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MARE BASALT AND OTHER CLASTS IN YAMATO LUNAR METEORITES Y-791197, -82192 AND -82193

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Abstract: A study of lithic clasts >0.1 mm in size in new thin-sections of the lunar meteorites Y-791197, -82192 and -82193 revealed that Y-791197 and -82192 may contain components of low-Ti mare basalt, which has not previously been identified in any of the four known lunar meteorites. Of eleven clasts from Y-791197, one is a very low-Ti (VLT) mare basalt, four are ferroan mafic lithologies that are either low-Ti mare basalts or polymict breccias with a large component of low-Ti mare basalt, three are ferroan anorthositic rocks, and three are magnesian granulitic breccias. In Y-82192 and -82193 magnesian clasts, most of which are polymict, are relatively more abundant. Of nine clasts from Y-82192, one is a possible low-Ti mare basalt, two are ferroan mafic lithologies that are either low-Ti mare basalts or polymict breccias with a large component of low-Ti mare basalt, and six are more magnesian polymict breccias. Of four clasts from Y-82193, three are magnesian polymict breccias and one may be a fragment of a pristine Mg-suite lithology. The presence of a significant mare basalt component in at least three of the four lunar meteorites is consistent with orbital geochemical data that suggest that the farside highlands have a 30% component of mare basalts that may predate the final heavy lunar bombardment. The lunar meteorites need not be derived from a source region near visible maria. Available data are insufficient to say whether all four lunar meteorites were derived from a single impact.

1. Introduction

Antarctic meteorites ALHA81005, Y-791197, -82192 and -82193 are anorthositic regolith breccias from the lunar highlands, and are composed of a great variety of densely compacted lithic and mineral clasts, with various amounts of intergranular glass (see KEIL, 1985; YANAI and KOJIMA, 1985; TAKEDA *et al.*, 1985, 1986; OSTERTAG *et al.*, 1985; LINDSTROM *et al.*, 1985; YANAI *et al.*, 1986; BISCHOFF *et al.*, 1986). All four breccias contain ~25–30% lithic clasts >0.1 mm in size. In ALHA81005 and Y-791197 these clasts (excluding obvious melt rocks and glasses) are primarily of four types: ferroan anorthosites; ferroan mafic lithologies; very low-Ti (VLT) mare basalts; and magnesian, granulitic polymict breccias. In ALHA81005 the latter are most abundant, whereas in Y-791197 ferroan lithologies are more abundant (LINDSTROM *et al.*, 1985). Lithic clasts in Y-82192 and -82193 have not been characterized in as much detail as those in ALHA81005 and Y-791197, but similar lithologies appear to

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Table 1. Mineral compositions of clasts in three lunar Meteorites.

Clast designation	Size (mm)	Plagioclase (An)	Olivine (Fo, CaO)	Pyroxene (*mg*, Wo)
Y-791197,73-3				
1	0.3	96.9±0.6	—	19–68 3–38
2.2	0.7	97.4±0.6	67.1±0.8 0.3	53–69 11–34
3	0.4	97.7±0.5	65.8±1.2 0.4	34–64 18–40
4	0.6	96.3±0.4	67.1±1.5 0.05–0.4	73 5–8
7	0.4	96.1±0.2	57.8±0.4 0.2–0.3	63–68 11–37
9	1.5	96.6±1.4	52 0.1	40 6 50–60 35–40
10	0 7	97.5±0.4	61–62 0.1	40–65 6–20 58–70 37–39
2.1	0.35	96.4±0.3	—	57–61 5–11 67 39
5	0.9	96.9±0.2	78.2±1.1 0.1–0.2	81 6
6	1.0	96.6±0.6	81.3±0.4 0.1–0.2	—
8	1.4	96.1±0.5	79.0±0.3 0.1	81.0±1 2–3
Y-82192,50-3				
7	0.7	73–93	67.3±0.2 0.2	64–71 8–15 72–75 34–39
1	0.6	93.6±0.4	62–64 0.2	65–66 8–19 70 36
8	0.7	92.6±1.2	66.6±1.6 0.1–0.2	82 44
9	1.6	95.7±0.5	75.1±1.0 0.1	67–78 3–11 81 40
3.1	1.2	96.0±0.4	73.2±0.3 0.1	74–76 5–17 80 40

Table 1 (continued).

Clast designation	Size (mm)	Plagioclase (An)	Olivine (Fo, CaO)	Pyroxene (*mg*, Wo)
3.2	0.8	95.0±0.7	72.6±0.4 0.1	76 17 76–80 37–40
4.1	2.1×1.2	93.9±1.2	72.4±1.9 0.1–0.2	74 5
4.2	1.2	93.6±0.7	72.6±2.5 0.1–0.2	77 3
6	0.4	96.9±0.4	—	80 3–4
Y-82193,91-3				
1	0.85×0.35	—	—	78 ±0.3 3.3±0.4 81.6±0.5 43.1±0.6
2	0.4	96.0±0.9	65.9±0.2 0.1	69–71 6–15 73 35
3	0.3	93.7±2.3	71.0±1.1 0.1	69–70 7–12
4	1.3	94.1±0.7	71.2±0.4	72–75 6–9 77 40

be present (BISCHOFF *et al.*, 1986; TAKEDA *et al.*, 1986).

