

**CUMULATE LITHOLOGIES AND MELT ROCKS FROM APOLLO 17 BRECCIAS: CORRELATION OF WHOLE-ROCK AND MINERAL CHEMISTRY;** James O. ECKERT, Jr.<sup>1</sup>, Lawrence A. TAYLOR<sup>1</sup>, Clive R. NEAL<sup>1\*</sup>, Roman A. SCHMITT<sup>2</sup>, Y.-G. Liu<sup>2</sup>, and Allan D. PATCHEN<sup>1</sup>, <sup>1</sup>Dept. of Geological Sciences, Univ. of Tennessee, Knoxville, TN 37996; <sup>2</sup>Radiation Center, Oregon State Univ., Corvallis, OR 97331; \*Present address: Dept. of Earth Sciences, Univ. of Notre Dame, Notre Dame, IN 46556.

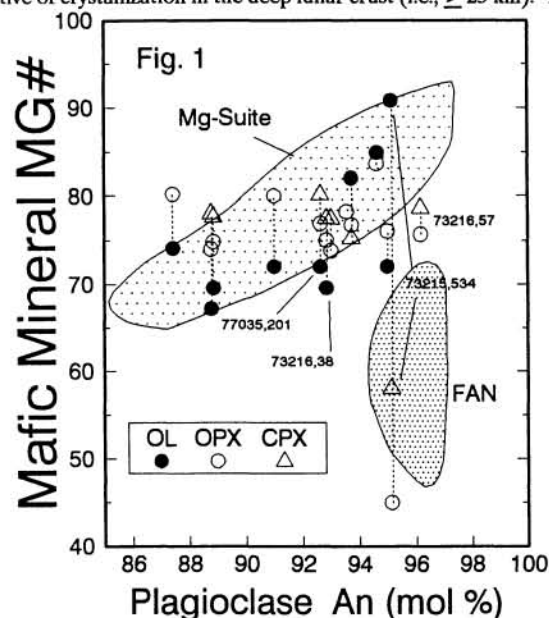
Studies of clasts from "pull-apart" efforts of lunar breccias have produced critical insights into the petrogenesis of lunar rocks [e.g. 1, 2]. Additional data from cumulate lithologies among these clasts have the potential to enhance our understanding of lunar plutonic processes and formation of the lunar crust. From a continuing pull-apart study of Apollo 17 breccias, major-element mineral (electron microprobe) and whole-rock (INA) chemical data are presented here for 11 cumulate lithologies and 2 basaltic rocks from breccias 73215, 73216, and 77035. Ranges of mineral compositions in six of these clasts were reported previously by Neal et al. [3]. Ranges of major-element mineral compositions for all thirteen rocks are reported here, along with a measure of the chondrite-normalized Eu anomaly (Eu/Eu\*), and with the assigned rock names (Table 1).

**TABLE 1: Mineral Compositions (Range of End-Member Assignments)**

Mineral	OLIV	PLAG	OPX	CPX	ILM	SPINEL				
Molar	Fo	An	Wo/En/MG#	Wo/En/MG#	MG#	Cr#	MG#	Eu/Eu*	Rock Type	Nature
73215,534*	89-92	91-96	3-5/42-44/44-46	40-42/34-34/56-59	-	9-11	76-85	2.39	T	LM
73215,539	74-92	90-97	2-8/68-88/71-92	-	-	10-10	74-77	0.51	D	P
73216,36*	-	87-95	4-5/70-72/73-78	38-39/47-48/72-78	21-22	-	-	0.75	A	LM
73216,38*	69-71	85-96	4-5/70-74/74-79	29-39/47-53/75-79	22-26	-	-	0.37	B	P(MR)
73216,42*	66-68	78-93	4-4/71-74/74-77	39-40/46-48/77-78	24-26	-	-	0.52	T	P(MR)
73216,49*	68-70	68-70	4-5/70-75/74-79	39-40/46-47/77-78	-	-	-	0.39	N	P
73216,57*	-	93-98	4-5/71-73/75-76	39-41/46-47/78-79	24-25	-	-	1.69	G	LM
77035,206	71-74	93-96	4/73/76(1)	-	19-25	-	-	1.15	N	P
77035,172	72-88	92-96	5-8/68-75/74-79	15-19/61-65/74-75	-	-	-	0.05	D	P
77035,227	70-74	76-96	3-6/67-78/70-81	-	18-20	-	-	0.34	B	P(MR)
77035,185	-	92-94	3-5/74-76/78-78	-	-	-	-	1.08	N	M
77035,200	71-77	85-91	2-4/75-82/79-83	-	-	-	-	5.12	A	LM
77035,201	68-75	74-97	3-5/65-76/68-78	27-36/49-58/77-82	19-23	-	-	0.60	A	P

\*Ranges of mineral end members were reported previously [3]. **Rock Types:** T = troctolite; D = dunite; A = anorthosite; B = basalt; N = norite; G = gabbro. **Nature:** LM = Largely Monomict (major elements), M = predominantly Monomict, and P = Polymict (determinations based primarily on mineral homogeneity, [including Fe-Ni metals], correspondence of mineral and whole-rock compositions, and consideration of trace-element characteristics [including siderophiles]). (MR) = melt rock, based on other polymict criteria in addition to textural indicators.

