y-791186 was originally a eucrite-rich breccia containing a significant pyroxenite component that was metamorphosed and as a result the Fe/Fe+Mg ratios of the various lithic components were almost totally homogenized. Only the larger pyroxenite fragments preserved some of the variability of Fe/Fe+Mg that may have been present originally. Y-791186 is, therefore, a metamorphosed polymict eucrite. Representative mineral composition data are given in Table 3a. Feldspar compositions (Fig. 3) vary more than in the eucrites but most analyses fall between $An_{83}Or_{1.2}$ and $An_{88}Or_{0.6}$. Ilmenite and chromite show a little chemical variation and are approximated by the data of Table 3a.

TAKEDA (personal communication, 1984) suggests that Y-791186 is the same as the Y-792510 eucrite. The observed shock features and the large modal differences suggest that they are different. However, the sample of Y-791186 described by TAKEDA *et al.* (1984a) is quite different from the sample studied, indicating that this meteorite is heterogeneous. TAKEDA *et al.* (1984a) also suggest that Y-791186 may contain polymict areas. Further petrographic study of this meteorite is needed to clarify these conflicting observations.

(2) *Y-791960* is a polymict pyroxene-plagioclase breccia (Fig. 11) that has very strong similarities to the Yamato polymict eucrite suite. The thin section studied (91-1) contains numerous mafic lithic clasts in addition to mineral clasts but does not contain the large heterogeneous or Pasamonte-type clasts so typical of Yamato polymict eucrites (TAKEDA, 1979). Modally (Table 1) Y-791960 is identical to the other Yamato polymict eucrites (DELANEY *et al.*, 1984c). This specimen differs from most other Yamato polymict eucrites, however, as it contains rare magnesian orthopyroxene. About 2% of the total pyroxene analyzed falls in the compositional range En_{70} to En_{78} and corresponds to a diogenitic component that is not found in other Yamato polymict eucrites. If the nomenclature of MASON (1983) is followed, then Y-791960 is a howardite. This specimen is so similar to other Yamato polymict eucrites, however, that it seems more

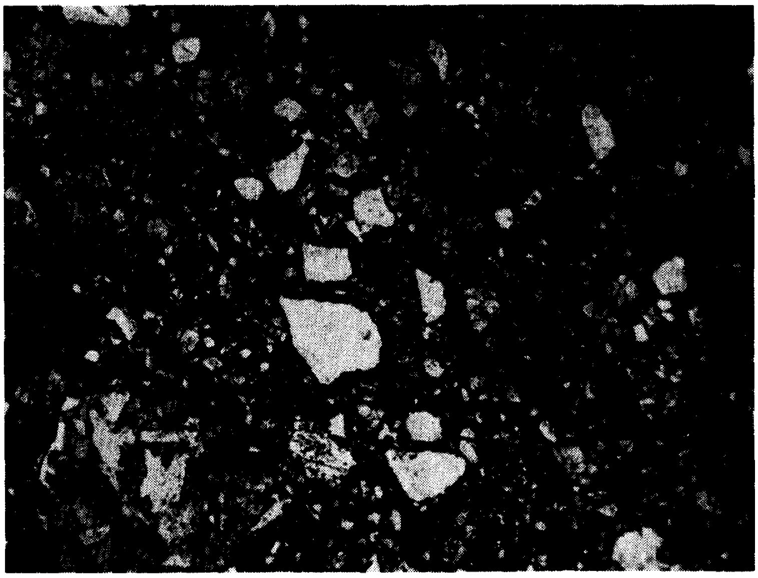

Fig. 11. Micrograph of Y-791960 polymict eucrite showing breccia texture. Long dimension is 5 mm, plane polarized light.

Fig. 12. "Dimict" texture of Y-791192 polymict eucrite showing basalt clasts and glassy matrix. Long dimension is 5 mm, plane polarized light.

realistic to classify it as a polymict eucrite and equate it with the Yamato I suite of DELANEY *et al.* (1984c). Thus, Y-791960 contains the same small diogenite component that is characteristic of polymict eucrites such as Allan Hills 78006 and the non Antarctic specimens (DELANEY *et al.*, 1984c).

Pyroxene clasts in Y-791970 range in composition between the magnesian $En_{77}Wo_2$ and an Fe-rich clast with $En_{36}Wo_2$ pyroxene. The iron-rich, eucritic pyroxene is much more common and analyses from four large basaltic clasts all fall in the range En_{45} to En_{36}. Pyroxene showing all the exsolution styles discussed by TAKEDA (1979) is present. The Binda-type of exsolved pigeonite, however, seems less common than in some Yamato I specimens. Feldspar in Y-791960 ranges in composition from An_{92} to An_{80} (Fig. 3) with most analyses falling close to An_{90}.

(3) *Y-791192.* The third polymict eucrite studied is also an unusual specimen as it is dominated by two lithologies (Fig. 12). The mode of this sample resembles Y-

791186, as it contains 64% pyroxene (Table 1). The thin section studied (91-1) contains one large and several smaller eucritic clasts set in a pyroxene-rich matrix, The matrix of this sample is dominated by pyroxene in the composition range, $En_{66}Wo_3$ to $En_{57}Wo_3$ (Table 3b) but more iron-rich material (En_{50}–En_{35}) is also present. The feldspar of the matrix is fairly calcic ranging from $An_{91}Or_{0.2}$ to $An_{87}Or_{0.3}$. Many matrix clasts are embedded in glass (Fig. 13). Both pyroxene and feldspar may show a variety of shock features: mosaicism, fracturing, diaplectic glass formation suggesting that the glass in the matrix may have formed because of shock melting. Despite the overprint of shock features, however, the matrix pyroxene shows varied exsolution styles suggesting derivation from several rock types.

The basalt clast fragments in Y-791192 (Fig. 14) show some of the same shock modification as the matrix. Compositionally and texturally they are quite distinct indicating that Y-791192 was less modified by metamorphism than Y-791186 (for example). The largest clast contains 26% (vol) orthopyroxene; 13% "pigeonite"; 17.9% augite; 36.9% feldspar; 4.6% silica; 1% ilmenite+chromite, troilite and phosphate. Most of the "pigeonite" fraction represents orthopyroxene-augite overlaps. In

Table 3b. Mineral analyses for Y-791192 matrix and clast.