We examined lithic clasts >0.1 mm in size in the three thin-sections Y-791197, 73–3, -82192,50–3, and -82193,91–3, with special attention to possibly pristine highlands and mare lithologies. In this paper we describe a total of twenty-four clasts: eleven from Y-791197, nine from Y-82192 and four from Y-82193. Table 1 lists number designations, sizes, and major element compositions for these clasts. Our results show that clasts in Y-791197 are primarily ferroan anorthosites and mare basalts, in agreement with LINDSTROM *et al.* (1985). In Y-82192 and -82193 magnesian clasts, most of which are polymict, are relatively more abundant. Y-82192 contains one unmetamorphosed clast that is probably a low-Ti mare basalt, a lithology that has not previously been identified in any of the lunar meteorites. Y-791197 and -82192 both contain ferroan mafic clasts, with various textures, that we suggest are either low-Ti mare basalts or polymict breccias containing a significant component of low-Ti mare basalt.

2. Petrography and Mineral Compositions

2.1. *Y-791197*

One clast in Y-791197,73–3 (clast 1, 0.3 mm) is a VLT mare basalt with a subophitic texture (Fig. 1A). Its plagioclase varies only from An [100×molar Ca/(Ca+

Na)] 96 to 97, which is unusual for a mare basalt and might be a result of sampling bias, because there are only three plagioclase crystals (the largest ~0.3 mm) in the clast. However, TREIMAN and DRAKE (1983) observed a similarly restricted range of plagioclase composition in a well-sampled VLT basalt clast in lunar meteorite ALHA81005. Fe contents in the plagioclase (0.3–0.5 wt%) are typical of mare basalts and distinctly higher than those of highlands rocks (CROZAZ *et al.*, 1974). Major element compositions of pyroxenes (Fig. 2) are consistent with those of mare basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981) and similar to those of the VLT basalt clast in ALHA81005 (TREIMAN and DRAKE, 1983). Pyroxenes in the 81005 clast extend to more Fe-rich compositions than those of clast 1 [*mg* 00 *vs.* *mg* 19; $mg = 100 \times$ molar Mg/(Mg+Fe)], but this may be a result of poor sampling of clast 1. High-Ti, low-Ti, and VLT mare basalts can be distinguished from one another and from highlands lithologies on the basis of TiO_2-*mg* relations in pyroxenes. Pyroxenes in clast 1 have low TiO_2 contents (0.1–0.8%), typical of those in Apollo 17 VLT mare basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981). They show a trend of increasing TiO_2 content with decreasing *mg* (Fig. 3), which is indicative of crystallization from Ti-poor magmas that are not saturated with ilmenite. Similar trends are shown by pyroxenes in Apollo 17 and Luna 24 VLT mare basalts (TAYLOR *et al.*, 1977, 1978; VANIMAN and PAPIKE, 1977). NIELSEN and DRAKE (1978) used a plot of molar Ti/(Ti+Cr) *vs.* Fe/(Fe+Mg) in pyroxenes to distinguish VLT from low-Ti basalts. On this plot (Fig. 4), the pyroxenes in clast 1 fall within the field defined by Apollo 17 VLT basalts.