Modal mineralogies were estimated by entering mean mineral compositions into iterative calculations of proportions to fit the whole-rock chemistry obtained by INAA. Rock names are assigned using these modal calculations. Pristine origins or monomict derivation are not necessarily implied but are not precluded. Troctolite 73215,534 contains Cr-bearing, Mg-rich spinel and an assemblage indicative of crystallization in the deep lunar crust (i.e.,  $\geq 25$  km). This rock is discussed in detail in a separate abstract in this volume [4].



**PETROGRAPHY.** Textures of rocks with troctolitic compositions exhibit either apparent recrystallization of a previously brecciated texture (73215,534; [see 4]) or domination by acicular, radiating plagioclase (73216,42) which crystallized, apparently during rapid cooling, possibly from an undercooled melt. Dunites exhibit cataclastic texture; one (73215,539) also contains spinel and a glass mesostasis cored by a SiO<sub>2</sub> phase. Anorthosite textures range from predominantly pristine-cumulate with plagioclase chadocrysts and pyroxene oikocrysts (73216,36) [6] to apparently recrystallized (77035,201). Basalts, which appear to be melt rocks, contain angular to xenomorphic-irregular, poikilitic grains of plagioclase and olivine in a fine-grained, granoblastic matrix of plagioclase and low-Ca pyroxene. Norite textures range from apparently recrystallized cataclastic with relict strain, but monomict and probably pristine (77035,185), to cataclastic. Anorthositic gabbro 73216,57 exhibits striking cumulate texture in thin section; neither plagioclase nor high-Ca clinopyroxene exhibits any evidence of recrystallization or recovery. This clast, with the most distinct textural indicators of original igneous history of any in this suite, clearly originated by plagioclase accumulation followed by interstitial crystallization of pyroxenes.

**MINERAL CHEMISTRY.** The highest Fo contents in this suite (Fo<sub>89-92</sub>) are from spinel troctolite 73215,534. Mean compositions and ranges of orthopyroxene are generally similar from sample to sample, with the exception of 73215,534. Only troctolite 73216,42 does not contain orthopyroxene. From the newly analyzed samples, high-Ca clinopyroxene is present only in anorthosite 77035,201. Pigeonite (low-Ca clinopyroxene) occurs in anorthositic gabbro 73215,57 and dunite 77035,172. High-Ca clinopyroxene occurs in

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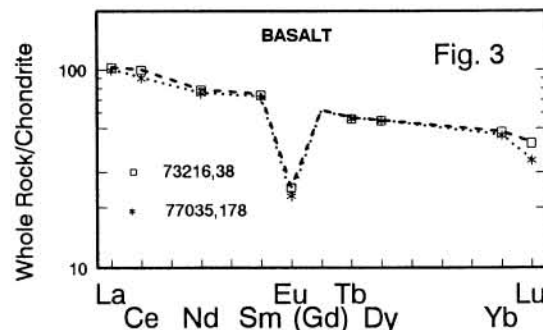
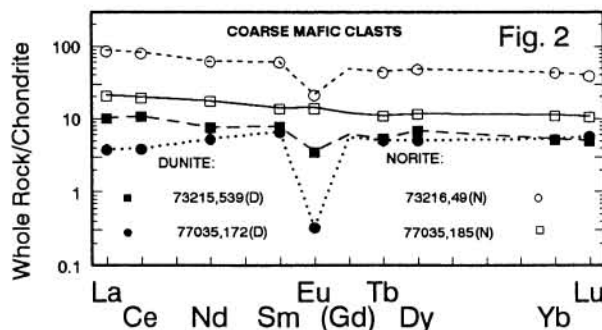
anorthosite 73216,36; basalt (melt rock) 73216,38; norite 73216,49; and anorthositic gabbro 73216,57. Compositions of plagioclase are highly calcic (An<sub>92-96</sub>) in all samples, except anorthosite 77035,200; troctolite 73216,42; and norite 73216,49, where the plagioclase is nominally more sodic (An<sub>87-89</sub>). Microscale compositional variability in plagioclase and mafic minerals is specific to each sample; ranges of end-member contents for each sample are listed in Table 1.

