APATITE IN GRANULITE 79215: GEOCHEMISTRY OF A LUNAR METASOMATIC FLUID. A. H. Treiman[1], J. W. Boyce[2], J. Gross[3], Y. Guan[2], J. M. Eiler[2], E. M. Stolper[2]. [1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058 (treiman#lpi.usra.edu). [2]Geosciences, Caltech, Pasadena CA. [3]American Museum of Natural History, NY NY 10024.

Volatile species may play significant roles in lunar magma generation and crustal evolution [1,2]. Apatite is a mineralogical tracer of lunar volatiles because it contains essential F, Cl, and OH, and can record abundance ratios of volatile components in the fluids and melts from which the apatite crystallized. Apatite is abundant in the lunar granulite 79215; apatite [3] and bulk rock compositions are consistent with metasomatic alteration by a halogen-rich KREEP-derived fluid,that was affected by merrillite fractionation.

79215: Apollo sample 79215 is a feldspathic granulitic impactite formed from troctolitic precursors [4,5]. Clasts of plagioclase- and olivine-rich material, ~25% of the rock, are set in a fine-grained granoblastic matrix. 79215 contains ~1 vol % apatite that occurs as matrix grains and as euhedra and subhedra up to 1.5 mm long [4,5], concentrated along curvilinear bands in the matrix and along edges of clasts [3]. Fe metal is rare but more abundant near the apatite-rich bands.

Chemical Analyses: Elemental abundances in 79215 (Figure 1) are from the compilation of [6]. Abundances of P are from the single direct analysis and calculated from modal abundances of apatite [3,6]. SIMS analyses of apatite for H abundance and isotope ratios of H, Cl, and S were acquired at the Division of Geological and Planetary Sciences Caltech, with a Cameca 7f-GEO, e.g. [7].

Apatite in 79215 is homogeneous, REE-poor, and F-rich (F/Cl≈10) [3]. The apatite contains ~35 ppm H_2O by SIMS, for a molar OH/(OH+F+Cl)=~0.002 (consistent with the calculation from EMP data of <0.02 [3]). The apatite has δD=+1000±280‰ (2σ), [12] consistent with analyses in [8]. Sulfur in the apatite has $\delta^{33}S$=+5.5±0.6‰ and $\delta^{34}S$=+10.5 ±2.2‰ (2σ), comparable to lunar soils [2] and consistent with sulfur in terrestrial apatite occurring with pyrrhotite of $\delta^{34}S$≈0‰ [9] (typical for lunar pyrrhotite). The apatite has $\delta^{37}Cl$=+30.9±3.2‰ (2σ) [12]; see also [10, 11].

Geochemistry: Compared to 'typical' lunar granulites, (e.g., 78155, 77017 [6]), 79215 is unusual in its enrichment in P, Ba, U, and K, and its super-chondritic (and super-urKREEP) Ba/U and U/Th ratios (Fig. 1). 79215 is enriched in P by an order of magnitude, but it is also enriched (relative to 78155) in K, U, and Ba. In contrast, Th the REEs, Ta, Zr, and Hf all have similar relative and absolute abundances in these two rocks. Compared to urKREEP (Fig. 1b), 79215 is enriched in Eu, HREE, P, Ba, U, and K. The first two 'enrichments' represent only the relative depletions in KREEP itself; in 79215, Eu and the HREE are fractionated little compared to other REE. The last four elemental enrichments are indigenous to 79215.

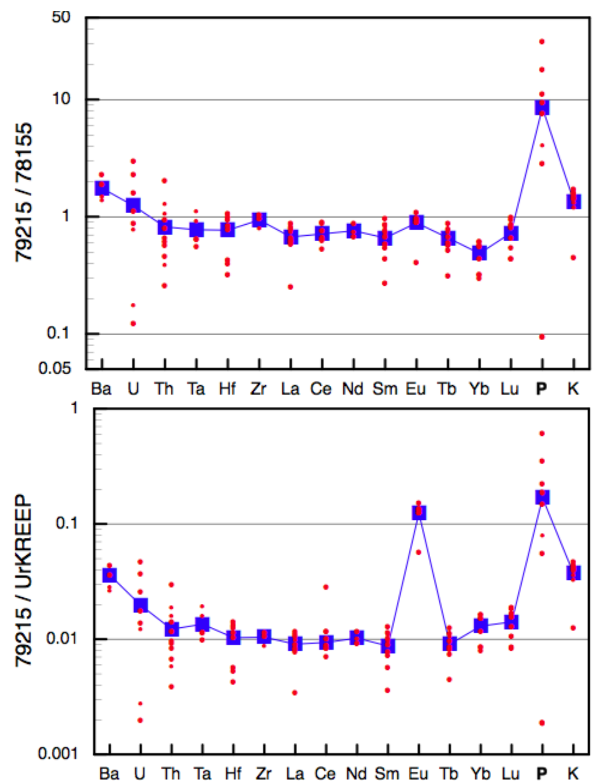

Figure 1. Abundances of selected elements in 79215, compared to the 'typical' granulite 78155 and urKREEP [13]. Red dots are individual analyses [3,6]; blue squares are unweighted averages. The range in analyses reflects the brecciated nature of 79215, and the irregular distribution of its apatite. Note: enrichment in P, flat REE pattern vs. 78155; distinct enrichment in Ba, U, & K (compared to 78155 and urKREEP); U/Th ~1.6x CI & KREEP.