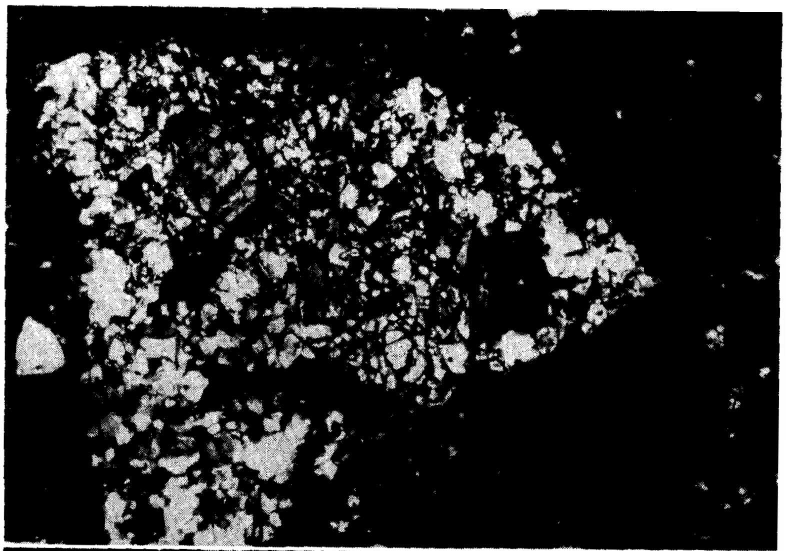
Four other clasts in Y-791197,73–3 are ferroan mafic lithologies that may be mare basalts or have mare basalt components. Two of these, clast 2.2 (~0.7 mm) and clast 3 (~0.4 mm) have subophitic textures (Fig. 1B, C). Both have uniform plagioclase compositions (~97), which is probably not a result of sampling bias because more than 10 crystals were analyzed in each clast. Both clasts contain olivine (Fo 66–67) with high CaO contents (0.3–0.4), typical of mare basalts (RYDER, 1984). The pyroxenes in these clasts are similar in major element compositions to those in VLT clast 1, though somewhat more magnesian (Fig. 2). TiO_2 contents of the pyroxenes (0.8–1.5 in clast 2.2 and 0.9–2.1 in clast 3) are higher than those of pyroxenes with the same *mg* in VLT clast 1 and typical of pyroxenes in low-Ti mare basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981). On the plot of molar Ti/(Ti+Cr) *vs.* Fe/(Fe+Mg) for pyroxenes (Fig. 4) these clasts plot unambiguously outside the VLT field, in an area of overlap between low-Ti mare basalts and highlands lithologies. However, TiO_2 contents of the pyroxenes show no systematic variation with *mg*. This may be a consequence of the relatively small range of *mg*. Fe contents of the plagioclase (0.2–0.5% in clast 2.2 and 0.1–0.5% in clast 3) are higher than those of plagioclase with the same An content in highlands rocks and are in the range of those for plagioclase in mare basalts (CROZAZ *et al.*, 1974). These clasts might be low-Ti mare basalts. However, they must be poorly sampled, because no ilmenite was observed. It is also possible that these clasts are polymict impact melts. Nevertheless, their mafic composition suggests that they contain a mare basalt component, because mare basalts are the most common mafic-rich lunar rock type. This component must be a mare basalt with higher TiO_2 than VLT mare basalts, though not necessarily identical to previously sampled mare basalt types.

A. VLT mare basalt clast 1 (0.3 mm diameter), Y-791197, 73–3. Crossed nicols.

B. Clast 2.2 (0.7 mm diameter), Y-791197, 73–3. Plane polarized light.

C. Clast 3 (0.4 mm diameter) on right, Y-791197, 73–3. Crossed nicols.

Fig. 1. Transmitted light photomicrographs of mare basalt and ferroan mafic clasts (low-Ti mare basalts?) in Yamato lunar meteorites.



D. Clast 4 (0.6 mm across), Y-791197, 73–3. Crossed nicols.

E. Low-Ti mare basalt clast 7, Y-82192, 50–3. Field of view 0.9 mm wide. Plane polarized light.

F. Clast 1, Y-82192, 50–3. Field of view 0.6 mm wide. Crossed nicols.

Fig. 1 (continued).

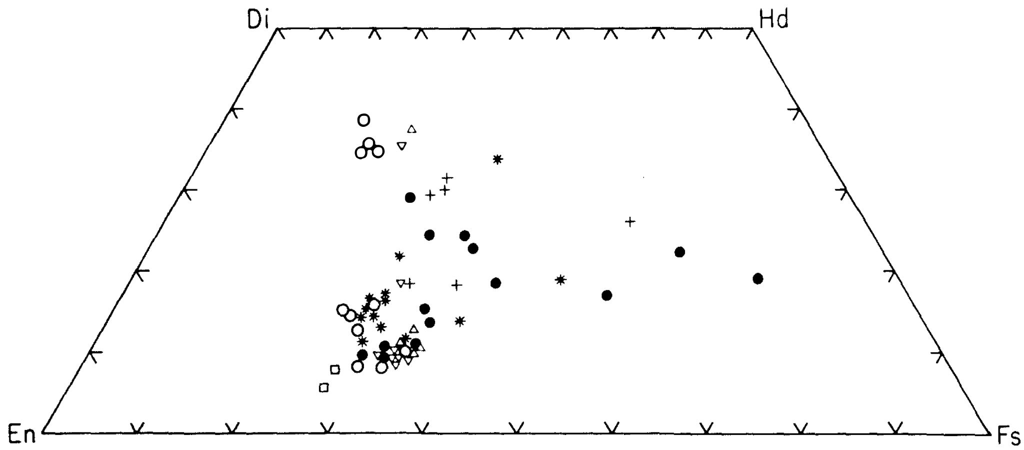


Fig. 2. Major element compositions of pyroxenes from basalts and ferroan mafic clasts in Y-791197,73–3 and -82192,50–3. ●=*clast 1, Y-791197.* ○=*clast 7, Y-82192.* *=*clast 2.2, Y-791197.* ▽=*clast 1, Y-82192.* +=*clast 3, Y-791197.* □=*clast 4, Y-791197.* △=*clast 7, Y-791197.*