Matrix	pyx_1	pyx_2	pyx_2 lamellae	$feld_1$	$feld_2$	ilm_1	ilm_2	cm_1	cm_2
SiO_2	52.9	52.4	51.2	44.5	47.0	0.1	0.14	bd	bd
TiO_2	0.20	0.30	0.47	bd	bd	52.9	51.3	3.5	5.8
Al_2O_3	0.31	0.26	0.76	36.2	34.5	bd	0.13	8.5	7.5
Cr_2O_3	0.29	0.17	0.32	na	na	0.41	0.70	50.2	47.1
FeO	20.0	22.3	9.7	0.11	0.17	42.4	45.3	33.1	36.0
MnO	0.82	0.90	0.39	na	na	0.73	0.83	0.60	0.63
MgO	23.1	19.5	14.1	0.11	0.13	3.0	0.94	1.74	0.97
CaO	1.31	4.1	21.3	18.4	17.7	bd	bd	bd	bd
Na_2O	bd	bd	0.07	0.98	1.5	na	na	na	na
K_2O	na	na	na	0.04	0.04	na	na	na	na
Total	99.0	99.9	98.2	100.4	101.1	99.7	99.4	97.7	98.1
En/An	65.5	55.9	40.5	91.0	86.7	—	—	—	—
Wo/Or	2.7	8.3	43.9	0.2	0.3	—	—	—	—

Basalt B1	pyx_1	pyx_2	feld	ilm	cm
SiO_2	49.7	50.0	47.7	<0.1	0.2
TiO_2	0.17	0.31	bd	52.9	4.2
Al_2O_3	0.60	0.42	34.5	bd	8.5
Cr_2O_3	0.21	0.17	na	0.05	50.0
FeO	33.9	16.5	0.22	45.5	34.1
MnO	1.20	0.56	na	0.85	0.62
MgO	13.0	10.5	0.11	0.97	0.77
CaO	0.82	20.6	17.1	<0.1	0.3?
Na_2O	bd	0.07	1.69		
K_2O	na	na	0.09		
Total	99.5	99.2	101.5	100.3	99.6
En/An	39.9	30.4	84.4	—	—
Wo/Or	1.82	42.8	0.52	—	—

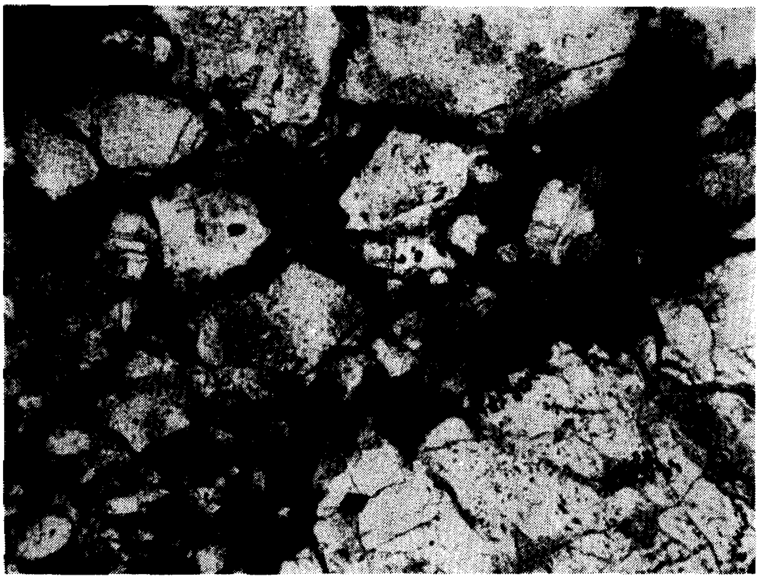

Fig. 13. Glassy matrix of Y-791192 containing shocked clasts and glassy interstices. Long dimension is 0.9 mm, plane polarized light.

Fig. 14. Largest basalt clast in Y-791192. Long dimension is 0.9 mm, plane polarized light.

comparison with the bulk mode (Table 1) the basalt fragments are feldspar and augite enriched. The composition of the pyroxene defines a tie line between an $En_{40}Wo_{1.8}$ host and $En_{30}Wo_{43}$ lamellae while the feldspar is significantly more sodic (An_{84}) than the feldspar of the matrix.

The Y-791192 sample, therefore, appears to be dominated by material (a pyroxene-rich lithology and a basalt) from two distinct source regions. Enough pyroxene of intermediate composition is present, however, to prevent this meteorite from being considered a truly dimict breccia. For this reason it is classified as a polymict eucrite.

5. Howardites

Four samples Y-791074, -791208, -791492, -791573 are polymict breccias containing a significant fraction of Mg-rich orthopyroxene clasts in addition to eucrite or eucrite-derived clasts. All these samples are, therefore, howardites (DELANEY *et al.*, 1983d).

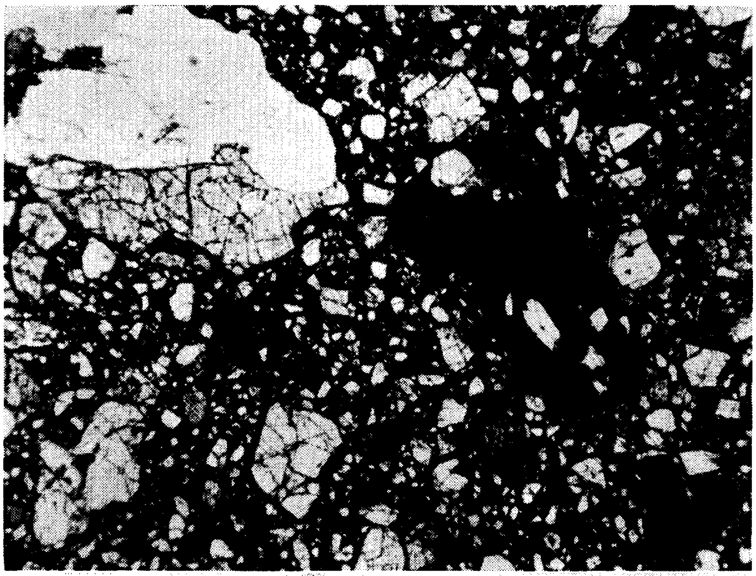

Fig. 15. General texture of Y-791208 howardite. Note basaltic and quench textured lithic clasts. Long dimension is 5 mm, plane polarized light.

