Mem. Natl Inst. Polar Res., Spec. Issue, 46, 3–20, 1987

GEOCHEMISTRY OF LUNAR METEORITE YAMATO-82192: COMPARISON WITH YAMATO-791197, ALHA81005, AND OTHER LUNAR SAMPLES

Paul H. WARREN and Gregory W. KALLEMEYN

Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California 90024, U.S.A.

Abstract: We report INAA compositional data for a 171 mg bulk-rock sample of lunar meteorite Yamato-82192, and for two small clasts extracted from the matrix. The two clasts were also studied petrographically, but both appear to be polymict impact melt breccias, not greatly different in composition from the bulk rock. Like two previously-studied lunar meteorites, Y-82192 is a regolith breccia from a highlands region with remarkably low contents of incompatible elements, by the standards of the small region of the central near side that was explored by the Apollo and Luna sample-return missions. Based on disparities in *mg* between Y-82192 and ALHA81005, and in Eu/Al and Na/Al between Y-82192 and -791197, we argue that these meteorites probably formed at three different locations, many km apart. Considering the low probability that a crater exists which is both sufficiently large and sufficiently young to account for all three meteorites, we conclude that more than one, and probably more than two, impacts were responsible for launching these samples off the Moon. It follows that at least one of these meteorites is almost certainly a product of the Moon's far side. The coincidence that all three are regolith breccias may be explained by postulating that these rocks were created out of incoherent soils by shocks associated with the same impacts that launched them off the Moon.

1. Introduction

The 36.7 g Yamato-82192 achondrite was first described by YANAI and KOJIMA (1984), who concluded from its overall composition, mineralogy, and texture, particularly the low MnO/FeO ratios of its mafic silicates, that this meteorite originated as a regolith breccia (a mass of lithified former soil) in a highlands region of the Earth's Moon. This discovery is obviously of great importance to lunar science. The six Apollo (manned, U.S.A.) and three Luna (unmanned, U.S.S.R.) sampling sites were confined to a small area of the central near side, around which a polyhedron could be drawn covering just 4.7% of the lunar surface (WARREN *et al.*, 1983). The exact sources of lunar meteorites such as Y-82192 may never be unambigously determined, but the majority are presumably not from this same 4.7% of the surface. Despite pervasive mixing by great impacts, available data for the ancient, nonmare lunar crust indicate considerable lateral heterogeneity (ADLER and TROMBKA, 1977; WARREN and TAYLOR, 1981). Lunar meteorites are therefore extremely valuable as constraints on lateral variations in the composition and petrology of the lunar crust.

Two other meteorites of lunar highlands regolith origin had previously been discovered: Y-791197 (YANAI and KOJIMA, 1984), found about 80 km north of Y-82192; and ALHA81005, found 3000 km across Antarctica from Y-82192. Another lunar stone, Y-82193 (27.0 g; not studied for this work) was found within a few meters of Y-82192, which it resembles petrographically (BISCHOFF *et al.*, 1986; TAKEDA *et al.*, 1986b; YANAI *et al.*, 1986) as well as compositionally (FUKUOKA *et al.*, 1986b). The Y-82192 and -82193 stones are therefore presumably paired, *i.e.*, from a single fall that broke up either low in the Earth's atmosphere or upon impact with the Earth's surface.

From the standpoint of value of these meteorites as samples of the lunar crust, the worst possible scenario would be that all three of them (or four, if Y-82192 and -82193 are counted as separate meteorites) came from a single impact-induced launch off the Moon's surface. Of the six manned missions that returned with lunar rock samples, only Apollo 16 ventured to land at a "true" highlands site, remote from all mare basalt terrains. According to classifications by RYDER and NORMAN (1980), only about 9.1% of Apollo 16 rock samples are regolith breccias (the remainder comprising fragmental breccias, 35%; impact melt breccias, 35%; impact glass fragments, 7%; dilithologic breccias, 4%; and others, 10%). Assuming these statistics are representative, a crude statistical calculation therefore implies that the probability for three totally random lunar highlands rocks all being regolith breccias would be $0.091^3=0.0008$. Actually, the abundance of regolith breccias among Apollo 16 rocks might be artificially low, because Apollo regolith breccias tend to be friable, and friable rocks probably tended to be difficult for the astronauts to pick up and transport (SPUDIS, 1984). Nevertheless, the fact that all three lunar meteorites are regolith breccias strongly suggests a common origin, and thus, by the simplest possible interpretation, a common provenance. The presence of large traces of mare basaltic material in both ALHA81005 (TREIMAN and DRAKE, 1983) and Y-791197 (LINDSTROM *et al.*, 1986) is another remarkable similarity. A major current task for lunar science is to test the single-launch-site hypothesis for the lunar meteorites. Resolution of this question will affect interpretation of these meteorites in terms of lateral variations in the composition and petrology of the Moon's crust; and in terms of natural processes capable of transporting rock fragments from other planets to the Earth—with ramifications for the debate as to whether the "SNC" achondrites are derived from Mars (*e.g.*, MCSWEEN, 1985) or merely from (an) asteroid(s) (*e.g.*, VICKERY and MELOSH, 1983).

One way to test the single-launch hypothesis is to compare precise geochemical data for the three meteorites. In any case (but especially if the single-launch hypothesis is not correct), estimates of the bulk composition, mineralogy, and degree of lateral homogeneity of the Moon's crust will have to be revised based on the new data for Y-82192 and the other lunar meteorites. Models of crustal genesis will also have to be revised, based particularly on compositional-petrographic results for individual lithic clasts. Ultimately, models of lunar bulk composition and origin will have to be re-examined based on the lunar meteorites. We have analyzed by instrumental activation analysis (INAA) three samples of Y-82192: bulk-rock (matrix) sample Y-82192,71, clast Y-82192,52A, and clast Y-82192,83B.

2. Analytical Procedures

The INAA procedure used was similar to that of KALLEMEYN and WARREN (1983). Resulting data for 36 elements are shown in Table 1. Unless otherwise specified in Table 1, uncertainties from counting statistics are $\leq$5% (relative). Uncertainties and detection limits tend to be far higher for the two tiny clasts than for the larger bulk-rock sample. All three samples were analyzed as received from Tokyo; both clasts had already been extracted from surrounding matrix materials. After being irradiated and counted for INAA, the clasts were converted into thick sections and studied petrographically (including electron probe analyses). Finally, the thick sections of the clasts were converted into polished thin sections for transmitted-light petrography. The thin section of the tiny ,83B clast was unfortunately lost when it "plucked out" during final polishing of the thin section. Bulk-rock sample Y-82192,71 appears heterogeneous (Fig. 1), though less so than typical samples of ALHA81005 and Y-791197 (*e.g.*, WARREN and KALLEMEYN, 1986). Important sampling "errors" are inevitable when small fragments of such a heterogeneous material are analyzed.

3. Descriptions of the Two Analyzed Clasts

Clast Y-82192,52A has a texture (Fig. 2) that is difficult to precisely classify: cataclastic, at least mildly granulitic, but conceivably monomict (pristine). The mode of our tiny (4-mm^2, in two pieces) thin section has about 80 vol% plagioclase, the remainder being roughly 12 vol% pyroxene and 8 vol% olivine. A trace of ilmenite is present, and a few tiny grains of Fe-metal, but none large enough to analyze even with the electron probe. The largest intact plagioclase in the section is 0.4 mm across; the largest pyroxene is 0.16 mm across. About half of the area of the thin section consists of aphanitic-glassy impact debris, which in places appears to be in a resorption relationship with the rims of the coarser grains. In some areas the texture of this groundmass material appears to be micropoikilitic, as typically found in impact melt breccias. However, grain sizes show a continuous gradation up to the aforementioned maxima, and in places the texture shows signs of monomict cataclasis of an originally coarse-grained anorthosite. Thus, conceivably the lithology as a whole is pristine, albeit severely shock-metamorphosed. More likely, however, this lithology is a complex polymict assemblage dominated by a coarse anorthosite plus an aphanitic-micropoikilitic impact melt. The bulk-clast Ni content (Table 1) is high even for a mafic pristine rock, and especially for a pristine rock with so much plagioclase (*e.g.*, Al=158 mg/g); thus, the bulk-clast Ni datum tends to indicate that the clast is not pristine.