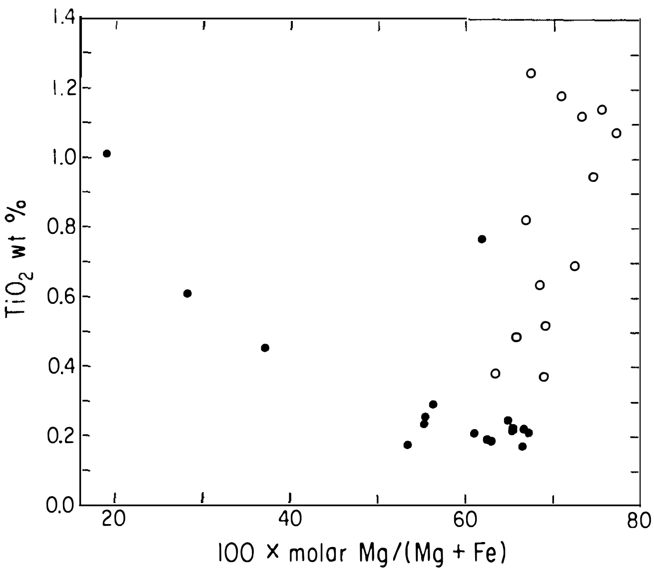


Fig. 3. Plot of wt% TiO_2 vs. 100× molar Mg/(Mg+Fe) for pyroxenes in VLT mare basalt clast 1, Y-791197,73–3 (filled circles) and low-Ti mare basalt clast 7, Y-82192,50–3 (open circles).

The two other clasts that might be low-Ti mare basalts, clast 4 (~0.6 mm) and clast 7 (~0.4 mm), have granular textures (Fig. 1D). Their mineral compositions are similar to those of clasts 2.2 and 3 (Table 1; Fig. 2). CaO in olivine in clast 4 is lower (0.05–0.1%) than in clasts 2.2 and 3, which could be a result of metamorphism. These clasts might be recrystallized mare basalts whose precursors were similar to clasts 2.2 and 3, or polymict breccias with a mare basalt component.

Three clasts in Y-791197,73–3 are ferroan anorthositic rocks. Clasts 9 (~1.5 mm) and 10 (~0.7 mm) are anorthosites that are only lightly shocked and have cumulate

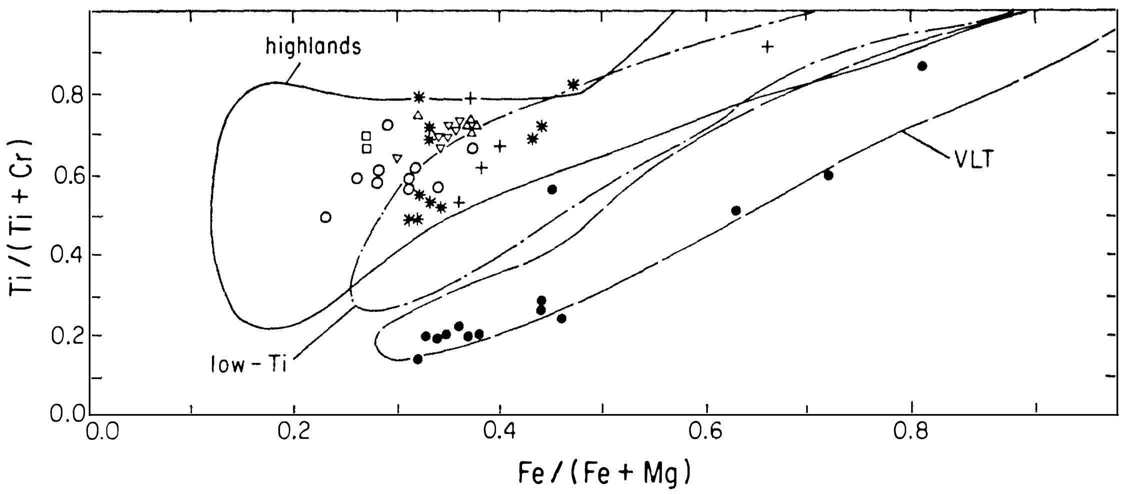


Fig. 4. Plot of molar Ti/(Ti+Cr) vs. Fe/(Fe+Mg) for pyroxenes in basalts and ferroan mafic clasts in Y-791197,73–3 and Y-82192,50–3. Symbols as in Fig. 2. Fields for VLT, low-Ti and highlands lithologies from NIELSEN *and* DRAKE *(1987).*

textures (maximum size of mafic minerals ~0.15 mm). On a plot of *mg* for mafics *vs.* An for plagioclase they plot within the field of pristine ferroan anorthosites (Fig. 5A). CaO contents of olivine are low (~0.1), and pigeonite and augite contains submicron exsolution lamellae. Pyroxenes in clast 9 plot within the field of highlands compositions of the Ti/(Ti+Cr) *vs.* Fe/(Fe+Mg) diagram (Fig. 4). Plagioclase in this clast has low Fe contents (0.06–0.14), distinctive of highlands anorthositic rocks (CROZAZ *et al.*, 1974). Pyroxenes in clast 10 show considerable scatter in Fig. 4, and the Fe contents of plagioclase range from 0.1 to 0.4. These features suggest that, compositionally, the clast is not completely pristine. Clast 2.1 is a noritic anorthosite with a granular (granoblastic) texture, which also plots within the ferroan anorthosite field in Fig. 5A and has plagioclase with low Fe contents (0.13–0.15). It is probably a metamorphosed ferroan anorthosite.

