COMPOSITIONAL-PETROGRAPHIC INVESTIGATION OF TWO NEWLY-ACQUIRED MOON ROCKS

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We have studied the two newest lunar meteorites from Antarctica, EET87521 and MAC88104/5. EET87521 is a 30.7-g mafic, Fe-rich breccia that was originally classified as a eucrite. MAC88104/5 is a pair of stones (61.2 and 662.5 g) of an anorthositic, obviously lunar, lithology [1]. Our compositional results (Table) were derived from our standard INAA-based procedure. Note, however, that the results for MAC88104/5 are *highly* preliminary. Except for a few short-lived nuclides, our INAA counting is only about half complete, due to prior (12/89) technical difficulties at our preferred activation reactor.

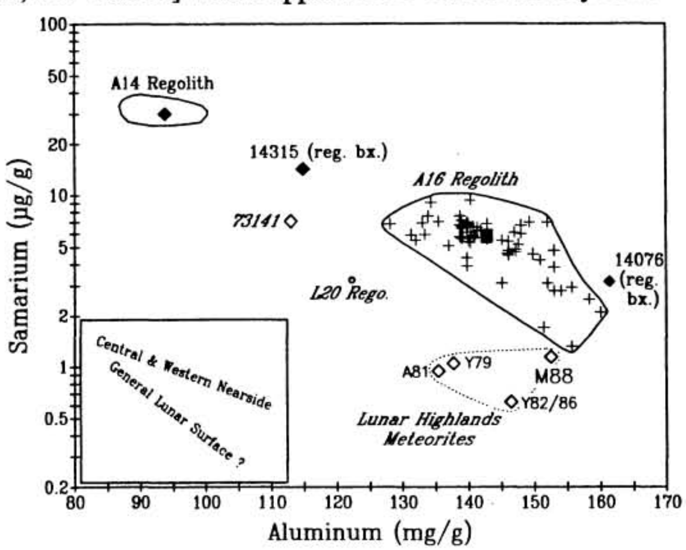
We studied EET87521 as part of a compositional-petrographic survey of Antarctic achondrites, expecting it to be a relatively evolved variety of eucrite. However, trace-element chemistry and detailed petrography reveal traits that only a lunar rock, and certainly not a eucrite, could possess [2]. The Fe/Mn ratio and bulk Co content of EET87521 are far higher than expected for a eucrite. Only one known type of extraterrestrial material resembles EET87521 in all important respects: very-low-Ti (VLT) lunar mare basalts. Even compared to most "VLT's," EET87521 is enriched in REE. Delaney [3] reached the same conclusion based on microprobe analyses of a single thin section; and R. N. Clayton and T. K. Mayeda (pers. comm., 1989) have confirmed it using oxygen isotopes.

Several clasts in EET87521 preserve clear vestiges of coarse-grained igneous, possibly orthocumulate, textures. Mineralogically these coarse-grained clasts are diverse; e.g. olivine ranges from Fo_{15} in one to Fo_{67} in another. Noteworthy for their absence are fine-grained subophitic textures featuring elongated, lath-shaped plagioclase. One clast with an anomalously fine-grained texture is anorthositic and contains exceptionally Mg-rich pyroxene (average composition $En_{55}Wo_{28}$) and Na-poor plagioclase (average $An_{93.1}$), along with the only FeNi-metal in the thin section. This clast is probably an impact melt breccia from the lunar highlands. Its FeNi-metals have compositions typical of metals incorporated into lunar soils and polymict breccias as debris from metal-rich meteorites. However, the low Ni and Ir contents of our bulk-rock analyses imply that the proportion of impact-projectile matter in our "chip" sample is probably small. The moderate degree of lithologic diversity among the lithic clasts, and the bulk composition in general, indicate that EET87521 is dominated by a single rock type: VLT mare basalt. The fundamental distinction between mare and nonmare lunar materials has traditionally been based primarily on Ti content, and secondarily on such characteristics as Ca/Al ratio and REE pattern. However, EET87521, recent studies of Apollo 12 and Apollo 14 rocks, and the many apparent VLT basalts reported earlier as clasts in lunar-highlands meteorites [e.g., 4-6] all tend to indicate that the dichotomy of lunar magmatism into distinct nonmare and mare styles may have been less abrupt than commonly envisaged.