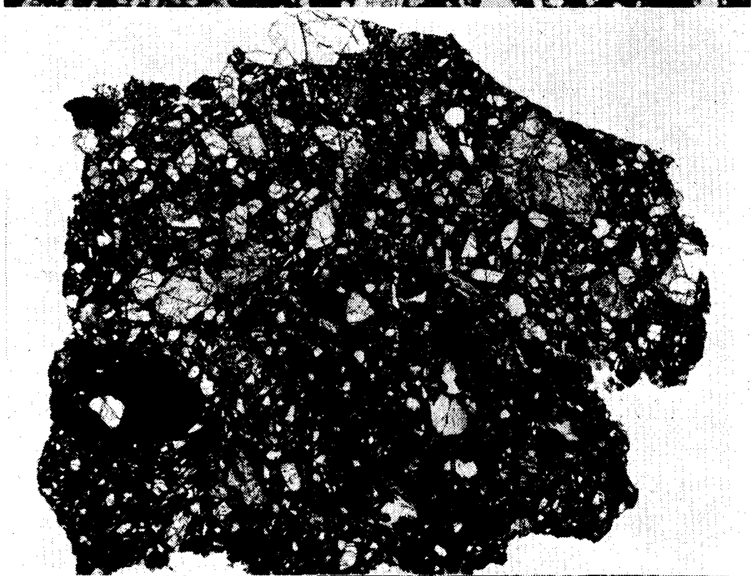

Fig. 16. Texture of Y-791492. Long dimension is 9.5 mm, plane polarized light.

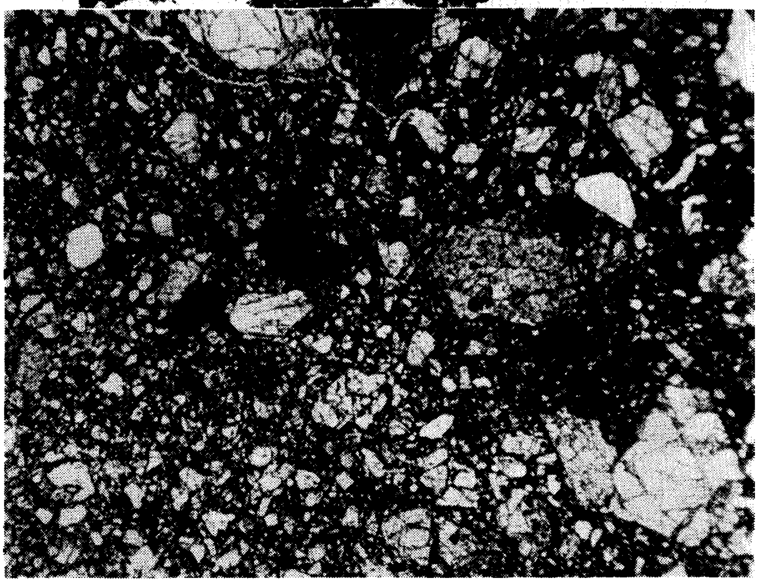

Fig. 17. General texture of Y-791573 howardite. Long dimension is 5 mm, plane polarized light.

All four samples have very similar modes although Y-791074 has slightly more abundant "pigeonite" and feldspar.

(1) *Y-791208*, *-791492*, *-791573* are all very similar texturally and mineralogically (Figs. 15–17) and will be considered as a group. Olivine is present in all of these sections (Table 1) and is most abundant in Y-791573. The composition range of the olivine in Y-791492 and -791573 is, however, fairly limited with most analyses falling between Fo_{80} and Fo_{90}, the typical range for olivine from howardites (DELANEY *et al.*, 1980; DESNOYERS, 1982). In Y-791208 olivine has a greater composition range (Fo_{45} to Fo_{92}), and most compositions are between Fo_{65} and Fo_{75}.

Pyroxene in these three samples covers a very broad range from $En_{87}Wo_{1}$ orthopyroxene in Y-791573 to $En_{30}Wo_{25}$ augite in Y-791492. These values represent the extreme range identified by the automated modal analysis program and the ranges of each sample are essentially identical. Within this range, the abundance of particular pyroxene compositions is essentially identical in all three samples. All are dominated by pyroxene with compositions in the range En_{70} to En_{80}, indicating that in each specimen, approximately one third of all the pyroxene in these samples is derived from a diogenite-like component. All three meteorites also contain a small amount ($\sim 5\%$?) of pyroxene more magnesian ($\sim En_{85}$) than typical diogenitic pyroxene that perhaps crystallized together with the magnesian olivine discussed. The remaining pyroxene ($\sim 2/3$) is more iron rich than En_{70} and is spread evenly across the compositional ranges of cumulate eucrites (En_{65} to En_{46}) and eucrites (En_{42}–En_{30}).

Pyroxene in lithic clasts from these three samples covers a wide range from $En_{77}Wo_{2}$ to En_{29}. Some of these lithic clasts are clearly mafic clasts that may ultimately be classified into the petrologic groups discussed by DELANEY *et al.* (1981b) and, therefore, are of great importance to the study of petrologic diversity on the Basaltic Achondrite Planetoid (BAP). The present reconnaissance study cannot, however, provide the detail necessary for such grouping. Other lithic fragments, especially the more magnesian clasts, appear to be impact melts of a howarditic regolith. Several of these fragments contain angular grains of pyroxene with compositions that cannot be at equilibrium with the surrounding melt compositions and hence must be xenocrysts rather than phenocrysts. These impact melt clasts are useful for studying the diversity of the BAP regolith and may provide evidence for the presence of components not yet recognized as lithic fragments.