Three other clasts (clast 5, 0.9 mm; clast 6, 0.9 mm; clast 8, 1.4 mm) that we examined in Y-791197,73–3 are granulitic breccias. These clasts plot in the gap between ferroan anorthosites and Mg-suite rocks in Fig. 5 (see Table 1 for mineral compositions). They are texturally and compositionally identical to granulitic breccias in ALHA81005 (GOODRICH *et al.*, 1984; WARREN *et al.*, 1983a; RYDER and OSTERTAG, 1983), and like these are assumed to be polymict—mixtures of Mg-suite rocks and ferroan anorthosites.

2.2. *Y-82192*

Clast 7 (~0.7 mm) is a low-Ti mare basalt with a subophitic texture (Fig. 1E). Plagioclase ranges from An 73 to 93, which is more typical of mare basalts than the restricted compositional range of plagioclase in the Y-791197 basalts. Fe contents of plagioclase (0.1–0.7) are typical of mare basalts, but overlap with those of KREEP breccias and basalts (CROZAZ *et al.*, 1974). Nevertheless, the K contents are much lower than in KREEPy plagioclase. Pyroxene compositions (Fig. 2) are consistent with those of low-Ti mare basalts of Appollo 12 or 15 (BASALTIC VOLCANISM STUDY PROJECT, 1981), but are relatively restricted in *mg* (64–75), and are more magnesian than in the Y-791197 basalts. The more Fe-rich part of pyroxene compositional trends shown by Apollo 12 and 15 low-Ti basalts is absent. TiO_2 contents of the pyroxenes (0.4–1.2%) are typical of pyroxenes with similar *mg* in low-Ti mare basalts. In terms of molar Ti/(Ti+Cr) *vs.* Fe/(Fe+Mg), the pyroxenes are distinct from VLT compositions, but are in an area of overlap between low-Ti mare basalts and highlands lithologies (Fig. 4). However, on a plot of TiO_2 *vs.* *mg* (Fig. 3) they show a trend of decreasing TiO_2 with decreasing *mg*, which is indicative of concurrent crystallization of ilmenite and typical of low-Ti mare basalts. Surprisingly, the ilmenite content of this clast is low (<1%). This might be a result of poor sampling, although mineral grain sizes of the clast (plagioclase laths 0.2–0.3 mm long, pyroxenes typically 0.09 mm) are relatively small compared to the clast size.

