HIGHLY SIDEROPHILE ELEMENT AND OSMIUM ISOTOPE COMPOSITIONS OF PRISTINE LUNAR CRUST AND IMPACT-CONTAMINATED RUSTY ROCKS. J.M.D. Day[1], Y. Srivastava[1], F.M. McCubbin[2], F., Moynier[3] [1]Scripps Institution of Oceanography, La Jolla, CA 92093, USA (jmdday@ucsd.edu). [2]NASA-JSC, Houston, Texas, USA. [3]IPG-Paris, France.

Introduction: The Moon's plagioclase-rich crust is considered to have formed early in its history (>4.3 Ga) from a magma ocean (e.g., [1]). Anorthosites and associated rocks that are thought to form much of the ancient crust preserve evidence for crystallization and post-crystallization events (e.g., [1,2]). Unravelling the processes affecting lunar crustal rocks, however, is complex and includes consideration of effects such as vapor condensation [3]. As part of a larger study [4,5], our goal is to better understand the relationship of crystallization and post-crystallization processes acting on the lunar crust. Here we examine the relationship of impact processes, KREEP enrichment and 'rust' that can occur in some Apollo 16 lunar crustal samples.

Samples and Methods: In addition to the "Genesis Rock" ferroan anorthosite (FAN) 15415, a major focus of the study is to characterize samples from the Apollo 16 site. We examined troctolitic (62237) and noritic (62236) FAN, cataclastic anorthosites (60015, 60215, 65325, 68515), as well as anorthositic breccias (65035 67455), a feldspathic fragmental breccia (67016) and a polymict breccia (60018). Glass coatings were measured from 65035 and 68515 and four components were measured in impact melt rock 61016; FAN, crystalline anorthosite, grey vitrophyric material and black impact melt.

Analyses were conducted at the Scripps Isotope Geochemistry Laboratory (SIGL) on homogeneous powder aliquots using described methods for major-, trace-element abundance, Os isotope and ID highly siderophile element (HSE: Os, Ir, Ru, Pt, Pd, Re) abundance determination [6,7]. Total analytical blanks resulted in variable corrections for samples, with the most significant corrections for FAN samples.

Results: FAN samples have high Al_2O_3 (>29 wt.%) and CaO (>16 wt.%) and are characterized by overall low rare earth element (REE) abundances (<1 × CI), aside from the characteristic positive Eu* anomaly (Eu* = $(Eu_{CI}/(Sm_{CI}\times Gd_{CI})^{0.5})$ of 23 to 71 (**Fig. 1**). Anorthosite breccia 67455, cataclastic anorthosite 68515 and the FAN component of 61016 have elevated abundances of the REE relative to other FAN (~1 to 6 × CI) with Eu* of 4 to 17 (**Fig. 1**) and we term these "FAN with breccia/melt veins". Impact melts and fragmental breccias from the samples have the highest REE, Ti and Ni contents, with Eu* from 0.3 to 1.8.

From an HSE abundance perspective, most FAN samples lie within the field of pristine lunar crust (**Fig. 2**), with measured $^{187}Os/^{188}Os$ ranging from 0.120 to 0.142. FAN with breccia/melt veins lie within the upper range or above HSE abundances of pristine crust samples with $^{187}Os/^{188}Os$ from 0.115 to 0.137. Impact melts and fragmental breccias are typical of impact-affected rocks from various Apollo sites (e.g., [8-13]), with $^{187}Os/^{188}Os$ from 0.127 to 0.139.

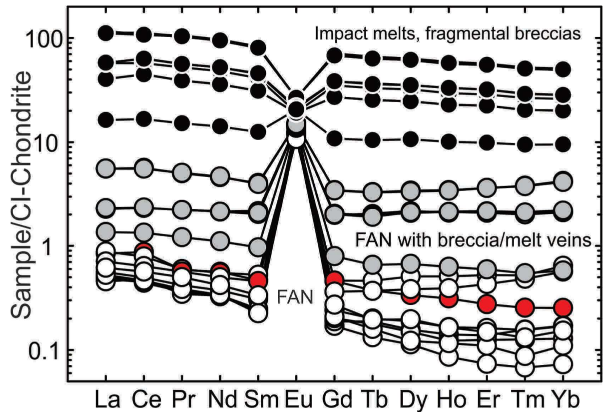

Figure 1: CI-chondrite normalized REE patterns for Apollo 16 samples and 15415 (red circles).