Feldspar in these three howardites (Y-791208, -791492, -791573) shows broad, essentially similar ranges with most analyses falling between An_{88} to An_{92} (Fig. 3). No feature of any of these three howardites is sufficiently distinct that the specimen can be treated separately from the other two and considered to be a different meteorite (see also TAKEDA *et al.*, 1984b). The observed petrographic differences merely reflect heterogeneities within the meteorite. Since they contain more modal calcic pyroxene, more modal feldspar and their pyroxene is generally more iron rich than in Y-7308, they are presently believed to be samples of a meteorite distinct from Y-7308.

(2) *Y-791074* is a howardite specimen texturally similar to the three specimens discussed above (Fig. 19). It differs, however, as it contains more feldspar, less olivine and less orthopyroxene (Table 1) and the composition of its silicate phases tend to be

more iron rich.

The composition range of the olivine (Fo_{40}–Fo_{75}) is significantly more iron rich than in the other samples studied (Fig. 18). Similarly, the pyroxene composition range, in addition to the large diogenitic component (En_{70}–En_{80}) present in the meteorite (25–35% of the total pyroxene) contains a significant cluster of analyses (En_{60}–En_{65}) more iron rich than diogenites that presumably samples pyroxene rich cumulates similar to Binda (GARCIA and PRINZ, 1978), Y-75032 (TAKEDA and MORI, 1981; TAKEDA *et al.*, 1979a,b) or the pyroxene-rich meteorites discussed below. Feldspar in Y-791074 has a similar composition range to the three discussed above.

Unlike Y-791208, -791492 and -791573, many of the larger mafic clasts in Y-791024 are of eucritic composition ($En_{40-30}Wo_5$ pyroxene with anorthitic feldspar). The differences between Y-791074 and the other howardites described, therefore, suggest that it is a separate meteorite from either Y-7308 or the Y-791208 group, and thus represents the third known Yamato howardite.

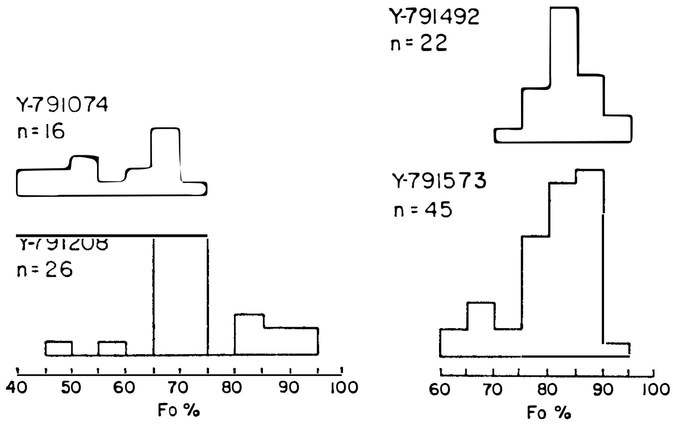

Fig. 18. Olivine Fo histograms for 4 howardites: Y-791074, -791208, -791492 and -791573.

6. Pyroxene-Rich Meteorites

Seven of the samples studied from the Yamato-79 collection have abundant pyroxene but contain more feldspar than a typical diogenite such as Y-74097 (Table 1). Using textural criteria, these seven samples have been split into three subgroups: (1) Y-791199; (2) Y-791200 and -791201; (3) Y-791000, -791072, -791073, -791422.

(1) *Y-791199* is a very coarse grained pyroxene-rich sample with little brecciation (Fig. 20). The pyroxene and plagioclase show minor shock features, and neither mineral is as severely shock modified as in the specimens to be described below. The very coarse crystal size of the pyroxene in this section suggests that the observed modal abundance of feldspar (Table 1) need not be representative. This sample was also studied by TAKEDA and YANAI (1982) and TAKEDA and MORI (1984) but no mode was given. Almost all the pigeonite identified by the modal program must represent orthopyroxene-augite overlaps as the pyroxene of Y-791199 is beautifully exsolved on both (001) and (100) (see also TAKEDA and MORI, 1984). Pyroxene composition in Y-791199

Fig. 19. General texture of Y-791074 howardite. Long dimension is 5 mm, plane polarized light.

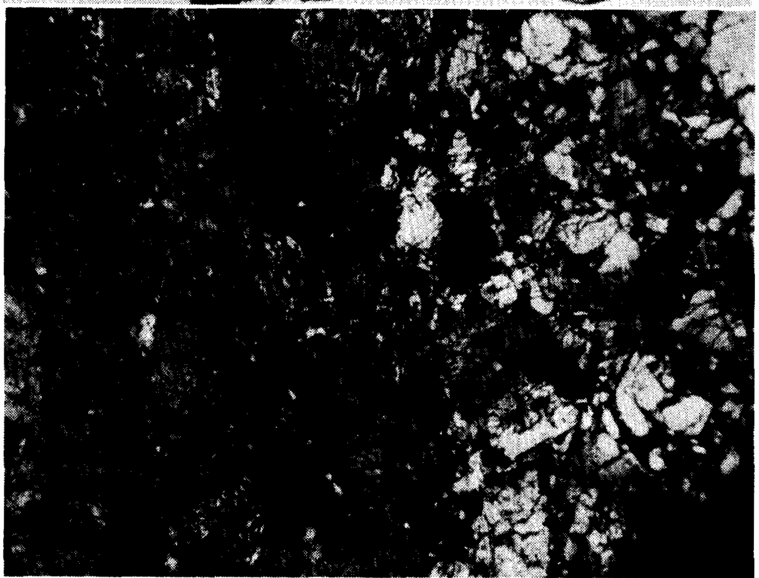

Fig. 20. Y-791199 pigeonite cumulate eucrite. Note very coarse grain size of exsolved pigeonite. Unbrecciated clast with minor feldspar (dark) is on left, breccia is on right. Long dimension is 5 mm, crossed polarizers.