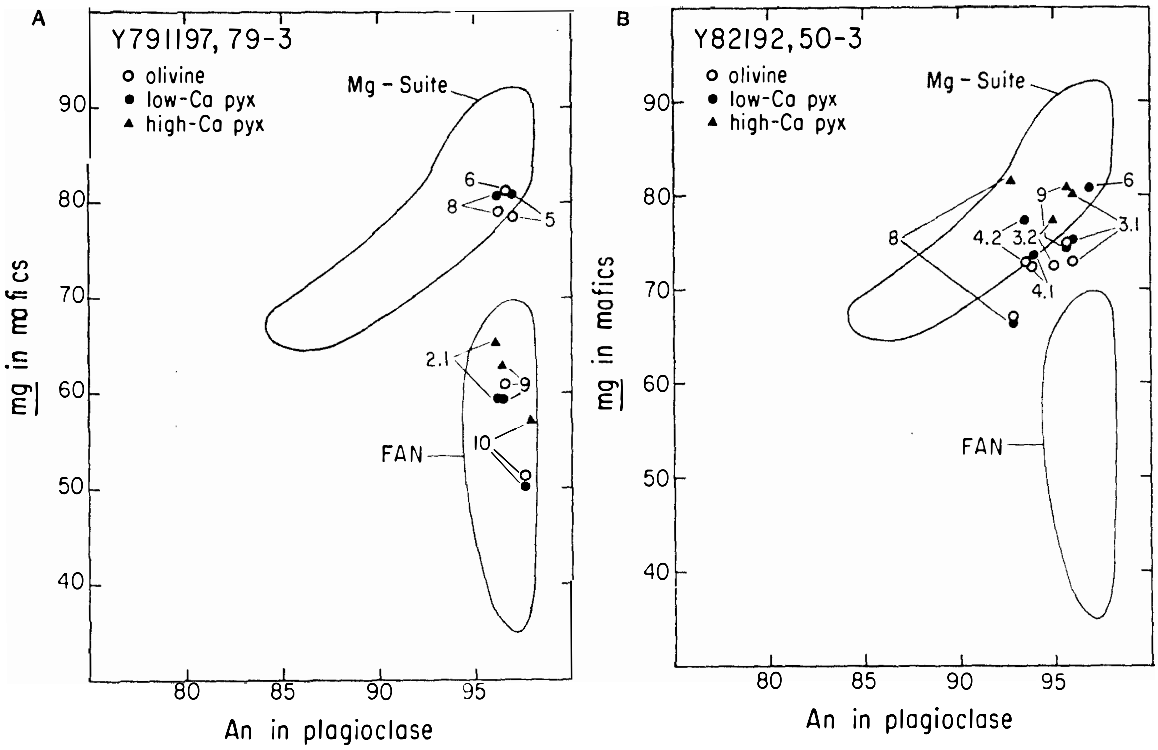
Clast 1 (0.6 mm), which has a poikilitic-granulitic texture, (Fig. 1F) is compositionally similar to basalt clast 7 (Table 1; Fig. 2), except for a restricted range of plagioclase composition (An 93.6 ± 0.4), similar to that of the basalts in Y-791197. Fe contents of plagioclase (0.2–0.3) are unambiguously higher than those of plagioclase with the same An content in highlands rocks (CROZAZ *et al.*, 1974). TiO_2 contents of the pyroxenes (0.7–2.5%) are typical of low-Ti mare basalts. However, in terms of molar Ti/(Ti+Cr) *vs.* Fe/(Fe+Mg), they plot in the region of highlands lithologies (Fig. 4) and show no systematic variation of TiO_2 with *mg*. Like the ferroan mafic clasts in Y-791197, this clast is either a metamorphosed low-Ti mare basalt, or a breccia with a significant low-Ti mare basalt component.

Clast 8 (0.7 mm) is a gabbroic clast with a somewhat ambiguous texture that is probably a result of melting and/or recrystallization. Olivine and pigeonite appear to form a network around rounded plagioclase laths, and have rims of what is probably a very fine-grained melt product of mafic minerals and plagioclase (this material contains 16–18% Al_2O_3, 11–12% CaO, 9–16% FeO and 7–9% MgO). Mineral compositions (Table 1) span the gap between ferroan anorthosites and the Mg-suite (Fig. 5B). This clast is probably a polymict breccia. The relatively low An content of its plagioclase (~94) suggests that it might have a mare basalt component.

Clast 9 (~1.6 mm) is a highly-shocked gabbroic anorthosite with a few relict mafic grains (0.3 mm), and extensive melted areas consisting of fine-grained intergrowths of plagioclase and mafics. Mineral compositions (Table 1) span the gap between the Mg-suite and ferroan anorthosites (Fig. 5B). This clast resembles impact melt breccias in ALHA81005 (GOODRICH *et al.*, 1984) and is probably a mixture of highlands lithologies.

Four clasts, 3.1 (~1.2 mm), 3.2 (~0.8 mm), 4.1 (~2.1×1.2 mm) and 4.2 (~1.2 mm) are fine-grained (<100 μ) granulitic breccias, similar to those in Y-791197 and ALHA81005. Like those, their mineral compositions (Table 1) span the gap between ferroan anorthosites and Mg-suite rocks (Fig. 5B) and they are probably mixtures of highlands lithologies.

Clast 6 (0.4 mm) contains a single plagioclase crystal surrounding a single grain of pigeonite that has an irregular, rounded shape. This texture is ambiguous and could



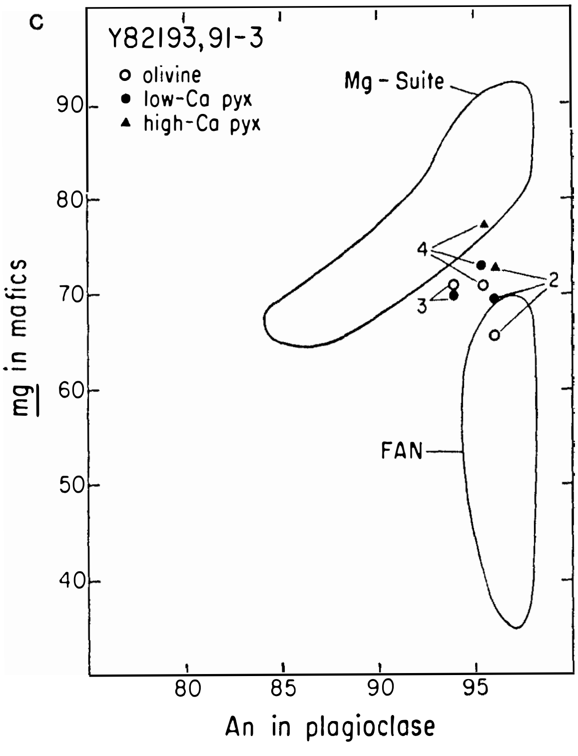


Fig. 5. Plot of mg in mafic minerals vs. An in plagioclase for nonmare clasts in Y-791197, 73-3 (A), Y-82192, 50-3 (B), and Y-82193, 91-3 (C). Fields for Mg-suite rocks and ferroan anorthosites from WARREN *et al. (1983c), as modified by* TREIMAN *and* DRAKE *(1983). Numbers refer to clasts as designated in text.*

