ABUNDANT APATITE IN GRANULITE 79215: SPOOR OF ANOTHER VOLATILE-RICH LUNAR FLUID. A. H. Treiman[1] and J. Gross[2]. [1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058 (treiman#lpi.usra.edu). [2]American Museum of Natural History, Central Park West at 79th St., NY NY 10024.

Rrecent evidence of OH in lunar mamgas [1] and of S-rich fluids in the highlands crust [2] imply that volatiles have had significant roles in lunar petrogenesis. Another fluid, rich in P and F, is evident from lunar granulite 79215. Its abundant apatite grains are concentrated in curvilinear traces, suggesting fluid entry along cracks. The apatite-forming fluid was not KREEPy; 79215 has K/Sm > KREEP and P/Sm >> KREEP. It seems most reasonable that the apatite was deposited from an aqueous fluid or a dense vapor. These explanations are, however, not compelling.

79215: Apollo sample 79215 is a feldspathic granulitic impactite, developed from a plutonic troctolite precursor [3,4]. It was a large fragment in an impact melt breccia, and possibly from a deep layer in Van Serg crater. 79215 consists of plagioclase (~80% of the rock; Fig. 1), olivine, orthopyroxene, augite, apatite, etc. Its texture is granoblastic, of equant mineral grains <100µm across with grain boundary angles at ~120°. Clasts of plagioclase- and olivine-rich material compose ~25% of the rock. By major elements & mineral compositions, 79215 is intermediate between FAN and magnesian-suite rocks (olivine ~Fo72, plagioclase An92-96) [3,5]. However, its high Th/Sm precludes such an origin [6]. 79215 has REE at 10-20 x CI, with small enrichments in LREE and Eu [4].

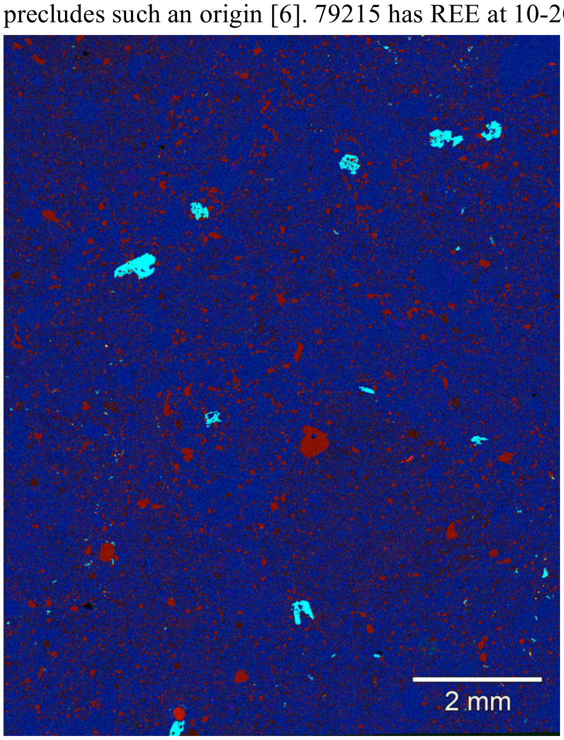

Fig. 1: False-color EDS element map of a thin section of 79215; green=P, blue=Ca, red=Fe. Apatite is cyan; plagioclase is blue, olivine is red, opx is dark.

Table 1. Average chemical analysis of 79215 apatite.

	Avg*	1 σ	To 8 cations	
SiO_2	0.41	0.02	Ti	0.001
TiO_2	0.01	0.02	Al	0.001
Al_2O_3	0.01	0.02	Ce	0.002
Ce_2O_3	0.05	0.02	*REE*	*0.012*
REE_2O_3	*0.21*	**	Fe	0.014
FeO	0.20	0.06	Mn	0.002
MnO	0.02	0.02	Mg	0.017
MgO	0.14	0.03	Ca	4.973
CaO	54.86	0.15	*Sr*	*0.002*
SrO	*0.05*	***	Na	0.001
Na_2O	0.01	0.01	K	0.000
K_2O	0.00	0.00	P	2.939
P_2O_5	41.03	0.14	Si	0.002
SO_2	0.03	0.00	S	0.034
F	3.34	0.14	F	0.893
Cl	0.66	0.02	Cl	0.091
O=F,Cl	-1.55	0.06	Charge	
Total	99.46	0.25	Sum	-0.011

*Average of 44 spot analyses. **Assuming chondritic relative REE abundances.***Assuming a chondritic Ca/Sr ratio. 5.025 octadhedral cations (green), ideally 5. 2.975 tetrahedral cations (yellow), ideally 3. 0.984 anions, ideally 1.

79215 contains abundant apatite, ~1 vol % on average, or ~0.4% P_2O_5 in bulk. The apatite occurs as small grains in the granulitic texture, and also as euhedra (to 1.5 mm long) that enclose rounded grains of silicate minerals (Fig. 1). The apatite is concentrated in patches and in long curved bands (Fig. 1).