If it is pristine, as admittedly seems unlikely, clast Y-82192,52A would be compositionally unique, bridging the "gap" between ferroan anorthosites and Mg-rich rocks. Its plagioclase is consistently Na-poor, averaging An-96.35$\pm$0.62, with a range among 25 analyses of 95.26–97.67 (possible normal zoning, from An-96.95 to An-95.62, was apparent in one lath-shaped grain). The mafic silicates have Mg/(Mg+Fe) ratios that are neither "ferroan" nor "Mg-rich." Olivine averages Fo-70.5$\pm$1.4, with a range among 6 analyses of 67.8–71.6. Pyroxenes (Fig. 3) have average molar Mg/(Mg+Fe) (abbreviation: *mg*)=0.755$\pm$0.006 among 6 analyses with Wo contents

Table 1. New data for Y-82192 and, for comparison, averaged compositions of other lunar regolith samples.

	Y-82192 whole-rock 171.1 mg	Y-82192 clasts ,52A 6.4 mg	Y-82192 clasts ,83B 3.5 mg	Y-791197 wtd. mean, literature	ALHA81005 wtd. mean, literature	Luna-20 soil, lit. average	Ap-16 soil, lit. average	Ap-17 soil 73141	Ap-14 regolith brec. 14315
Na mg/g	2.73	2.71	4.39	2.43	2.24	2.45	3.50	3.12	4.9
Mg mg/g	32±5	31±7	12±4	36.8	49.4	58	35	58.8	48.8
Al mg/g	134	158±12	165±13	138.3	136	121	143	113	115
K mg/g	0.173±20	0.14±2	0.26±3	0.221	0.194	0.59	0.92	1.17	2.75
Ca mg/g	102	140±10	138±8	110.2	107	103	112	92.9	92.0
Ti mg/g	2.1±4	<5	<6	2.02	1.57	2.8	3.4	7.3	5.0
Fe mg/g	44.7	26.2	13.1	49.5	42.7	60.0	41.0	62.3	59.3
Sc μg/g	13.5	6.6	6.2	13.3	9.1	16.4	9.3	16.2	15.6
V μg/g	36±4	15±5	25±8	32	24.6	27	20	37	—
Cr μg/g	1010	700	500	900	890	1500	720	1480	1400
Mn μg/g	600	380	226	660	580	800	530	840	820
Co μg/g	16.7	12.8	4.0±5	18.7	21.0	20.0	27.0	27.2	31.5
Ni μg/g	122±8	115±21	<200	174	198	260	377	239	390
Zn μg/g	7.3±7	23±2	45±5	34.5	8.7	21	18	16	34
Ga μg/g	2.8±3	4.0±3	5.5±5	5.9	2.7	3.2	5.4	2.6	5.9
Br ng/g	<170	—	—	176	190	140	140	110	—
Sr μg/g	143±12	147±45	250±60	134	135	144	163	137	152
Zr μg/g	24±9	<360	235±75	32	26.8	120	167	219	460
Cs ng/g	<160	<770	<800	64	24	70	87	236	420
Ba μg/g	22±5	<140	<180	31	28.4	94	127	154	390
La μg/g	1.54	1.34±8	1.91±12	2.11	1.98	6.3	12.0	15.5	38
Ce μg/g	3.78±21	3.3±7	2.4±8	5.49	5.2	18.0	31.0	37.8	91
Nd μg/g	2.32±33	—	—	3.47	3.2	10.8	19.0	24.9	53
Sm μg/g	0.68	0.46	0.33	1.05	0.95	3.1	5.7	7.0	14.3
Eu μg/g	0.87	0.83	1.30	0.78	0.69	0.94	1.20	1.20	1.56
Tb μg/g	0.174±16	—	—	0.253	0.214	0.65	1.13	1.5	3.1

Table 1 (continued).

	Y-82192 whole-rock 171.1 mg	Y-82192 clasts ,52A 6.4 mg	Y-82192 clasts ,83B 3.5 mg	Y-791197 wtd. mean, literature	ALHA81005 wtd. mean, literature	Luna-20 soil, lit. average	Ap-16 soil, lit. average	Ap-17 soil 73141	Ap-14 regolith brec. 14315
Dy μg/g	1.28±21	0.75±13	—	1.53	1.33	4.1	7.4	9.3	19.9
Ho μg/g	0.243±19	0.15±3	0.17±5	0.34	0.31	—	—	2.4	4.3
Yb μg/g	0.79	0.47±7	0.65±20	0.99	0.84	2.4	4.0	5.4	10.7
Lu μg/g	0.121	0.063±15	—	0.146	0.124	0.39	0.59	0.80	1.55
Hf μg/g	0.73	0.31±7	0.32±12	0.84	0.73	2.4	4.1	5.2	11.3
Ta μg/g	0.038±11	<0.5	<0.7	0.103	0.093	0.30	0.51	0.75	1.32
Ir ng/g	6.4	<8	<4	6.6	6.8	9.5	11.1	12	18.8
Au ng/g	1.4±4	—	—	5.1	2.2	6.4	7.3	6	12.7
Th μg/g	0.188±14	<0.32	<0.43	0.33	0.29	1.10	1.90	2.4	5.6
U μg/g	0.058±13	—	—	0.116	0.098	0.33	0.56	0.70	1.38
mg	0.622	0.73	0.68	0.631	0.737	0.689	0.662	0.684	0.654

The Y-791197 composition is a mass-weighted mean of data from eight studies (see text). Composition for Apollo-14 regolith breccia 14315 is an average of data from ROSE *et al.* (1972) and JERDE *et al.* (1987). See KALLEMEYN and WARREN (1983) regarding sources of data for ALHA81005, Luna 20 soil, Apollo 16 soil, and Apollo 17 soil 73141.

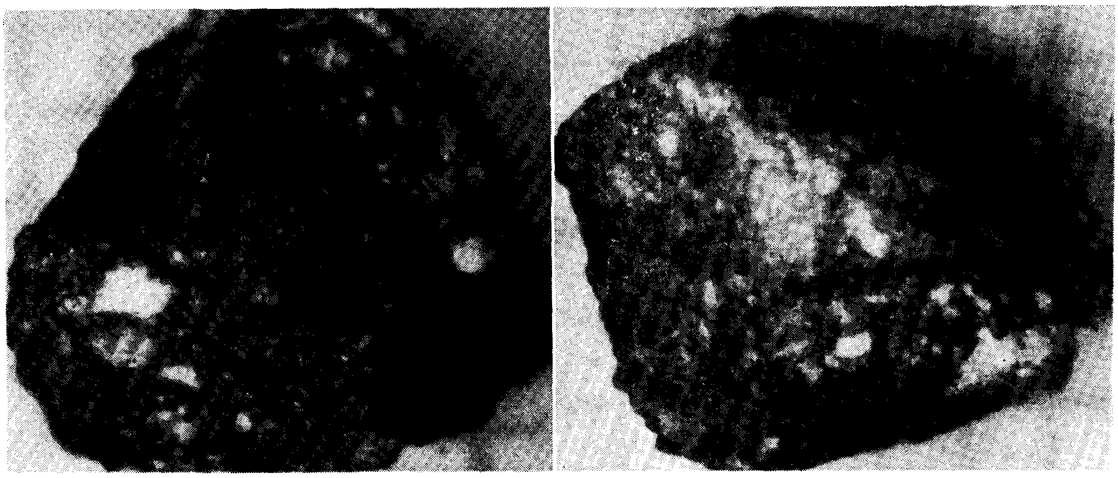

Fig. 1. Macroscopic views of bulk-rock sample Y-82192,71. Note heterogeneity. Divisions in background = mm.