be metamorphic or igneous. Mineral compositions (Table 1) are just within the Mg-suite field (Fig. 5B). This clast might be a fragment of a pristine Mg-suite norite, but might also be a polymict melt-rock.

2.3. Y-82193

Clast 1 is a fine-grained impact melt rock, containing an 0.85×0.35 mm fragment of a single pyroxene crystal. The crystal is pigeonite (*mg* 78, Wo 3) with exsolution lamellae of augite (*mg* 82, Wo 43). These compositions are similar to those of Mg-suite rocks. The relatively coarse grain size, presence of exsolution lamellae indicating slow cooling, and composition of this mineral fragment suggest that it is a relict from a crystalline (possibly pristine) Mg-norite or gabbronorite.

Two gabbroic clasts, 2 (~0.4 mm), and 3 (0.3 mm), have somewhat indistinct boundaries and ambiguous textures (subophitic-fragmental). They have similar mineral compositions (Table 1), which plot within or span the gap between pristine, Mg-suite-rocks and ferroan anorthosites (Fig. 5C) and are probably polymict breccias.

Clast 4 (~1.3 mm) is a granulitic breccia and is texturally and compositionally similar to granulitic breccias in Y-791197, -82192 and ALHA81005 (Table 1; Fig. 5C).

3. Discussion

3.1. Summary of clast types

Of eleven clasts >0.1 mm in size in Y-791197,73–3, eight are ferroan rocks representing pristine lunar lithologies (mare basalts, ferroan anorthosites, ferroan mafic rocks). Of nine clasts >0.1 mm in Y-82192,50–3, only two are ferroan (mare basalt and ferroan mafic rock), and of four clasts >0.1 mm in Y-82193,91–3, none are ferroan. The remaining clasts in these 3 samples are more magnesian, polymict breccias whose mineral compositions fall within or span the gap between those of pristine Mg-suite rocks and ferroan anorthosites (Fig. 5). Our results agree with those of LINDSTROM *et al.* (1985) in indicating the dominance of ferroan lithologies in Y-791197. Y-82192 and -82193 resemble ALHA81005 (WARREN *et al.*, 1983b; RYDER and OSTERTAG, 1983) in having a greater proportion of magnesian lithologies. No definite clasts of pristine Mg-suite rocks have been found in any of the lunar meteorites.

3.2. Basalt clasts

One subophitic VLT mare basalt clast was found in lunar meteorite ALHA81005 (TREIMAN and DRAKE, 1983). The VLT mare basalt clast 1 in Y-791197,79–3 is texturally and compositionally similar to the 81005 clast. Mesostasis is not represented in clast 1, but this is probably due to sampling bias and may also be the reason that the very Fe-rich pyroxenes found in the 81005 clast were not observed in clast 1. Two basalt clasts separated from Y-791197 were identified as VLT mare basalts by LINDSTROM *et al.* (1985). One of these has a subophitic-granular texture and appears to be similar to the 81005 clast and to clast 1. All three of these basalts have a very restricted range of calcic plagioclase composition (An 94–98, 96–97, and 90–93), more restricted than that of Apollo 17 or Luna 24 VLT basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981). They nevertheless show a wide range in pyroxene composition (*e.g.* *mg* 00 to 55), similar to that of Apollo 17 or Luna 24 basalts. The second Y-791197 clast that was considered by LINDSTROM *et al.* (1985) to be a VLT is a quenched melt with a bulk TiO_2 content of 1.9%. This is higher than TiO_2 contents of Apollo 17 or

Luna 24 VLT basalts (~0.4–1%) and more typical of Apollo 15 low-Ti mare basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981). We suggest that this clast represents a low-Ti mare basalt magma. LINDSTROM *et al.* (1985) also found a mare basalt fragment apparently consisting mostly of mesostasis (pyroxferroite, hedenbergite, troilite) in Y-791197. This fragment is probably similar to the HPF clast (containing pyroxferroite-hedenbergite, plagioclase, fayalite, silica and troilite) described by TAKEDA *et al.* (1985) in Y-791197,120–1. The sizes of these clasts are insufficient to indicate whether they represent low-Ti or VLT basalts.