Metasomatism: What were the cause(s) and ultimate source(s) of these element enrichments in 79215? KREEP is a known lunar reservoir of abundant K and P (Fig. 1), and it is also a plausible source for enrichments in U, Ba, Cl, and F [13]. The 79215 apatite has $\delta^{37}Cl$ similar to (but not precisely like) apatite from KREEP-rich rocks (e.g., 12013, 14305, 72275 [10,12]).

If KREEP were the ultimate source of the P and other enrichments in 79215, an explanation is needed for its differential enrichments (Fig. 1) – how some KREEP elements were transported into 79215 (P, Cl, F, U, Ba, & K) but others were not (Th, the REE, Ta, Zr, & Hf). We consider two general mechanisms to explain differences in element abundances between 79215 and KREEP: apatite accumulation, and mineral-fluid partitioning during generation of the metasomatic fluid. Apatite accumulation could produce most of the geochemical signatures of 79215, but would not yield enrichments in K and Ba, and is not consistent with the spatial distribution of apatite [3]. To evaluate mineral-fluid partitioning, one needs to constrain the nature of the metasomatic fluid and the residual phases in its source..

Although not unique, one set of residual phases that could yield the observed enrichments includes: merrillite, plagioclase, zircon, and ilmenite. Residual merrillite would retain Th and REE (except Eu) nearly quantitatively in the source rock [16], but would not retain F or Cl, and not all P and U [14-16]. A fluid that equilibrated with merrillite in a KREEPy source could thus be rich in P, Cl, and F, contain little REE [17], and have U/Th > KREEP. Residual plagioclase would retain Eu in the source rock. Residual zircon would retain Zr and Hf in the source rock, but abundant residual zircon could deplete the fluid in U and Th [19]. Residual ilmenite would retain Ta in the source rock [18]. All of these minerals are present in KREEPy rocks, and are plausible as residual phases under low degrees of partial melting or dissolution.

The nature of the metasomatizing fluid is not clear. The spatial distribution of apatite in 79215 [3] suggests deposition from a vapor or inviscid fluid. Vapor-phase transport was responsible for P mobility (and REE in some cases) in some lunar rocks and other planetary materials [20-22]. However, the abundance of apatite in 79215 suggests a deposition from a liquid because elemental carrying capacities of vapors are generally small. Silicate melts rich in incompatible elements are commonly siliceous and thus unsuitably viscous. However, silicate liquid immiscibility can generate inviscid melts rich in large multi-valent cation (not including Si & Al), e.g. the REEP-frac derived from KREEP [23,24]. If such a melt had equilibrated with merrillite, plagioclase, zircon and ilmenite, it might be a suitable metasomatic agent for the formation of 79215 [23].

Geological Setting: We suggest the following scenario for the formation of 79215. Its precursors were feldspathic igneous rocks and granulites [5] like the precursors of other A17 granulites. These materials were heated in a major impact event (possibly Serenitatis [25]) and deposited in its ejecta blanket at T ≥ 1100°C [25]. These materials were deposited on a substrate rich in KREEP (e.g., 72275 clasts [26]) that was heated by the impact or ejecta to yield a low-volume partial melt rich in P, Cl, F, U & Ba; merrillite, zircon, and ilmenite remained in the substrate [17] and retained the REE, Th, Ta, Zr & Hf from the original KREEP. This fluid permeated and metasomatized the precursor to 79215 in the overlying ejecta blanket (e.g., akin to deposition by fumaroles [27,28]). The association of apatite and Fe metal could reflect oxidation of P in the fluid by reduction of Fe in the original silicates. After the ejecta blanket had cooled, a subsequent impact delivered 79215 to its find site.

Lunar Metasomatism: Metasomatic alteration of lunar rocks is rare, except for the common permeation by a KREEP component, generally ascribed to transport by silicate melt [13,23]. Sulfide metasomatism has also been documented [2], and halogen-metal vapor transport has affected some impact melts and breccias [10,28,29]. 79215 is the first recognized example of substantial phosphate-halogen metasomatism of a lunar rock. We conclude that the moon has supported many fluid-mediated geochemical processes, which span a wide range of fluid types and transported elements.

KREEP Stable Isotopes: If 79215 was metasomatized by fluid derived from KREEP, then the stable isotope ratios of elements enriched during metasomatism could help define the stable isotopic characteristics of KREEP. The δ^{37}Cl of 79215 is in the range of KREEPy rocks [10,12], but at least one non-KREEPy mare basalt has similar δ^{37}Cl, and an impact melt breccia has much higher δ^{37}Cl [12]. The δD of 79215 is higher than KREEPy samples analyzed so far [8], but it is similar to that of many mare basalts [8]. So the stable isotopic composition of KREEP remains uncertain.

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