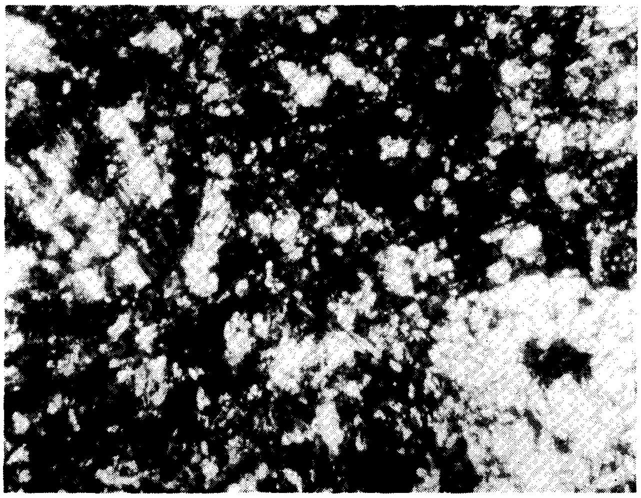

Fig. 2. Transmitted light (crossed nicols) photomicrograph of clast Y-82192,52A. View is 0.9 mm long.

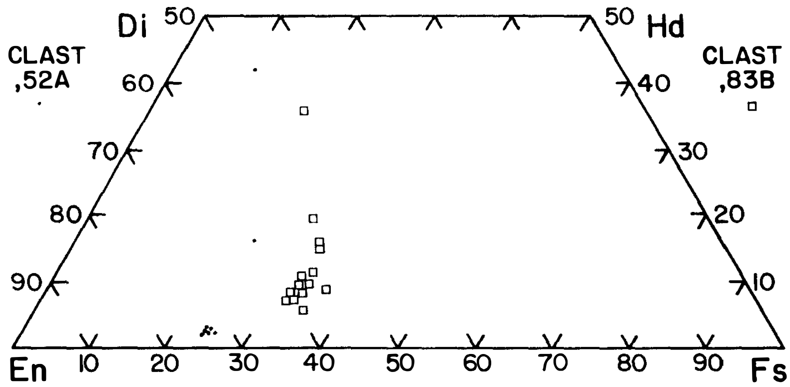

Fig. 3. Pyroxene Mg-Fe-Ca proportions for clasts Y-82192,52A and -82192,83B.

≤3.4. These mineral compositions would place clast ,52A about midway between ferroan anorthosites and Mg-rich rocks on the type of diagram (average plagioclase An *vs.* average *mg* in low-Ca mafic silicates) most commonly used to classify pristine non-mare rocks (*e.g.*, Fig. 3 of WARREN *et al.*, 1983). The bulk-clast data (Table 1) for *mg* and plagiophile element ratios such as Na/(Na+Ca), Ga/Al and Eu/Al, similarly indicate a composition about midway between ferroan anorthosites and high-*mg* members of the Mg-rich group (*cf.* Figs. 1–3 of WARREN, 1986). The possibility that clast ,52A is a unique type of pristine lithology highlights the desirability of further studies of individual clasts separated from lunar meteorites.

Clast Y-82192,83B is easier to classify. The thin section (observed only briefly, before the "plucking" mishap) contained roughly 85–90 vol% plagioclase and 10–15 vol% pyroxene. Its texture was that of an impact melt rock: fine-grained, with dominantly lath-shaped plagioclase. Mineral-composition data corroborate this interpretation. Plagioclase is non-uniform, averaging An-95.1±1.7, with a range among 23 analyses of 90.2–97.1. The pyroxene is mostly unexsolved pigeonite (Fig. 3), with *mg* ranging from 0.603–0.656. Such mineral compositions are not normal for plutonic lunar anorthosites, but they are typical for impact melt breccias. Apparently, based on the low *mg* ratios of the pyroxenes as well as the bulk clast (Table 1), a major component of this polymict clast is ferroan anorthosite.

4. Comparison with Other Lunar Regolith Samples

Our INAA results confirm that Y-82192 is a regolith breccia from the lunar highlands. For example, the Y-82192 whole-rock Fe/Mn ratio (74.5, Table 1) is typical for a lunar regolith sample. As noted by LAUL and SCHMITT (1973), Fe/Mn is nearly constant at 80 (±about 5) among all Apollo and Luna soils. The Y-82192 Fe/Mn ratio is essentially identical with the Fe/Mn ratios of Y-791197 and ALHA81005 (71.2 and 73.6, respectively), and distinctly higher than the Fe/Mn ratios for plagioclase-rich meteorites from parent bodies other than the Moon: eucrites, howardites, and "SNC" achondrites, all have Fe/Mn ratios close to 40 (KALLEMEYN and WARREN, 1983).

Regolith breccias such as Y-82192, -791197, and ALHA81005 form by mechanical consolidation of former lunar soil. Compositional data for these samples may be appropriately compared with corresponding data for actual lunar soils artificially brought to Earth. Table 1 also shows average literature data for lunar regolith materials from several additional locations, and for the Y-791197 and ALHA81005 meteorites. The composition shown for Y-791197 is a mass-weighted mean of data from 8 different studies (FUKUOKA *et al.*, 1986a; KACZARAL *et al.*, 1986; LINDSTROM *et al.*, 1986; NAKAMURA *et al.*, 1986a; OSTERTAG *et al.*, 1986; TAKAHASHI *et al.*, 1986; WARREN and KALLEMEYN, 1986; YANAI and KOJIMA, 1984). Aside from the lunar meteorites, and regolith samples from Apollo 16 and Luna 20, few regolith samples of purely highland origin are available. All soils, and all large regolith breccias, from Apollos 11, 12 and 15, and from Lunas 16 and 24, probably contain too much mare material to be meaningfully compared with Y-82192. Apollo 14 soils, *sensu stricto*, not only contain a considerable mare component, they are also extraordinarily rich in incompatible elements such as Th and K (ADLER and TROMBKA, 1977). However, 14315, a uniquely Al-rich and Ti-poor regolith breccia from Apollo 14 (JERDE *et al.*, 1987), is comparatively low in KREEP and mare components. Likewise, although most Apollo 17 soils contain considerable mare components, soil 73141, the most Al-rich soil from Apollo 17 (for references, see WARREN and KALLEMEYN, 1986), appears to be nearly free of mare material. In other words, Y-82192 generally resembles 14315 and 73141 more closely than it resembles any other regolith sample from the Apollo 14 and 17 sites, respectively.

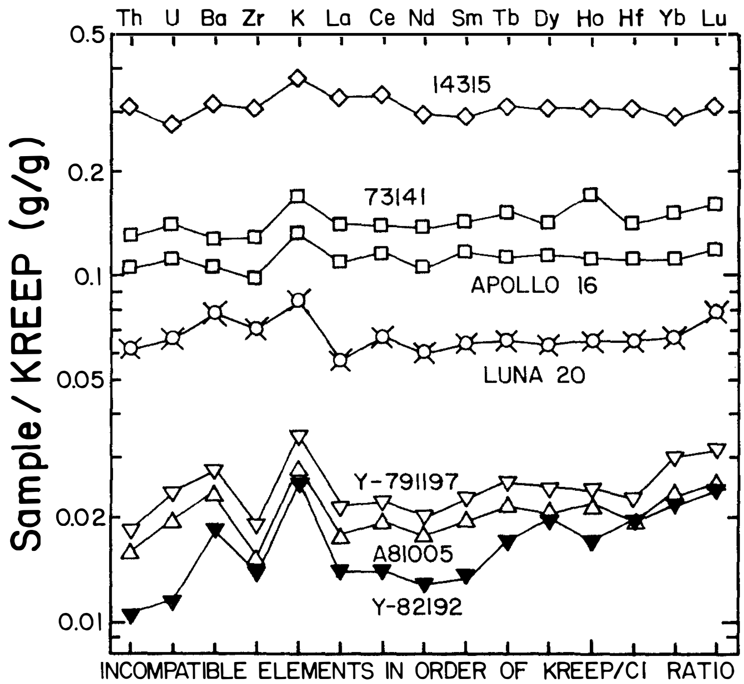

Fig. 4. Incompatible element concentrations in bulk-rock sample Y-82192,71, and averages of literature data for other lunar regolith samples (Table 1), normalized to average high-K KREEP (WARREN and WASSON, 1979).