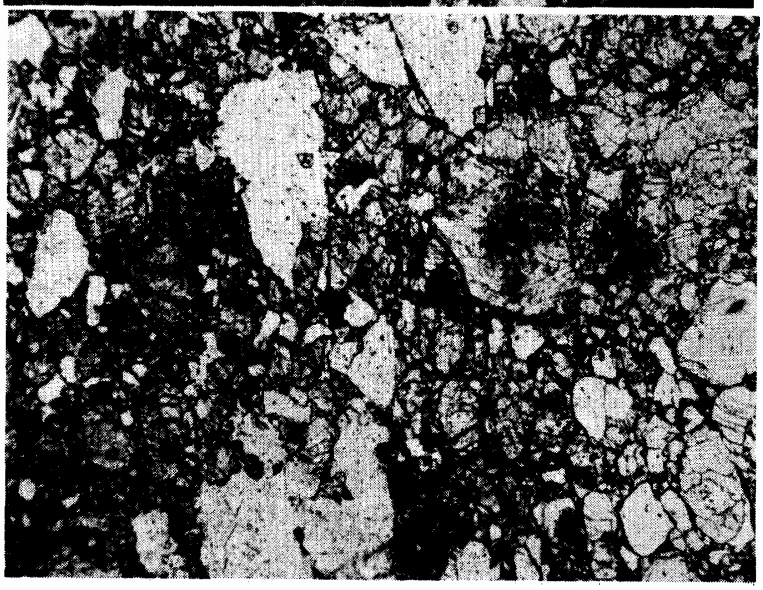

Fig. 21. General texture of Y-791201 pigeonite cumulate eucrite. Long dimension is 5 mm, plane polarized light.

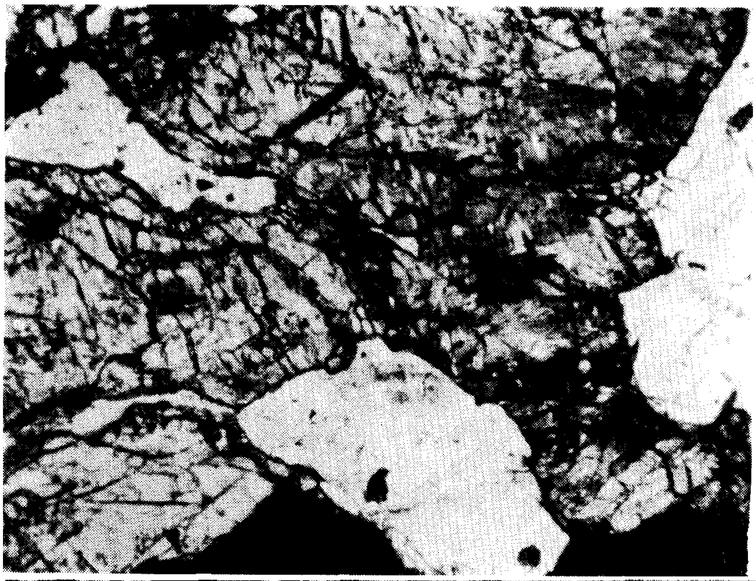

Fig. 22. Gabbroic clast in Y-791201. Inverted pigeonite and plagioclase. Long dimension is 1.75 mm, crossed polarizers.

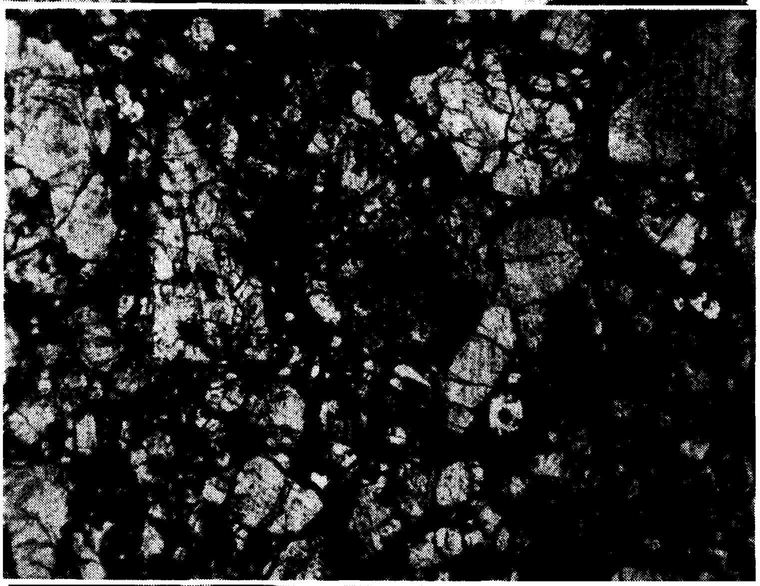

Fig. 23. General texture of Y-791000 pigeonite cumulate eucrite. Long dimension is 5 mm, plane polarized light.

Fig. 24. Most of thin section of Y-791073 pigeonite cumulate eucrite. Long dimension is 5 mm, plane polarized light.

is generally $En_{66-64}Wo_{2-3}$ with lamellae of $En_{43}Wo_{44}$ augite although rare Fe-rich grains (En_{54} and En_{46}) occur in the brecciated portion of the thin section. Since the lithic fragments that dominate this sample contain compositionally homogeneous pyroxene, these Fe-rich grains probably represent a very minor component derived from a different lithology. Apart from this minor contaminant, Y-791199 is essentially monomict.

Some variation of feldspar composition may be observed from grain to grain and between the lithic fragments and the matrix breccia. In the lithic fragments, feldspar is typically about $An_{82}Or_1$ in composition. The total analyzed range from $An_{75}Or_3$ to $An_{84}Or_{0.3}$ in these fragments appears to reflect original igneous zoning, but further study of the feldspars in more samples is needed to characterize the zoning. Feldspar in the breccia is more calcic ($An_{90}Or_{0.4}$) suggesting the presence of a component unrelated to the large lithic fragments. Ilmenite contains up to 3.2% MgO, and chromite has ~2.0% TiO_2, 8–9% Al_2O_3 and 2–2.5% MgO.

The presence of large, relatively unmodified lithic fragments in this sample make it particularly suited to further detailed study to relate its petrogenesis to the evolution of the basaltic achondrite parent. In particular, its modal and compositional characteristics suggest that it is transitional between the diogenitic orthopyroxenites and the various groups of eucrites (*cf.* TAKEDA and MORI, 1981, 1984).

(2) *Y-791200 and -791201.* Despite their large modal differences, Y-791200 and -791201 are texturally and mineralogically similar and are believed to be samples of the same meteorite. Both are breccias dominated by pyroxene and plagioclase set in a brown glassy matrix (Fig. 21). Pyroxene in both samples is exsolved pigeonite showing lamellae parallel to (001) and blebby exsolution comparable to that in Binda or Moama is very common. TAKEDA and MORI (1984) also recognize blebby exsolution on subgrain boundaries.