VLT mare basalts have not been observed in Y-82192 or -82193. TAKEDA *et al.* (1986) observed that Fe-rich ($mg< \sim 50$) pyroxene fragments are absent in these meteorites and suggested that this indicates a lack of mare basalt component. However, clast 7 in Y-82192,50–3 appears to be a low-Ti basalt. Paradoxically, although this clast has a typically wide range of plagioclase composition (An 73 to 93) with high (mare-like) Fe contents, it has a restricted range of relatively magnesian pyroxene compositions. If this basalt has been representatively sampled, then a significant low-Ti mare basalt component could be present in these two meteorites without contributing Fe-rich pyroxenes.

3.3. *Ferroan mafic clasts*

Ferroan mafic lithologies have been reported in ALHA81005 (TREIMAN and DRAKE, 1983; WARREN *et al.*, 1983a; GOODRICH *et al.*, 1985) and Y-791197 (LINDSTROM *et al.*, 1985). These clasts, which vary in texture from subophitic, to granular, to "relict cumulate" (WARREN *et al.*, 1983a), are compositionally similar to ferroan anorthosites but are noritic or gabbroic in mode. We have described four clasts in Y-791197 and one in Y-82192 that are modally and compositionally similar to these and have subophitic or granular textures. Ferroan mafic lithologies are rare among Apollo or Luna samples. Noritic ferroan anorthosite 67215 (WARREN *et al.*, 1983b) is the best example, but even this rock is less mafic than the ferroan mafic clasts in the lunar meteorites. It has been suggested that these clasts are products of the magma(s) that produced ferroan anorthosites (GOODRICH *et al.*, 1985). However, it seems likely that at least some of them are low-Ti mare basalts, or are polymict and contain a significant component of low-Ti mare basalt. As discussed above, the Ca contents of their olivines and the Fe contents of their plagioclases are typical of mare rather than highlands rocks. The same is true of the ferroan gabbroic norite in ALHA81005 that was described by GOODRICH *et al.* (1984). They have a very restricted range of plagioclase composition, which is not in general typical of mare basalts but appears to be typical of VLT basalts in ALHA81005 and Y-791197. They also have a relatively restricted range of magnesian pyroxene compositions. However, this is also the case for the one clast in Y-82192 that, with reasonable certainty, appears to be a low-Ti mare basalt. Whether these ferroan mafic clasts are mare basalts or breccias with a mare basalt component, the mare basalt magmas that they represent were low-Ti magmas. At least two mare basalt magmas are therefore represented among the lunar meteorites.

3.4. *Lunar meteorite source region*

All four lunar meteorites are similar in terms of petrography (YANAI and KOJIMA, 1985; YANAI *et al.*, 1986; OSTERTAG *et al.*, 1985; BISCHOFF *et al.*, 1986; TAKEDA *et al.*, 1985, 1986) and chemistry (WARREN and KALLEMEYN, 1985, 1986; FUKUOKA *et al.*, 1985, 1986; TAKAHASHI *et al.*, 1985, 1986; KACZARAL *et al.*, 1985, 1986; NAKAMURA *et al.*, 1985, 1986). Furthermore, petrographic and chemical data indicate that Y--82192 and -82193 are probably paired (YANAI *et al.*, 1986; BISCHOFF *et al.*, 1986; FUKUOKA *et al.*, 1986). However, there are also significant differences between these meteorites. Y-82192 and -82193 contain much less glass than Y-791197, which contains less than ALHA81005 (BISCHOFF *et al.*, 1986). All four have distinct volatile/mobile trace element ratios (KACZARAL *et al.*, 1986). Y-791197 and -82192 have lower bulk *mg* (62 and 65, respectively) than ALHA81005 (74.9) (WARREN and KALLEMEYN, 1986), which is reflected in the variations in their lithic clast populations observed by LINDSTROM *et al.* (1985) and in our study. Nevertheless, these differences are not great enough to rule out the possibility that all four lunar meteorites were derived from the same general source region by one impact, because lunar regolith breccias from Apollo sites show considerable local heterogeneity (*e.g.* MCKAY *et al.*, 1986). Cosmic ray exposure histories could, theoretically, distinguish more than one impact event among the lunar meteorites. However, modeling of exposure histories on the basis of cosmogenic nuclides is complex, because exposure occurred both on the moon and in space, and the samples could have been at various depths in the regolith and meteoroid(s). Preliminary cosmogenic nuclide data and modeling of exposure history are indeterminate (NISHIIZUMI *et al.*, 1986).

In any case, the source regions of all four lunar meteorites must be highlands areas low in KREEP, rich in ferroan anorthosite, including some hyperferroan anorthosite, and with VLT and probably low-Ti mare basalt components. The presence of a significant component of mare basalt in the lunar meteorites is consistent with orbital geochemical data that suggests that the lunar farside highlands have a 30% mare basalt component (DAVIS and SPUDIS, 1985). As discussed by DAVIS and SPUDIS (1985), these mare basalts may be older than the final heavy lunar bombardment. Therefore, the lunar meteorite source region(s) need not be near visible maria.

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