Incompatible element concentrations in Y-82192,71 (Fig. 4) are remarkably similar to those of ALHA81005 and Y-791197, and far lower than those of most other lunar regolith samples. The crust in the region(s) that spawned these meteorites was apparently close to, if not entirely, devoid of KREEP. A Ta "anomaly" for Y-82192 is at best only marginally significant, due to the large uncertainty in our Y-82192 Ta datum (Table 1). Nonetheless, the striking similarity among the three meteorites on Fig. 4 is potentially misleading, concerning the degree of proximity of their provenances. Orbital spectrometry data (ADLER and TROMBKA, 1977) indicate that abundant KREEP is found almost exclusively in the central near side, *i.e.*, the very region sampled by the Apollo and Luna missions. Thus, the uniformly low incompatible element contents of Y-791197, ALHA81005, and Y-82192 might simply reflect separate origins at more representative locations, scattered across the far side and/or parts of the near side such as the eastern limb.

Enrichments of volatile elements such as Zn and Ga in several analyses of Y-791197 led to a suggestion (KACZARAL *et al.*, 1985) that Y-791197 could not have come from the same lunar region as ALHA81005. Our own analysis (WARREN and KALLEMEYN, 1986) found only modest Zn and Ga enrichments in Y-791197 *vs.* ALHA81005, and we find that Y-82192 has considerably lower Zn and Ga concentrations than Y-791197 (Table 1). Further, the upper limit we find for Br indicates modest overall contents of volatile elements (as we also inferred from our Br datum for Y-791197 (WARREN and KALLEMEYN, 1986)). Note, however, that the two Y-82192 clasts (,52A and ,83B) have far higher Zn and Ga than the bulk rock (,71).

One possibly significant difference between Y-791197 and ALHA81005 is that Y-791197 has a far lower *mg* ratio (WARREN and KALLEMEYN, 1986). Our *mg* ratio for Y-82192 (0.622) is based on an INAA Mg datum that has a relatively high uncertainty (nominally 14%). However, NAKAMURA *et al.* (1986b) and FUKUOKA *et al.* (1986b) report similarly low *mg* ratios of 0.613 and 0.626, respectively (the latter figure is an average for Y-82192 and -82193). ALHA81005 analyses (KOROTEV *et al.*, 1983; LAUL *et al.*, 1983; PALME *et al.*, 1983; KALLEMEYN and WARREN, 1983) consistently indicate an *mg* ratio between 0.721 and 0.739—higher than that of any other lunar regolith sample. In stark contrast, Y-82192 and -791197 both have unusually low *mg* ratios (Fig. 5). The *mg* range between Y-82192 and ALHA81005 exceeds the range among regolith breccias from Apollo 16, which come from traverse stations as far as 8.5 km apart in an area specifically chosen to straddle two genetically distinct formations (the Cayley Plains and Descartes Highlands formations). In fact, orbital gamma-ray spectrometry data (Fig. 6) suggest that the Apollo 16 site is an area of extraordinarily steep gradient in regolith *mg* ratio. Taken at face value, the results of HUBBARD and WOLOSZYN (1977) imply that the regolith *mg* ratio varies from 0.77 just 200 km to the west of the Apollo 16 site, to 0.60 just 200 km to the east; and even these figures, being limited by the spatial resolution of the orbital spectrometry method, represent averages of large (roughly 60×60 km) areas of the crust: the actual range, including variations at scales <60 km, could be much more extreme than 0.60–0.77.

The 8.5 km spread among Apollo 16 sampling stations cannot be taken as an

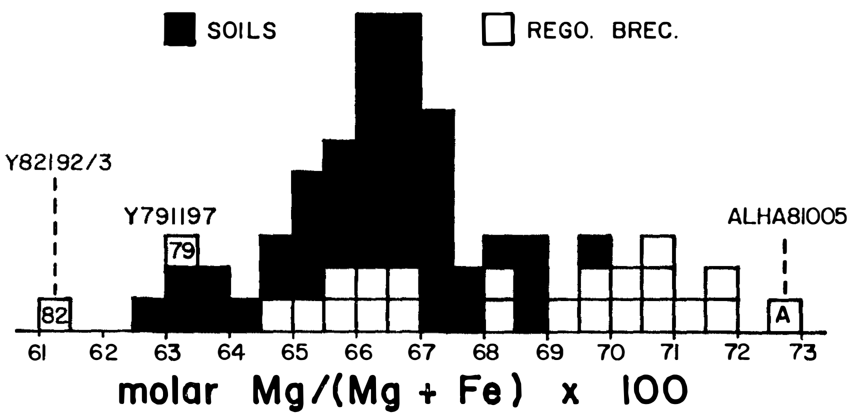

Fig. 5. Histogram of mg ratios for lunar meteorites, and for comparison, Apollo 16 regolith samples. Lunar meteorite mg ratios are from Table 1 except for Y-82192, which is an average of the Table 1 datum and data for Y-82192 and -82193 by FUKUOKA *et al. (1986b) and* NAKAMURA *et al. (1986b). Data for Apollo 16 regolith samples are from* MCKAY *et al. (1986),* JERDE *et al. (1987), and compilations of earlier data by* RYDER *and* NORMAN *(1980) and* MORRIS *et al. (1983).*

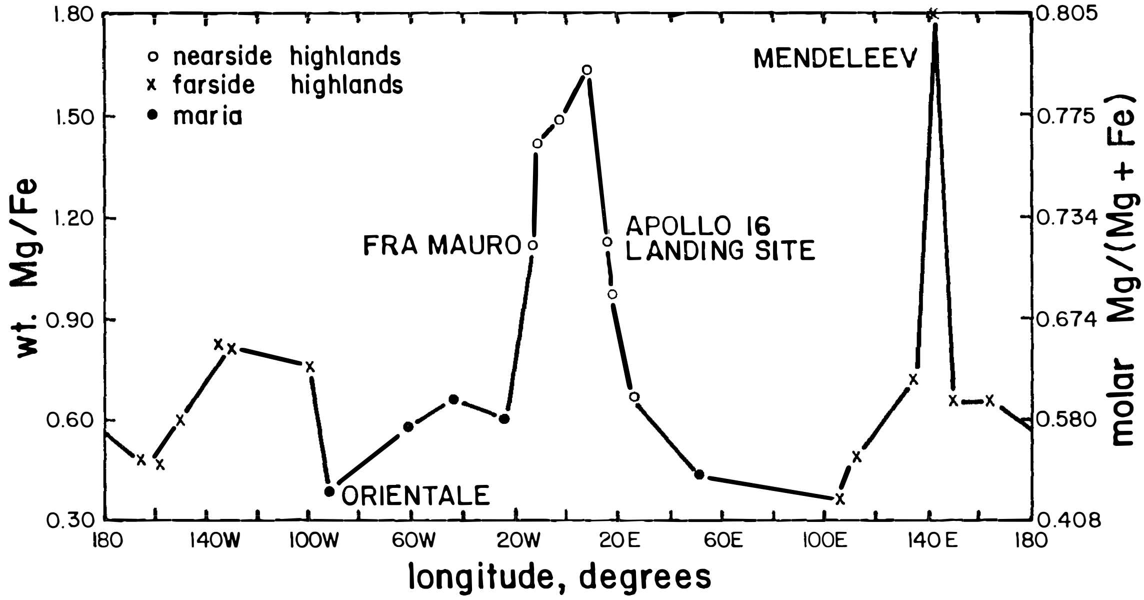

Fig. 6. Results from Apollo 16 orbital spectrometer experiment (as interpreted by HUBBARD and WOLOSZYN, 1977): mg ratio vs. longitude along a ground track which passed directly over the Apollo 16 site at 15.5°E.

absolute standard for comparison, because all of the Apollo 16 soils (including core samples) were taken from within about 2.2 m of the surface, whereas the lunar meteorites probably originated at various depths; *e.g.*, ALHA81005 and Y-791197 appear to have originated at depths "on the order of meters" with Y-791197 significantly shallower than ALHA81005 (SUTTON, 1986). However, the Apollo 16 deep drill core displays "remarkable chemical uniformity" over its whole 2.2 m length, with a far smaller range in *mg*, 0.653–0.689 (NAVA *et al.*, 1976; see also EHMANN *et al.*, 1977; GOLD *et al.*, 1977), than is found among soils from Apollo 16 (Fig. 5). Even at the Apollo 17 site, which (by design) straddles a mare/highlands boundary, a 2.9 m deep drill core manifests only slight compositional heterogeneity: the range for *mg* is 0.483–0.548 (LAUL and PAPIKE, 1980).