Chemical Analyses: Silicate and oxide minerals were analyzed by EMP at JSC by normal methods. Apatite was analyzed at AMNH by the method of [7], in which F, Cl and Na are analyzed at low accelerating potential (10keV) on grains that have never seen high-voltage electrons (i.e., BSE imaged). MgF_2, scapolite and boracite were used as F and Cl standards. We obtained 44 analyses on five apatite grains of varied orientations (Table 1); the only prior analysis [3] gave only Ca, P, and F (at ~1/2 that in our analyses). All our analyses are identical within 1σ uncertainties (Fig. 2), which shows that the method is reproducible and unaffected by grain orientation. Based on its Ce_2O_3 abundance, apatite must contain nearly all the rock's REE. The apatites' halogens are dominated by F (F/Cl ≈ 10); molar OH/(OH+F+Cl) is no greater than 2%.

Origin of Apatite: 79215 is usually considered to be a normal, exemplary lunar granulite [4-6,8,9]. The

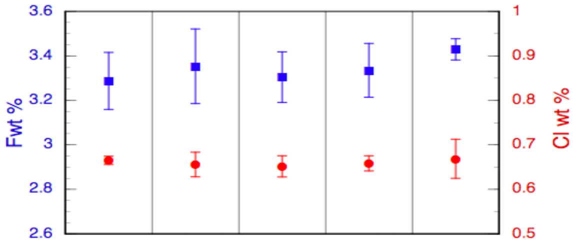

Fig. 2. Averages and 1σ variances for F and Cl analyses on five apatite grains, of random orientations.

apatite pre-dates the intense metamorphism that 79215 experienced (~1050°C [5]), because apatite grains are found within the fine granoblastic texture (Fig. 1) and because the large apatite grains include rounded grains of the other minerals (e.g., plagioclase, olivine) [10].

However, the apatite grains are not distributed randomly nor found in specific clasts or in matrix. Rather, apatite is concentrated in curvilinear bands and swaths (Fig. 1). Such a distribution pattern has been inferred to represent channels of fluid flow [11,12], and that conclusion seems reasonable for 79215.

Geochemistry & Apatite-Forming Fluid: What sort of fluid could transport abundant P into 79215, but not the REE [3]? In fact, 79215 is enriched in no incompatible elements besides P and alkalis; their abundances [4] are all at 0.03 – 0.06 x urKREEP [13], while P is at 0.5 x urKREEP.

Bickel et al. [3] suggested that the apatite was deposited from intercumulus magma in the parent troctolite; that is inconsistent with the rock's high P/Sm (Fig. 3) compared to those of A17 plutonic rocks, KREEP, and mare basalts. Merrillite fractionation could increase P/Sm by removal of REE [14], but that process should concentrate other incompatible elements (Ta, Ba, Hf) relative to REE. This is not observed.

Ionic melts (e.g., halide-rich) can transport significant P and REE [15-17], and so are (in general) un-

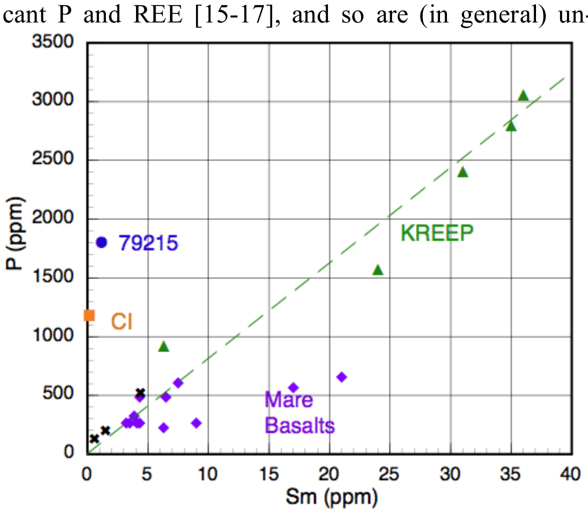

Fig. 3. P and Sm in bulk 79215 and other materials. 79215 (blue) is entirely distinct from KREEP (green), mare basalts (purple), and A17 norites and troctolites (black).

likely to cause strong fractionation of P from REE.

Vapor generated during lunar impacts can transport P and REE [18,19], and might fractionate P from the REE. Vapor transport could be tested via the Cl isotopic composition of the apatite [20]. However, the abundance of apatite in 79215 (Fig. 1) seems more consistent with transport by a condensed fluid.

Finally, the action of an aqueous fluid cannot be excluded (see [21]), and some such fluids could presumably transport P but not REE. However, there is no direct evidence of an aqueous fluid, and the apatite contains nearly no OH (Table 1).

Conclusion: Granulite 79215 is significantly enriched in fluor-apatite (and thus P, F, and Cl) compared to other lunar materials, and textures indicate that the apatite was deposited by a fluid that penetrated the rock. Of other elements, only K and possibly Na are enriched in 79215, so the fluid could not have carried much REE or other igneous incompatible elements. Thus, the fluid was likely not silicate magma. Of the remaining choices, aqueous fluid and vapor seem plausible, though we lack compelling evidence. In any case, this represents a previously unrecognized lunar fluid, which could have significant implications for the distribution and redistribution of volatile constituents in the lunar crust.

O. Abramov and K. Joy built Fig. 1 as part of another study, and permitted us its use. Supported in part by the Center for Lunar Exploration and Science (D. Kring, PI) of the NLSI, and NASA Cosmochemistry Grant NNX08AH78G.

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