**DISCUSSION.** Most newly gathered mineral compositions from this suite plot within or near the margins of the Mg-suite array of pristine samples [5] (Fig. 1), the exceptions being olivine for 73216,38 and 77035,201. Also shown in Fig. 1 are previously analyzed compositions [3]; 5 of these 6 clasts also plot within the Mg-suite field. The exception is anorthositic gabbro 73216,57, pyroxenes from which plot between the Mg-suite array and the field for ferroan anorthosites. Five of these samples (73215,534; 73216,36 and 57; 77035,185 and ,200), based on mineral homogeneity (Table 1), correspondence of mineral and whole-rock chemistry, and textural criteria, are proposed to have mineral and whole-rock indicators which suggest they are predominantly monomict. The samples for which olivine plots outside the Mg-suite field appear polymict on the grounds of variable mineral compositions. Anorthositic gabbro 73216,57, in contrast, appears largely monomict (in terms of major elements) and has an apparently unmodified cumulate texture. The apparently pristine igneous-cumulate texture in this sample contradicts possible evidence for a polymict origin.

Of the 5 samples considered monomict or largely monomict, norite 77035,185 and anorthosite 77035,200 are proposed to be probably pristine based on the lack of detected Ir [e.g. 7], Cr/Ni ratios > 20 [e.g. 8], and Ni/Co ratios < 2 [e.g. 9]. Although the analyzed level of Ir (15 ppb) suggests anorthositic gabbro 73216,57 is not pristine, textures in this clast are clearly of an unmodified cumulate origin. This Ir might have been introduced by incomplete separation of this clast from the tough breccia matrix in the sample analyzed by INA.

A polymict origin can be indicated by mineral compositional variability [7], particularly grain-to-grain variation rather than zoning. Six of these samples (73215,539; 73216,38, 42; 77035,172, 227, and ,201) appear polymict based on *mineral compositional variability alone* (Table 1) and thus, aside from mixing of end members, cannot be interpreted quantitatively in terms of igneous petrogenesis. These samples could represent mixtures of various proportions of highland end-member surficial material in lunar soil [e.g. 10,11].

Norites and basaltic melt rocks plot near the orthopyroxene-plagioclase cotectic in the An-Ol-Qz diagram of Walker et al. [12], suggesting possible derivation as cotectic liquids. 73216,38 was termed high-Ti basalt [3]; although this is generally compatible with the whole-rock chemistry, textural criteria, including the occurrence of whitlockite inclusions in plagioclase, suggest that this sample is not pristine and is an impact melt [3]. This interpretation could be supported by the presence of detectable Ir (5 ppb) in the whole-rock INA analysis and with the rock texture. 77035,227 exhibits almost identical characteristics of bulk-rock major- and trace-element chemistry, suggesting a similar derivation. These granular-textured melt rocks likely represent impact melts rather than endogenous basalts.



**REE Abundances.** Rare earth element (REE) concentrations, normalized to chondrite [13], for the noritic, basaltic, and dunitic rocks are plotted in Figs. 2-3. Chondrite-normalized REE patterns from anorthositic rocks are presented in an accompanying abstract [6]. Abundances in the dunites (Fig. 2) are elevated for olivine-dominated rocks and do not show the HREE enrichment expected from recently determined olivine/liquid partition coefficients [14]. The pattern of olivine norite 73216,49 contrasts with that of apparently pristine norite 77035,185 by elevated abundances and by the deep negative Eu anomaly (Fig. 2). However, the pattern of this olivine norite is almost identical to those of granular basalts (melt rocks) 73216,38 and 77035,227 (Fig. 3); mineral-compositional variability indicates these basaltic melt rocks and the olivine norite are polymict. Similarity of these three rocks suggests that their bulk compositions may have formed from mixing of comparable proportions of similar surficial materials. In contrast, norite 77035,185 is proposed to be monomict and pristine. This norite provides another sample of pristine, relatively primitive Mg-suite norite from Apollo 17.

**References:** [1] Shervais et al. (1983), PLPSC XIV, p.B177-B192. [2] Lindstrom et al., PLPSC XV, p. C41-C49. [3] Neal et al., 1990, LPS XXI, p. 859-860. [4] Eckert et al. (1991a), LPS XXII, this volume. [5] McGee (1989), PLPSC IXX, p. 73-84. [6] Eckert et al. (1991b), LPS XXII, this volume. [7] Warren and Wasson (1977), PLSC VIII, p. 2215-2235. [8] Shervais et al. (1984), PLPSC XV, p. C25-C40. [9] (1980) Ryder et al., PLPSC XI, p. 471-479. [10] Garrison and Taylor (1980), Proc. Conf. Lunar Highlands Crust, p. 395-417. [11] Korotev (1989), LPS XX, p. 532-533. [12] Walker et al., (1973), PLSC IV, p. 1013-1032. [13] Nakamura (1974), GCA, v. 38, p. 757-775. [14] McKay (1989), MSA Rev. Mineral., v. 21, p. 45-77.