The huge disparity in *mg* ratio between Y-82192 and ALHA81005 (Fig. 5) imposes a key constraint on the origins of these meteorites. In order to account for them both as products of a single launch, without assuming that they were many km apart before the impact, we would have to assume that the impact happened to strike an exceptionally heterogeneous area. The possibility of a heterogeneous source region is of course impossible to rule out, but the *mg* disparity is not simply a result of impact at a site close to a mare basalt formation. At the Apollo 17 site, for example, soils were obtained from stations up to 11.5 km apart. Mixing of mare basalt with highland material causes the *mg* ratios of these soils to range from about 0.684 for the most nearly pure highlands soil (73141: Table 1) down to about 0.483 for a nearly pure mare soil such as 75061 (RHODES *et al.*, 1974). However, this variation in *mg* ratio is accompanied by tell-tale variations in other compositional parameters, most notably Al content (Fig. 7). No such drop-off in Al content accompanies the decrease in *mg* ratio between ALHA81005 and the other two lunar meteorites (Fig. 8). Thus, the *mg* disparity

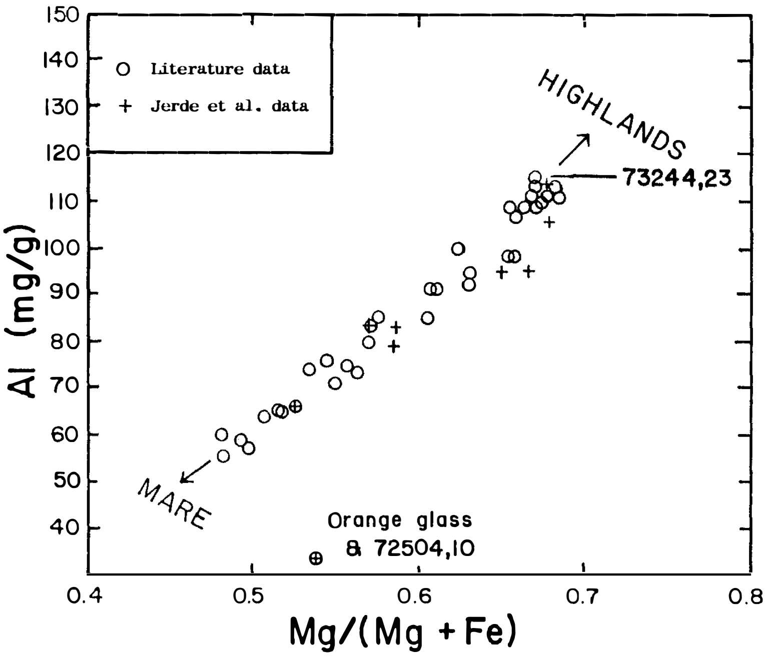

Fig. 7. An excellent correlation between Al and mg (caused by mixing between mare basalts and higher-Al, higher-mg highland materials) is observed among Apollo 17 regolith samples. After JERDE *et al. (1987).*

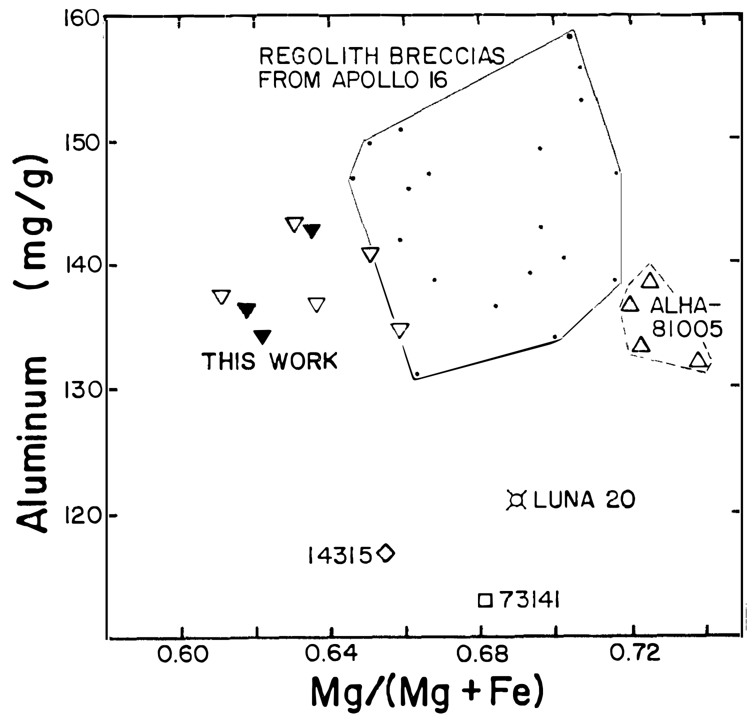

Fig. 8. Al content vs. mg ratio for lunar meteorites, and for comparison, 21 Apollo 16 regolith breccias (references: see Fig. 5) and other lunar regolith compositions from Table 1. Unfilled inverted triangles represent individual literature analyses of Y-791197 (references: see text), and filled inverted triangles represent individual analyses of Y-82192 or -82193 (Table 1, and FUKUOKA *et al., 1986b).*

between ALHA81005 and Y-82192 strongly suggests a pre-launch separation at least comparable to the 8.5 km spread between the Apollo 16 sampling stations; and a separation of $\gg$8 km seems preferable.

Although Y-82192 and -791197 have compositions that are remarkably similar in most respects, including *mg* ratios, there are some important differences between these two meteorites. TAKEDA *et al.* (1986b) find that extremely Fe-rich pyroxenes are common in both ALHA81005 and Y-791197, but completely lacking in Y-82192 (and -82193). We note that compared to Y-791197 and ALHA81005, Y-82192 has higher contents of certain "plagiophile" (plagioclase-loving) elements such as Eu and Na. Figure 9 shows our data, and the data of FUKUOKA *et al.* (1986b), for Eu and Na, normalized to Al in order to exclude the possibility that the Eu and Na enhancements are artifacts of over-sampling of plagioclase at the expense of mafic silicates. To put these disparities into perspective, the field around the Apollo 16 regolith average shows the range among all Apollo 16 regolith samples. Although not as significant as the *mg* disparity between Y-82192 and ALHA81005, the Eu/Al and Na/Al disparities between Y-82192 and -791197 suggest a pre-launch separation at least comparable to the 8.5 km spread between the Apollo 16 sampling stations.

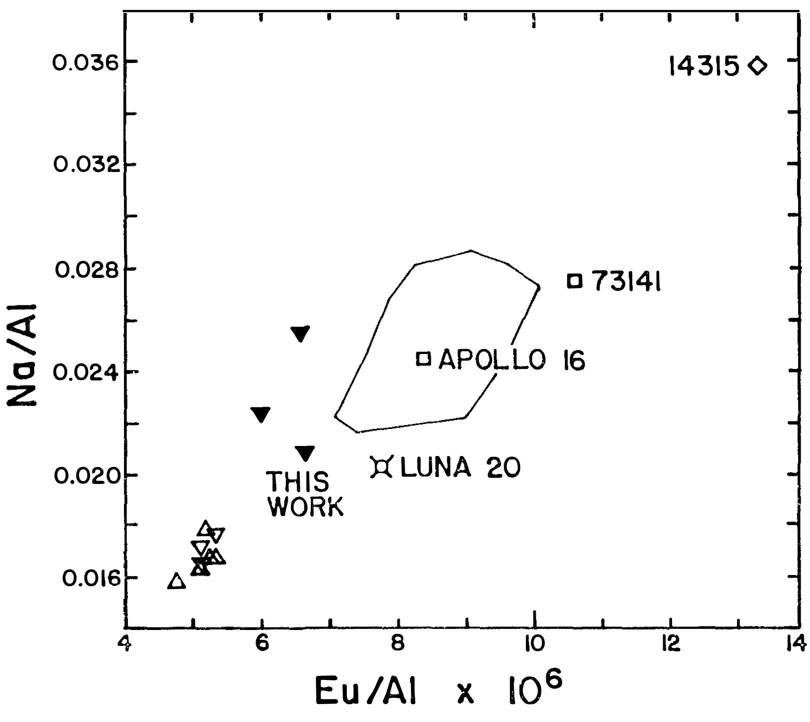

Fig. 9. Eu/Al vs. Na/Al (weight ratios) for lunar meteorites, and for comparison, other lunar regolith compositions, including a field surrounding 21 Apollo 16 regolith breccias. For explanation of symbols and data sources, see Fig. 8.