We analyzed five samples from MAC88105: a bulk chip (,34), an aliquot of powder (,41) produced from a 20-g sample of matrix by Gene Jarosewich, and pieces of three leucocratic clasts. We also studied large thin sections MAC88104,7 and MAC88105,86, and one thin section from each of the three clasts. Overall, the meteorite is a complex fragmental breccia. Like the Y82/86 lunar meteorite [7], this one contains a smattering of impact glass spherules, indicative of regolith derivation, but we found only one obvious spherule (of magnesian-anorthositic composition) in MAC88104,7 and MAC88105,86 combined. Thus, the M88 meteorite appears to be an extremely immature regolith breccia. It seems unlikely that M88 left the Moon together with Y82/86, because their cosmic-ray exposure histories seem completely different [1,8]. All three of the analyzed clasts are anorthositic. The "*w1*" clast (see Table) at first glance appears fragmental and mildly granulitic, but closer inspection indicates that some of the mafic silicates may have been derived from pockets of foreign impact melt. Most of the metal in *w1* is compositionally like typical meteoritic metal, as is the metal in clast *w3*, which is a fine-grained impact melt breccia. However, clast *w5* has a classically granulitic texture, with medium-grained plagioclase (monomineralic-annealed crush zones up to 0.8 mm) and fine-grained mafics (Fe-rich high-Ca px, low-Ca px and olivine, 10-50 μm). The sole metal grain in the *w5* thin section is extraordinarily Ni-rich (~51 wt%). Conceivably, *w5* is compositionally pristine, albeit texturally it has been severely altered. One clast in MAC88104,7 (not analyzed by INAA) bears a texture that clearly indicates pristinity: Equant plagioclase (An_{93-98}), constituting roughly 80% of the mode, is up to 1.5 mm. Anhedral-poikilitic olivine (Fo_{75-78}) is optically continuous up to 2.0 mm. Pyroxene, spanning a wide range of Wo ratios, is also present. This clast is probably a hypabyssal variant of the Mg-suite, but its olivine and plag compositions lead to a slight narrowing of the compositional gap between Mg-rich rocks and ferroan-suite rocks. One possibly pristine clast in MAC88105,86 is a tiny (3 mm) "anorthosite" with extraordinarily ferroan olivine (Fo_{40-41}) and pyroxene (average opx, $En_{53}Wo_2$), and $An_{96.7}$ plag.

The bulk composition of MAC88105 (Table) is not greatly unlike those of previously-discovered lunar meteorites. M88 is even more aluminous than Y82/Y86. Like the other lunar meteorites, M88 is much poorer in incompatible elements (e.g., Sm) than regolith from the erstwhile "classic" highlands site, Apollo 16. However, considering the general inverse correlation between incompatible elements and Al in the lunar highlands (Figure), M88 resembles the most Al-rich Apollo 16 soils as well as it does the other lunar meteorites. Like the other lunar meteorites [9], M88 is relatively Ni-poor and has a low Au/Ir ratio compared to typical Apollo 16 material. Regolith breccias seem to be far more common among lunar meteorites than among Apollo 16 rocks [10]. Unless regolith tends to be lithified in the same event that propels these materials Earthward, it seems that the upper crust of the Moon is richer in regolith breccia than previously suspected. If so, present models of the porosity, and thus the global-insulating effect, of the megaregolith [e.g., K. L. Rasmussen et al., this volume] would appear to be conservatively low.