In Y-791200 pyroxene compositions range from $En_{70}Wo_2$, with lamellae of $En_{45}Wo_{44}$, to $En_{58}Wo_2$. A few grains show center to edge variations in Mg/(Mg+Fe) but most of the compositional range represents differences between grains rather than obvious zoning. Most of the pyroxene in this sample falls between En_{65} and En_{70}. The glass that surrounds the pyroxene and plagioclase is pyroxenitic but contains more Fe, Ca and Al than the pyroxene. Mg/(Mg+Fe) of the glass varies from 0.65 to 0.59. Therefore, the present range of pyroxene compositions in this sample may result from partial exchange of Fe and Mg between the pyroxene clasts (originally ~$En_{69}Wo_{4-5}$) and the interstitial melt phase. The observed range of compositions may, however, be an intrinsic property of source regions sampled. The abundance of glass in Y-791200 is between 5% and 12% (vol).

The feldspar in Y-791200 resembles devitrified maskelynite and is heavily shocked. Compositionally, this feldspar is uniform An_{92} to An_{89} (Fig. 3). The coexistence of melt glass with these devitrified maskelynites suggests that post-shock annealing may have homogenized any original zoning in the feldspar (OSTERTAG and STÖFFLER, 1982). Further study is, however, needed to adequately characterize these feldspars.

Y-791201 is texturally very similar to Y-791200 but contains much more feldspar (Table 1). It also contains a few gabbroic clasts (Fig 22), but these seem to be derived from a similar source rock to that of the surrounding breccia. In addition to the more abundant feldspar, Y-791201 also contains more glassy material. Of the 470 analyses of pyroxene in the Y-791201 mode, 69 may be misidentified glass. These 69 analyses represent all three pyroxene types in roughly their modal abundance. Pyroxene compositions range from En_{66} to En_{50}, and clustering of the modal analyses forms two main groups. The most common composition is $En_{59}Wo_2$ (with lamellae of $En_{42}Wo_{44}$), while the other group is more iron rich. The host in the second group is generally about $En_{53}Wo_2$ with lamellae of $En_{37}Wo_{43}$. The overlap of the pyroxene composition ranges of Y-791200 and -791201 is small. The feldspar in Y-791201 is essentially identical in composition, texture and setting to that in Y-791200.

The differences in modal feldspar and pyroxene composition between Y-791200 and -791201 make pairing of these two samples very tentative. Y-791200 and -791201 appear to represent two lithologies of their parent body that are closely related (perhaps adjacent layers in a layered complex) that experienced identical processing and were delivered to the earth at the same time. If they are part of the same meteorite, then the original meteorite must have had significant compositional and modal heterogeneities. TAKEDA and YANAI (1982) suggest that Y-791200 and -791201 may be paired with Y-75032.

(3) *Y-791000, -791072, -791073, -791422.* All of these samples have very similar textures (Figs. 23, 24). All contain shocked brecciated clinopyroxene in a matrix of fine-grained breccia with abundant dark glass. Large shocked feldspars are also present. Modally 791000, 791072 and 791422 are very similar. All are dominated by the low calcium pyroxene component but contain significant amounts of pigeonite and augite. Pyroxene accounts for 85–95% vol of these samples. Y-791073 differs, having 21.5% feldspar, but the sample studied is very small (12.6 mm^2) and contains several large feldspar grains. Because of this and the overall similarity between Y-791073 and the other three samples, this mode is, therefore, believed to be less representative than those of the other samples.

Pyroxene compositions in these samples are generally fairly magnesian, but some variation is observed. In Y-791000 most pyroxene is of uniform composition (En_{65-67} $Wo_{1.7}$) with augite lamellae and blebs of $En_{44}Wo_{44}$. Many of the analyzed pigeonite compositions in the mode of Y-791000 are artifacts produced by orthopyroxene-augite overlap and pyroxene-glass overlaps, but the modal augite content (which is unaffected by such overlaps) of this sample is very much greater than in any diogenite (*cf.* Y-74097, Table 1). Most of the pyroxene of Y-791000 and the others appears to be a clinopyroxene phase. TAKEDA (1984, personal communication) suggests that these pyroxenes were orthopyroxene that was transformed by shock into clinopyroxene. Such a transformation is compatible with the intensely shocked textures of these samples. All four samples contain a significant calcic pyroxene component that is seen modally as augite and pigeonite (Table 1). Most of this calcic pyroxene occurs as augite lamellae and blebs in the low calcium host pyroxene. Recalculation of the bulk composition of the pyroxene from which they exsolved indicates that the host pyroxene had a pigeonitic composition. The four samples Y-791000, -791072, -791073 and -791422, therefore, probably formed as pigeonite-rich rocks distinct from the diogenites (which crystallized only orthopyroxene). Since the modal pyroxene and plagioclase abundance of these samples varies, it is believed that they sample an originally coarse grained pigeonite-rich eucritic rock. The pyroxene abundance is generally very high, so that it is unlikely that original rock represents a liquid composition and, therefore, these are samples of either a pigeonite cumulate or a pigeonite residuum remaining after extraction of a more evolved liquid. In the absence of evidence to distinguish between these options, we describe this group as pigeonite cumulate eucrites. TAKEDA *et al.* (1978, 1979b) have described Y-75032, a unique pyroxene-rich meteorite that has many similarities to these four Y-79 samples. The partial mode of Y-75032 (TAKEDA and MORI, 1984) suggests that it is like Y-791000, the largest sample studied, but unfortunately no indication is given of the abundance of calcic pyroxene in Y-75032. It is, however, likely that Y-75032, -791000, -791072, -791073 and -791422 are all samples of one meteorite. Because the pyroxene in these samples is pigeonite and that in diogenites is orthopyroxene, it is further suggested that Y-75032 be described as a pigeonite cumulate eucrite rather than a diogenite.