NISHIIZUMI *et al.* (1986) report that the terrestrial age of ALHA81005 is 0.17 ± 0.05 Ma. This result is backed up by an upper limit reported by TUNIZ *et al.* (1983), <0.6 Ma. Two different studies have yielded upper limits for the Moon-Earth transit time for ALHA81005: "probably" <0.1 Ma (NISHIIZUMI *et al.*, 1986), and <2500 years, based on thermoluminescence data (SUTTON and CROZAZ, 1983). The age of the impact that propelled ALHA81005 to Earth is therefore apparently 0.17 ± 0.05 Ma, and almost certainly <0.3 Ma. The age of the Y-791197 impact is presently not as precisely constrained, but it is probably less than about 0.12 Ma (NISHIIZUMI *et al.*, 1986), assuming that the Moon-Earth transit took <0.02 Ma (SUTTON, 1986).

The number of craters that have been blasted into the Moon's surface in a given interval of the recent past can be estimated, as a function of crater size, based on extrapolation from ages determined for cratered surfaces studied through the Apollo program (*e.g.*, HARTMANN, 1983). This approach relies heavily on assumptions that the absolute ages of a few exceptionally young craters, most notably Copernicus and Tycho, have been reliably measured through indirect sampling; hence, the uncertainty of the results is difficult to even estimate. HARTMANN (1983) suggests that the uncertainty is a factor of 3. GRIEVE and DENCE (1979) find that cratering rates estimated based on land surfaces of the Earth agree, after correction (division by 1.5) for Earth-Moon differences in such factors as surface gravity, with HARTMANN's estimated cratering rates to within a factor of 1.2; or, using GRIEVE's (1984) revised estimate for the terrestrial cratering rate over the past 120 Ma, to within a factor of 1.6 (GRIEVE suggests that this terrestrial estimate has an uncertainty of a factor of 2, and that the Earth-Moon correction factor has an uncertainty of about 40%). HARTMANN's (1983) Fig. 10-22c implies that within the last 0.3 Ma only about 1 crater ≥ 3 km in diameter is likely to have formed on the Moon; the probability that a crater ≥ 8 km formed in the last 0.3 Ma is roughly 0.15; and the probability that a crater ≥ 20 km in diameter formed in the last 0.3 Ma is roughly 0.03. A distinct possibility remains that a crater >8 km in diameter happened to form <0.3 Ma ago. But even if it did, and if several meteorites reached us from random points within such a crater, these meteorites would seldom be from points $\gg 4$ km apart: the average separation would be about half the diameter of the crater. RYDER and OSTERTAG (1983) suggested that Giordano Bruno, a crater 20 km in diameter, is the source of ALHA81005. A crater such as Giordano Bruno might conceivably have yielded regolith breccias with *mg* ratios as disparate as ALHA81005 *vs.* Y-82192—but only if Giordano Bruno happens to be surprisingly young, and happens to be situated in an exceptionally heterogeneous area of the lunar crust.

Preliminary ^{10}Be results of NISHIIZUMI *et al.* (1986) suggest that Earth-Moon transit for Y-82192 took "more than a few million years." If correct, this result and the suggestions of <0.3 Ma ages for the ALHA81005 and Y-791197 launches would by themselves disprove the single-launch hypothesis. The extreme disparity in *mg* between ALHA81005 and the two Yamato meteorites (particularly Y-82192), and the disparities in plagiophile ratios between Y-82192 and both ALHA81005 and Y-791197, are also difficult to reconcile with the single-launch hypothesis.

The aluminum (plagioclase) content of Y-82192 is similar to those of previously analyzed lunar highlands regolith samples (Fig. 8). The average plagioclase content of the ancient crust is a key line of evidence in support of the lunar magmasphere hypothesis (WARREN, 1985). A magmasphere is probably the only plausible means of producing a crust with an average plagioclase content much greater than that of a basaltic partial melt (*i.e.*, much greater than about 55 wt%). The Al content of Y-82192 is high enough to strengthen the case for a primordial lunar magmasphere;

especially to the degree that Y-82192, -791197, and ALHA81005 come from widely-separated lunar locations.

5. Discussion: Clasts Found in Lunar Meteorites

We have now chemically analyzed a total of four clasts from lunar meteorites: two from Y-791197 (WARREN and KALLEMEYN, 1986) and two from Y-82192 (this work). All four, with the possible exception of Y-82192,52A, have turned out to be impact melt (polymict) breccias, and all four are similar in bulk composition, including trace elements (*e.g.*, Table 1), to the matrix portions of these meteorites. Clasts analyzed by other groups (*e.g.*, KOROTEV *et al.*, 1983; LAUL *et al.*, 1983; FUKUOKA *et al.*, 1986b) have also been generally similar in composition to the matrices of the host meteorites. Evidently the clasts in these meteorites tend to be well-mixed polymict breccias, and hence are compositionally akin to the regolith breccias themselves.

LINDSTROM *et al.* (1986) argue that "plutonic anorthositic norite" is the most abundant "precursor" component of the lunar meteorites; *i.e.*, more important than norite (*sensu stricto*) or anorthosite. In lunar nomenclature (STÖFFLER *et al.*, 1980), anorthositic norite is defined as differing from norite (*sensu stricto*) and anorthosite only by having an intermediate plagioclase content. LINDSTROM *et al.* (1986) apparently base their conclusion on the fact that the lunar meteorites have bulk compositions that resemble anorthositic norite. All four of these meteorites are polymict breccias, formed by thorough mixing of millions of fragments of pulverized, unrelated rock debris. The total mass of the largest lunar meteorite (Y-791197) is only 52.4 g, and the largest individual clast among the lunar meteorites is probably $\ll 1$ g. The anorthositic norites invoked by LINDSTROM *et al.* (1986) are presumably coarse-grained cumulates, for which a sample of the order 100 g would be necessary to be even approximately "representative" in terms of proportions of plagioclase to pyroxene and olivine. We see little hope for accurately distinguishing among anorthosites, norites, and anorthositic norites, on the basis of samples never larger than 1 g.

In terms of lunar crustal genesis, the most interesting clasts tend to be those that are compositionally pristine (unaltered by impact-induced mixing). Only a few such clasts have been found within lunar meteorites. In ALHA81005, WARREN *et al.* (1983) found a small but indubitably pristine clast of coarse-grained cumulate ferroan gabbro. Presumably, by analogy with larger Apollo rocks, this clast is an under-representative sample of a ferroan anorthosite. However, its pyroxenes tend to be unusually Ca-rich and Mg-poor for a ferroan anorthosite. GOODRICH *et al.* (1984) found a clast of "hyperferroan" anorthosite (see also TREIMAN and DRAKE, 1983), apparently pristine, in ALHA81005. TAKEDA *et al.* (1986a) describe a hedenbergite-plagioclase-fayalite clast, apparently pristine based on its compositional uniqueness, in Y-791197. An apparently monomict-brecciated clast ("II-1") described from Y-791197 by YANAI and KOJIMA (1984) consists mainly of An-96.9 plagioclase and Fo-56.6 olivine, and thus is apparently (except for a possibly under-representative mode) a typical pristine ferroan anorthosite. A very similar "crystalline" ferroan anorthosite clast is described from Y-82192 by TAKEDA *et al.* (1986b). With the possible (but unlikely) exception of clast Y-82192,52A, no clast has been found that combines a pristine texture with mineral chemistry befitting an Mg-rich rock, or even a lithology intermediate between ferroan anorthosites and Mg-rich rocks. The significance of this lack of Mg-rich rocks is limited by the small number of pristine-textured clasts; indeed, the common occurence of olivines as magnesian as Fo-92 (*e.g.*, YANAI and KOJIMA, 1984) suggests that Mg-rich lithologies are important components within all of these meteorites. It seems clear, however, that pristine rocks with "ferroan" mineral chemistry are common at the point(s) of origin of ALHA81005, Y-791197 and -82192.