References: [1] Score R. et al. *Ant. Met. Newsl.* **12**(3), 21. [2] Warren P. H. and Kallemeyn G. W. (1989) *GCA* **53**, 3323-3330. [3] Delaney J. S. (1989) *Nature* **342**, 889-890. [4] Treiman A. H. and Drake M. J. (1983) *GRL* **10**, 783-786. [5] Lindstrom M. M. et al. (1986) *Proc. Sym. Ant. Met.* **10**, 58-75. [6] Goodrich C. A. and Keil K. (1987) *Proc. Sym. Ant. Met.* **11**, 56-70. [7] Takeda H. et al. (1987) *Proc. Sym. Ant. Met.* **11**, 43-55. [8] Eugster O. *Science* **245**, 1197-1202. [9] Warren P. H. et al. (1989) *EPSL* **91**, 245-260. [10] Ryder G. and Norman M. D. (1980) *Catalog of Apollo 16 Rocks*, NASA-JSC.



Sample	mass mg	Na mg/g	Mg mg/g	Al mg/g	Si mg/g	K mg/g	Ca mg/g	Sc µg/g	Ti mg/g	Cr mg/g	Mn mg/g	Fe mg/g	Co µg/g	Ni µg/g	Zn µg/g	Ga µg/g	Sr µg/g
EET87521;6a (chip)	278	3.06	38.0	66	226	0.57	83.4	44.0	6.8	1.47	1.88	149	46	*29*	<5	5.27	104
EET87521;6b (chip)	290	3.11	43.8	74	222	0.48	82.8	40.6	4.9	1.87	1.88	143	50	*43*	<6	5.17	*126*
MAC88105;34 (chip)	366	2.40	24.5	152	209	0.21	121	8.9	1.48	0.64	0.51	33.9	14.5	141	*14*	3.3	--
MAC88105;41 (powder)	317	2.42	24.0	153	210	*0.24*	121	8.5	1.40	0.61	0.50	33.2	14.5	148	11.2	3.5	--
MAC88105;54 (clast w1)	111	2.47	--	--	--	*0.16*	140	5.0	--	0.35	0.32	22.6	11.4	136	<6.4	2.9	--
MAC88105;64 (clast w5)	35.5	2.39	--	--	--	<0.25	136	15.8	--	0.88	0.59	36.2	10.4	<149	--	*2.5*	--

	Zr µg/g	Cs ng/g	Ba µg/g	La µg/g	Ce µg/g	Nd µg/g	Sm µg/g	Eu µg/g	Tb µg/g	Dy µg/g	Yb µg/g	Lu µg/g	Hf µg/g	Ta µg/g	Ir ng/g	Au ng/g	Th µg/g	U µg/g
EET87521;6a	140	*0.04*	88	8.3	20.9	13.0	3.86	0.98	0.80	4.8	3.19	0.48	2.88	0.37	<1.2	<1.2	0.95	0.23
EET87521;6b	105	<0.08	68	8.1	20.1	12.4	3.68	0.97	0.83	*4.7*	2.85	0.41	2.62	0.29	<1.1	<1.1	0.99	0.27
MAC88105;34	<60	*0.08*	*31*	2.72	6.2	3.6	1.13	0.79	0.22	*1.42*	0.98	0.141	0.71	*0.14*	*11.6*	*1.62*	0.37	*0.10*
MAC88105;41	*42*	<0.14	32	2.77	6.3	3.8	1.15	0.81	0.25	*1.8*	1.01	0.147	0.83	*0.10*	*8.1*	2.7	0.40	0.081
MAC88105;54	*77*	<0.14	*25*	1.80	4.0	--	0.72	0.82	*0.13*	*1.21*	0.63	0.094	0.54	<0.15	7.4	*2.2*	0.30	*0.07*
MAC88105;64	<240	<0.51	<50	1.45	*4.0*	--	1.01	0.82	*0.21*	<1.6	0.93	0.138	*0.06*	<0.55	<5.8	<3	*0.38*	<0.13