The four samples studied have roughly correlated variation of pyroxene composition with modal feldspar and glass abundance. Y-791000 contains little feldspar content and has $En_{66}Wo_2$ pyroxene, whereas Y-791073 has 21% feldspar and pyroxene varies from $En_{65}Wo_2$ (with $En_{44}Wo_{42}$ lamellae) to $En_{53}Wo_2$ (with $En_{39}Wo_{45}$ lamellae). The increase in the amount of interstitial glass as the iron content of the pyroxene increases is perhaps caused by exchange of Fe and Mg between pyroxene and the interstitial melt phase. If this is true, the observed Fe/Mg variation may be a secondary feature of these samples. More work is, however, necessary to test this hypothesis against the possibility that the observed pyroxene compositional variations represent an igneous fractionation trend.

Feldspar in these samples has a compositional range from $An_{80}Or_{0.6}$ to $An_{91}Or_{0.3}$. Most variation is seen in Y-791073 (Fig. 3) but this may be an artifact caused by the rarity of feldspar in the other samples. Chromite is the most abundant oxide and contains TiO_2 ~2%; Al_2O_3 8–10%; MgO 1.8–3.4%. The rare ilmenite contains 2.4–3.3% MgO.

7. Discussion

The seventeen samples documented here, together with the Y-74097 diogenite sample, represent all the major groups within the basaltic achondrite suite with the exception of the feldspar cumulate eucrites. One specimen (Y-791195), although not a cumulate eucrite, has many similarities to that achondrite group and probably crystallized in a similar plutonic setting. The presence of a new group, the pigeonite cumulate eucrites, significantly increases the known diversity within the basaltic achondrite suite.

Of the monomict samples, the three eucrites have a variety of textures and mineral compositions that completely preclude their being paired with one another. Two of these meteorites (Y-74356 and -792510) are texturally similar to many non Antarctic eucrites. The complexity of the exsolution in Y-792510 deserves further detailed study since it appears to have had as complex a petrogenesis as Moore County (*cf.* HOSTETLER and DRAKE, 1978; TAKEDA *et al.*, 1981; NORD, 1983). The third meteorite, a gabbroic eucrite, is unlike any other monomict eucrite known. This sample does not have any discernable preferred orientation of either its pyroxene or plagioclase so that it should not be treated as a cumulate like Moore County (HESS and HENDERSON, 1949) or Moama (LOVERING, 1975). The Y-791195 gabbroic eucrite is, however, similar to several clasts observed in both the mesosiderites (DELANEY *et al.*, 1981a, 1982a; MITTLEFEHLDT, 1979) and howardites (DELANEY *et al.*, 1981b; BUNCH, 1975). The sampling of a gabbroic textured eucrite in Antarctica, therefore, confirms the evidence from the polymict achondrites indicating that eucritic magmas were both intruded and extruded on the basaltic achondrite parent body. The Y-791195 eucrite is also notable as it lacks fine-grained interstitial material and, in particular, phosphate minerals. Recent work on REE-rich phosphates in eucrites (DELANEY *et al.*, 1984b) indicates that if the contribution of merrillite ($30000 \times C1$) to the bulk REE patterns of most eucrites were removed, then the eucrites would be characterized by fairly flat REE patterns with positive Eu anomalies very similar to the patterns of cumulate eucrites. On the basis of its modal mineralogy and its major element mineral chemistry the REE pattern of Y-791195 may be predicted to be between $3\times$ and $5\times$ C1 chondrites with a significant positive Eu anomaly. This unique meteorite deserves much further study to characterize it thoroughly. In particular, consortium-type studies of the isotopic and trace element compositions should be very fruitful.

The second main group of monomict, or essentially monomict, specimens are the seven pigeonite cumulate eucrites. These samples appear to represent three distinct meteorites, that together represent a new group within the basaltic achondrites. Three of these samples have been described elsewhere, classified as diogenites, and paired with Y-75032 (TAKEDA and MORI, 1984). There are, however, significant differences between these meteorites and the diogenites as represented by both the Antarctic and non Antarctic meteorite collection. Diogenites are dominated by orthopyroxene ($En_{70-80}Wo_{1-2}$) with minor amounts of olivine, plagioclase, chromite, troilite and metal (MASON, 1962; KEIL, 1969). These Y-79 specimens on the other hand contain inverted pigeonite or pigeonite+orthopyroxene ($En_{55-69}Wo_{1-4}$), plagioclase, silica together minor chromite, troilite, ilmenite and metal. The high abundance of pyroxene in these samples suggests that they are not the crystalline equivalents of magma compositions but were produced by crystal-liquid fractionation. None of the samples is sufficiently large and unbrecciated enough to permit a petrofabric analysis that would test for a cumulus texture. Therefore, these samples may be either cumulates from a mafic liquid or residua remaining after extraction of a mafic liquid phase. Note that the Mg/(Fe+Mg) of these meteorites could be in equilibrium with eucritic liquids (STOLPER, 1977). Since pigeonite or inverted pigeonite is the most characteristic mineral in these samples, we suggest that this group be called the "pigeonite cumulate eucrites" to preserve the nomenclature commonly in use and to distinguish these samples from the feldspar cumulate eucrites.

DELANEY *et al.* (1984c) have used ternary plots of modal orthopyroxene-clinopyroxene-feldspar and low Ca pyroxene-high Ca pyroxene-feldspar to portray modal variations among the basaltic achondrites (Figs. 25a, b). Plotting the samples studied into this diagram reveals several useful features. The three eucrites, as expected, plot in the field of the known eucrites. The pigeonite cumulate eucrites, however, define a new field in these diagrams that was not previously occupied. The samples plotted by DELANEY *et al.* (1984c) included feldspar cumulate eucrites, orthopyroxene cumulate eucrite (Binda), eucrites, diogenites, howardites and polymict eucrites. The pyroxene-