6. Conclusions

The Yamato-82192 meteorite is definitely a product of the lunar highlands. In terms of major elements, its composition resembles soils from Luna 20 and Apollo 16, but its contents of incompatible trace elements are even lower than observed previously in lunar meteorites ALHA81005 and Y-791197. All three of these meteorites, and particularly Y-82192, probably formed at least 1000 km distant from the KREEP-rich area of the Moon's central near side that happened to be explored by the Apollo landings. The fact that these three meteorites are all regolith breccias is a remarkable coincidence, consistent with the hypothesis that all three samples were propelled from the Moon to the Earth by a single impact. However, bulk-rock compositional differences among the three meteorites render this hypothesis unlikely. Compared to Y-791197 and particularly Y-82192, ALHA81005 has a vastly higher *mg* ratio. Compared to both Y-791197 and ALHA81005, Y-82192 has far higher Eu/Al and Na/Al ratios. None of these ratios is easily affected by mineralogical sampling "error." Analogy to Apollo 16 regolith samples suggests that the three meteorites formed many km apart from one another; in particular, ALHA81005 probably formed $\gg$8 km apart from the others. Isotopic records of cosmic ray exposure histories (NISHIIZUMI *et al.*, 1986) also militate against the single-launch hypothesis. If the multiple-launch-site hypothesis is correct, then given the evidence (low incompatible element contents) that all of these samples originated far from the central near side, probability arguments imply that almost certainly one or more of these meteorites is a product of the far side. This conclusion would in turn strengthen the case for a Moon-wide highly anorthositic crust, and the corollary that much of the lunar crust formed by plagioclase flotation over a primordial magmasphere.

One of two clasts separated from Y-82192 is conceivably a monomict-brecciated (pristine) anorthositic cumulate of unique geochemical affinity, intermediate between ferroan anorthosites and Mg-rich rocks. Far more likely, however, this clast is merely a polymict impact melt breccia; which is certainly the case for the second clast. The majority of clasts separated from Y-791197 and -82192 appear to be polymict impact melt breccias.

The coincidence that all three lunar meteorites are regolith breccias may be explained by postulating that these rocks were created out of incoherent soils by shocks associated with the same impacts that launched them off the Moon (WARREN and KALLEMEYN, 1986; OSTERTAG *et al.*, 1986).

Acknowledgments

We thank J. T. WASSON for helpful discussions, E. A. JERDE for technical assistance, and the National Institute of Polar Research for providing the samples. This research was supported by NASA grant NAG 9–87.

References

ADLER, I. and TROMBKA, J. I. (1977): Orbital chemistry—Lunar surface analysis from the X-ray and gamma ray remote sensing experiments. Phys. Chem. Earth, **10**, 17–43.

BISCHOFF, A., PALME, H., SPETTEL, B., STÖFFLER, D., WÄNKE, H. and OSTERTAG, R. (1986): Yamato 82192 and 82193; Two other meteorites of lunar origin (abstract). Papers presented to the Eleventh Symposium on Antarctic Meteorites, 25–27 March 1986. Tokyo, Natl Inst. Polar Res., 34–36.

EHMANN, W. D., ALI, M. Z. and HOSSAIN, T. I. M. (1977): Chemical characterization of lunar core 60003 (abstract). Lunar Science VIII. Houston, Lunar Planet. Inst., 275–277.

FUKUOKA, T., LAUL, J. C., SMITH, M. R., HUGHES, S. S. and SCHMITT, R. A. (1986a): Chemistry of Yamato-791197 Antarctic meteorite; Evidence for its lunar highland origin. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 84–95.

FUKUOKA, T., LAUL, J. C., SMITH, M. R. and SCHMITT, R. A. (1986b): Chemistry of Yamato-82192 and -82193 Antarctic meteorites (abstract). Papers presented to the Eleventh Symposium on Antarctic Meteorites, 25–27 March 1986. Tokyo, Natl Inst. Polar Res., 40–42.

GOLD, T., BILSON, E., BARON, R. L., ALI, M. Z. and EHMANN, W. D. (1977): Chemical and optical properties at the Apollo 15 and 16 sites. Proc. Lunar Sci. Conf., 8th, 3633–3643.

GOODRICH, C. A., TAYLOR, G. J., KEIL, K., BOYNTON, W. V. and HILL, D. H. (1984): Petrology and chemistry of hyperferroan anorthosites and other clasts from lunar meteorite ALHA81005. Proc. Lunar Planet. Sci. Conf., 15th, Pt. 1, C87–C94 (J. Geophys. Res., **89** Suppl.).

GRIEVE, R. A. F. (1984): The impact cratering rate in recent time. Proc. Lunar Planet. Sci. Conf., 14th, Pt. 2, B403–B408 (J. Geophys. Res., **89** Suppl.).

GRIEVE, R. A. F. and DENCE, M. R. (1979): The terrestrial cratering record, II. The crater production rate. Icarus, **38**, 230–242.

HARTMANN, W. K. (1983): Moons and Planets. Belmont, Wadsworth, 509 p.

HUBBARD, N. J. and WOLOSZYN, D. (1977): Orbital gamma-ray data and large-scale lunar problems. Phys. Earth Planet. Inter., **15**, 287–302.

JERDE, E. A., WARREN, P. H., HEIKEN, G. and VANIMAN, D. T. (1987): A potpourri of regolith breccias; "New" samples of the lunar regolith and implications for the diversity of crustal rock types. Proc. Lunar Planet. Sci. Conf., 17th, Pt. 2, E526–E536 (J. Geophys. Res., **92** Suppl.).

KACZARAL, P. W., DENNISON, J. E. and LIPSCHUTZ, M. E. (1985): Yamato 791197; A trace element-rich lunar highlands sample (abstract). Papers presented to the Tenth Symposium on Antarctic Meteorites, 25–27 March 1985. Tokyo, Natl Inst. Polar Res., 101–102.

KACZARAL, P. W., DENNISON, J. E., VERKOUTEREN, R. M. and LIPSCHUTZ, M. E. (1986): Consortium studies of lunar meteorite Yamato 82192 and 691 (E3) (abstract). Papers presented to the Eleventh Symposium on Antarctic Meteorites, 25–27 March 1986. Tokyo, Natl Inst. Polar Res., 45–46.

KALLEMEYN, G. W. and WARREN, P. H. (1983): Compositional implications regarding the lunar origin of the ALHA81005 meteorite. Geophys. Res. Lett., **10**, 833–836.

KOROTEV, R. L., LINDSTROM, M. M., LINDSTROM, D. J. and HASKIN, L. A. (1983): Antarctic meteorite ALHA81005—Not just another lunar anorthositic norite. Geophys. Res. Lett., **10**, 829–832.

LAUL, J. C. and PAPIKE, J. J. (1980): The Apollo 17 drill core; Chemistry of size fractions and the nature of the fused soil component. Proc. Lunar Planet. Sci. Conf., 11th, 1395–1413.

LAUL, J. C. and SCHMITT, R. A. (1973): Chemical composition of Apollo 15, 16 and 17 samples. Proc. Lunar Sci. Conf., 4th, 1349–1367.

LAUL, J. C., SMITH, M. R. and SCHMITT, R. A. (1983): ALHA81005 meteorite; Chemical evidence for lunar highland origin. Geophys. Res. Lett., **10**, 825–828.