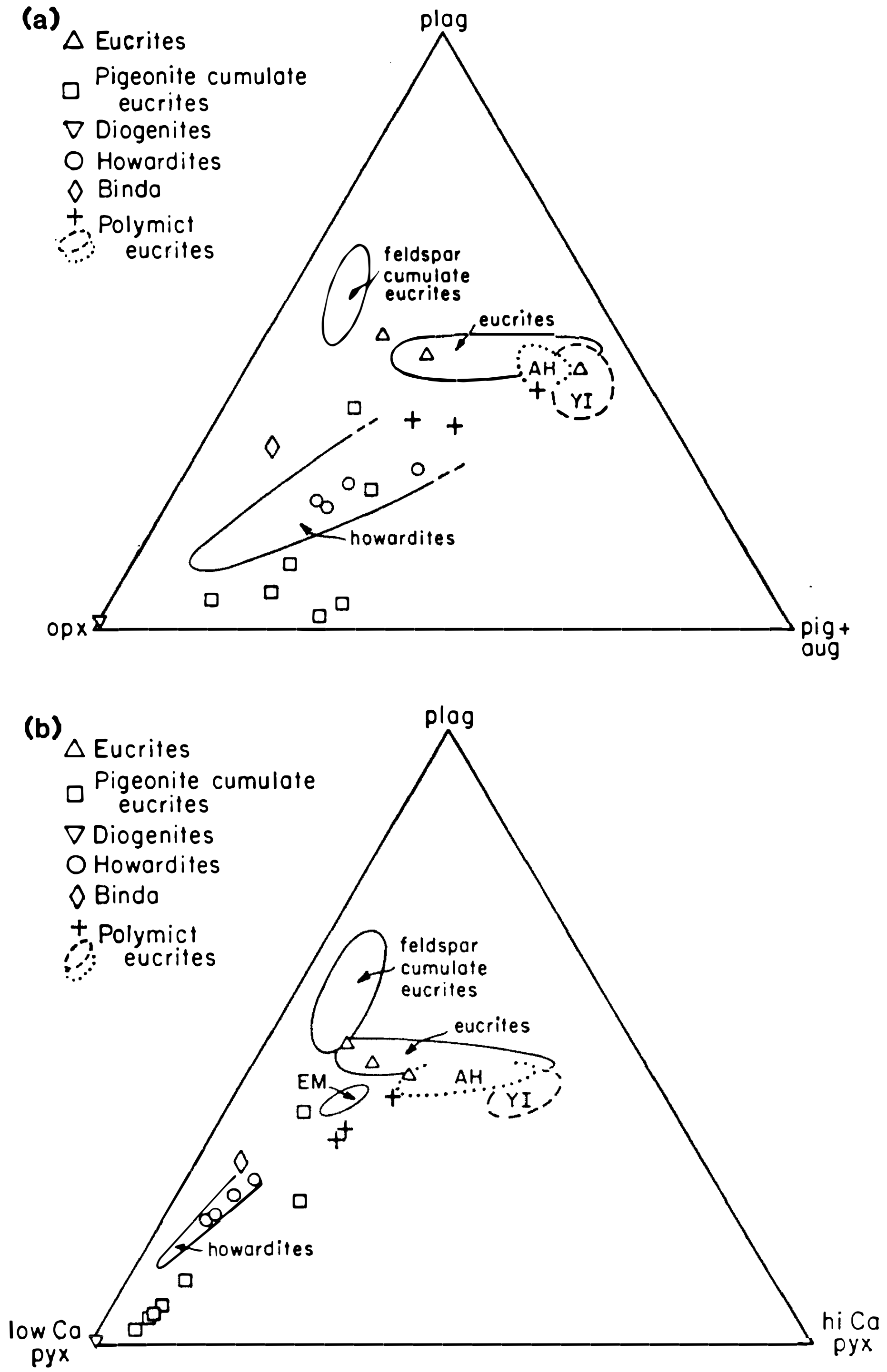

Fig. 25. (a) Orthopyroxene-clinopyroxene-feldspar modal ternary for Y-79 achondrites. All pigeonite and augite from modes are assigned to clinopyroxene. (b) As (a) but with pigeonite assigned to low Ca hand high Ca pyroxene in proportion to opx/aug ratio.

rich portion of the diagram was occupied only by diogenites, the orthopyroxene cumulate eucrite and the howardites which define a mixing line between diogenite and eucrite-like compositions. The pigeonite cumulate eucrites, however, are displaced on the clinopyroxene-rich side of the howardite field and define a field parallel to it (Fig. 25). The significance of this displacement toward more calcic pyroxene enrichment is not yet clear as part of the observed enrichment may be the contribution off the interstitial glass. Independent confirmation of this trend by bulk chemical analysis is desirable. These pigeonite-rich rocks may, however, be related to suites of relatively calcium-rich mafic rocks in howardites and mesosiderites that crystallized both pigeonite and augite from a melt (DELANEY, 1984; NEHRU *et al.*, 1980), rather than the one pyroxene phase (pigeonite) that crystallized in eucrites (BASALTIC VOLCANISM STUDY PROJECT, 1981). The modes of the pigeonite cumulate eucrites are intermediate between diogenites and eucrites (Fig. 1), however, whether they represent a transitional facies between these two meteorite groups as suggested by TAKEDA and MORI (1981, 1984) remains a hypothesis to be tested. The possibility that they are part of a basaltic achondrite fractionation sequence that led to the crystallization of two-pyroxene mafic rocks provides an alternative interpretation requiring detailed examination.

The polymict breccias examined in this study are comparable with the howardites and polymict eucrites examined by many previous workers. The four howardites appear to be samples of either one or two meteorites but do not appear to be paired with the previously known Yamato howardite Y-7308. These samples contain a diverse suite of lithic and mineral fragments that may provide greater constraints on the evolution of the basaltic achondrite parent body than may be had by study of the monomict achondrites alone (DELANEY *et al.*, 1981b). The polymict eucrite samples are generally less feldspar rich than the previously known Yamato polymict eucrites. If these samples are part of the same meteorite sampled by the Yamato 1974 and 1975 collections, then that meteorite is quite heterogeneous. The rare gas contents and cosmic ray exposure ages of these samples are needed to establish whether or not pairing of the many Yamato polymict achondrites (DELANEY *et al.*, 1984c) is justified. One sample (Y-791186) appears to be a metamorphosed polymict eucrite showing Fe-Mg homogeneity in its silicates. This meteorite, therefore, resembles the polymict eucrite sampled at Elephant Moraine in Victoria Land (EETA79004, 79011) and is distinct from the other Yamato polymict eucrites.

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