LINDSTROM, M. M., LINDSTROM, D. J., KOROTEV, R. L. and HASKIN, L. A. (1986): Lunar meteorite Yamato-791197; A polymict anorthositic norite breccia. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 58–75.

McKAY, D. S., BOGARD, D. D., MORRIS, R. V., KOROTEV, R. L., JOHNSON, P. and WENTWORTH, S. (1986): Apollo 16 regolith breccias; A multi-discipline characterization. Proc. Lunar Planet. Sci. Conf., 16th, Pt. 2, D277–D303 (J. Geophys. Res., **91** Suppl.).

McSWEEN, H. Y., Jr. (1985): SNC meteorites; Clues to martian petrologic evolution? Rev. Geophys. Space Phys., **23**, 391–416.

MORRIS, R. V., SCORE, R., DARDANO, C. and HEIKEN, G. (1983): Handbook of Lunar Soils. Houston, NASA Johnson Space Center, Planetary Materials Branch, Publication 67-JSC-19069, 914 p.

NAKAMURA, N., UNRUH, D. M. and TATSUMOTO, M. (1986a): REE, Rb-Sr and Pb isotopic characteristics of the Yamato-791197 meteorite; Evidence for a lunar highland origin. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 106–115.

NAKAMURA, N., UNRUH, D. M., TATSUMOTO, M., FUJIWARA, T. and OKANO, O. (1986b): REE abundance and Pb-Pb isotopic characteristics of the lunar meteorite, Yamato-82192 (abstract). Papers presented to the Eleventh Symposium on Antarctic Meteorites, 25–27 March 1986. Tokyo, Natl Inst. Polar Res., 47–48.

NAVA, D. F., LINDSTROM, M. M., SCHUHMANN, P. J., LINDSTROM, D. J. and PHILPOTTS, J. A. (1976): The remarkable chemical uniformity of Apollo 16 layered deep drill core section 60002. Proc. Lunar Sci. Conf., 7th, 133–139.

NISHIIZUMI, K., KLEIN, J., MIDDLETON, R., ELMORE, D., KUBIK, P. W. and ARNOLD, J. R. (1986): Exposure history of four lunar meteorites (abstract). Papers presented to the Eleventh Symposium on Antarctic Meteorites, 25–27 March 1986. Tokyo, Natl Inst. Polar Res., 58–59.

OSTERTAG, R., STÖFFLER, D., BISCHOFF, A., PALME, H., SCHULTZ, L., SPETTEL, B., WEBER, H., WECKWERTH, G. and WÄNKE, H. (1986): Lunar meteorite Yamato-791197; Petrography, shock history and chemical composition. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 17–44.

PALME, H., SPETTEL, B., WECKWERTH, G. and WÄNKE, H. (1983): Antarctic meteorite ALHA81005, a piece from the ancient lunar crust. Geophys. Res. Lett., **10**, 817–820.

RHODES, J. M., RODGERS, K. V., SHIH, C.-Y., BANSAL, B. M., NYQUIST, L. E., WIESMANN, H. and HUBBARD, N. J. (1974): The relationships between geology and soil chemistry at the Apollo 17 landing site. Proc. Lunar Sci. Conf., 5th, 1097-1117.

ROSE, H. J., Jr., CUTTITTA, F., ANNELL, C. S., CARON, M. K., CHRISTIAN, R. P., DWORNIK, E. J., GREENLAND, L. P. and LIGON, D. T., Jr. (1972): Compositional data for twenty-one Fra Mauro lunar materials. Proc. Lunar Sci. Conf., 3rd, 1215–1229.

RYDER, G. and NORMAN, M. D. (1980): Catalog of Apollo 16 Rocks. Houston, NASA Johnson Space Center Curatorial Branch, Publication 52-JSC16904, 1144 p.

RYDER, G. and OSTERTAG, R. (1983): ALHA 81005; Moon, Mars, petrography, and Giordano Bruno. Geophys. Res. Lett., **10**, 791–794.

SPUDIS, P. D. (1984): Apollo 16 site geology and impact melts; Implications for the geologic history of the lunar highlands. Proc. Lunar Planet. Sci. Conf., 15th, Pt. 1, C95–C107 (J. Geophys. Res., **89** Suppl.).

STÖFFLER, D., KNÖLL, H.-D., MARVIN, U. B., SIMONDS, C. H. and WARREN, P. H. (1980): Recommended classification and nomenclature of lunar highland rocks—A committee report. Proc. Conf. Lunar Highlands Crust, 51–70.

SUTTON, S. R. (1986): Thermoluminescence of lunar meteorites Yamato-791197 and ALHA81005. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 133–139.

SUTTON, S. R. and CROZAZ, G. (1983): Thermoluminescence and nuclear particle tracks in ALHA-

81005; Evidence for a brief transit time. Geophys. Res. Lett., **10**, 809–812.

TAKAHASHI, K., MASUDA, A. and SHIMIZU, H. (1986): REE abundances and Rb-Sr geochronology of Yamato-791197. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 96–105.

TAKEDA, H., MORI, H. and TAGAI, T. (1986a): Mineralogy of Antarctic lunar meteorites and differentiated products of the lunar crust. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 45–57.

TAKEDA, H., MORI, H. and TAGAI, T. (1986b): Mineralogy of lunar meteorites, Yamato-82192 and 82193 with reference to exploration of the lunar highlands (abstract). Papers presented to the Eleventh Symposium on Antarctic Meteorites, 25–27 March 1986. Tokyo, Natl Inst. Polar Res., 37–39.

TREIMAN, A. H. and DRAKE, M. J. (1983): Origin of lunar meteorite ALHA 81005; Clues from the presence of terrae clasts and a very low-titanium mare basalt clast. Geophys. Res. Lett., **10**, 783–786.

TUNIZ, C., PAL, D. K., MONIOT, R. K., SAVIN, W., KRUSE, T. H., HERZOG, G. F. and EVANS, J. C. (1983): Recent cosmic ray exposure history of ALHA 81005. Geophys. Res. Lett., **10**, 804–806.

VICKERY, A. M. and MELOSH, H. J. (1983): The origin of SNC meteorites; An alternative to Mars. Icarus, **56**, 299–318.

WARREN, P. H. (1985): The magma ocean concept and lunar evolution. Ann. Rev. Earth. Planet. Sci., **13**, 201–240.

WARREN, P. H. (1986): Anorthosite assimilation and the origin of the Mg/Fe-related bimodality of pristine Moon rocks; Support for the magmasphere hypothesis. Proc. Lunar Planet. Sci. Conf., 16th, Pt. 2, D331–D343 (J. Geophys. Res., **91** Suppl.).

WARREN, P. H. and KALLEMEYN, G. W. (1986): Geochemistry of lunar meteorite Yamato-791197; Comparison with ALHA81005 and other lunar samples. Mem. Natl Inst. Polar Res., Spec. Issue, **41**, 3–16.

WARREN, P. H. and TAYLOR, G. J. (1981): Petrochemical constraints on lateral transport during lunar basin formation. Multi-ring Basins, ed. by P. H. SCHULTZ. New York, Pergamon, 149–154.

WARREN, P. H. and WASSON, J. T. (1979): The origin of KREEP. Rev. Geophys. Space Phys., **17**, 73–88.

WARREN, P. H., TAYLOR, G. J. and KEIL, K. (1983): Regolith breccia Allan Hills A81005; Evidence of lunar origin, and petrography of pristine and nonpristine clasts. Geophys. Res. Lett., **10**, 779–782.

YANAI, K. and KOJIMA, H. (1984): Yamato-791197; Lunar meteorite in Japanese collections of the Antarctic meteorites. Mem. Natl Inst. Polar Res., Spec. Issue, **35**, 18–34.

YANAI, K., KOJIMA, H. and IKADAI, S. (1986): Four lunar meteorites including new specimen of Yamato-82193, preliminary examination, curation and allocation for consortium studies (abstract). Papers presented to the Eleventh Symposium on Antarctic Meteorites, 25–27 March 1986. Tokyo, Natl Inst. Polar Res., 25–27.

(Received October 23, 1986; Revised manuscript received January 13, 1987)