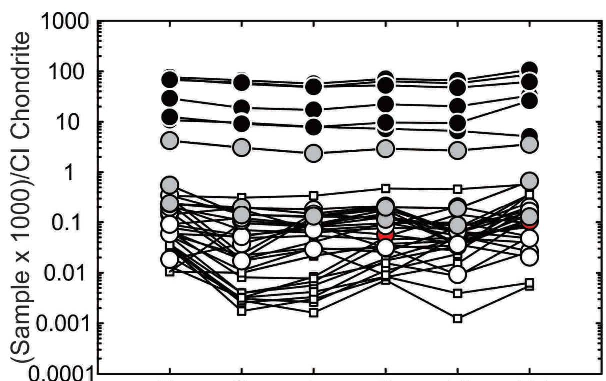

Figure 2: CI-chondrite normalized HSE patterns for Apollo 16 samples and 15415 (red circles), relative to pristine lunar crust [14]. Symbols same as for Fig. 1.

FAN 15415 has a distinct MREE/HREE ratio (Gd/Yb_n = 1.8) to most Apollo 16 FAN (Av. Gd/Yb_n = 1.3) (**Fig. 1**) and has HSE abundances consistent with being a pristine FAN [15], along with most of the other studied A16 FAN samples (**Fig. 2**).

Discussion: The new results significantly increase recognized pristine FAN and associate rocks measured for precise HSE abundances and Os isotopes and corroborates that the early lunar crust had very low initial HSE contents [14].

In Re-Os isotope space (**Fig. 3**), the A16 impact melts and fragmental breccias cluster around a 3.9 Ga chondritic reference isochron, consistent with their generation during impact events responsible for the Cayley Plains and Stone Mountain formations. By contrast, some of the FAN with breccia/melt veins and numerous FAN scatter around or away from the 3.9 Ga isochron, in some cases to possibly younger ages (**Fig. 3**), shown by a 0.6 Ga reference isochron anchored to the lowest measured $^{187}Os/^{188}Os$ from the present data. These suggest disturbance of the ^{187}Re-^{187}Os system through processes including later impacts, or neutron fluence effects on Re [14].

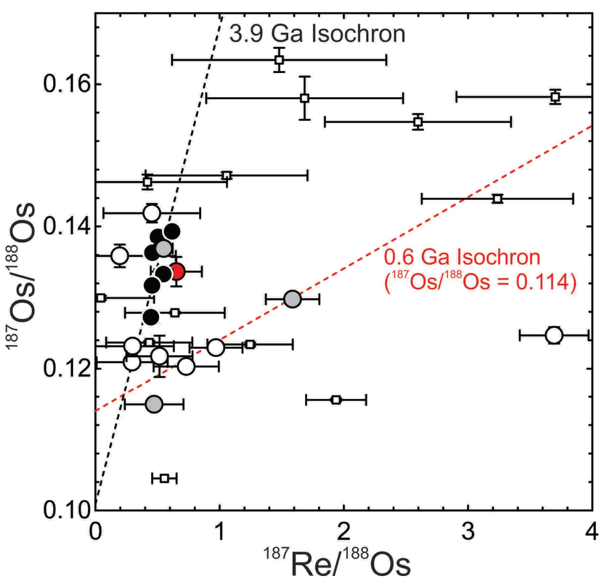

Figure 3: ^{187}Re-^{187}Os systematics for Apollo 16 samples and 15415 (red circle) relative to the lunar crust [14]. Shown are 3.9 and 0.6 Ga reference isochrons anchored to $^{187}Os/^{188}Os$ = 0.114. Symbols same as for Fig. 1.

A negative correlation exists between Eu* - a measure of relative Eu enrichment in FAN, or Eu depletion in KREEP-rich rocks – and HSE (Os) contents (**Fig. 4**). This unequivocally demonstrates addition of lunar-derived KREEP components to A16 samples is associated with impact, likely at ~3.9 Ga, during formation of major near-side basins. The relationship further suggests that where bulk rock REE data for FAN exhibit 'fanning' of the REE, some REE-rich FAN may be compromised by impact processes (e.g., FAN with breccia/melt veins). Impact melts and fragmental breccias are impact contaminated and contain various contributions from KREEP components (**Fig. 1**).

Several of the A16 samples examined in this study contain lunar-derived 'rust' (i.e., lawrencite and its associated alteration products; [4,5]), consistent with the early discoveries of rusty rocks from the same landing site [16,17]. The location of this rust appears to be in the cataclastic anorthositic/brecciated portion of the samples away from the impact melted region [4]. Additionally, there is an inconsistent relationship between the abundance of rust and/or volatile enrichment with the presence of the strongest impact signatures evident from HSE abundances, suggesting that these two phenomena may not be directly related [4,5]. Some lunar rocks, despite being considered "pristine" based on their HSE abundances, show evidence of rust. This raises the possibility that the rust is dominantly of an endogenous origin during degassing processes associated with the differentiation and cooling of the lunar interior.

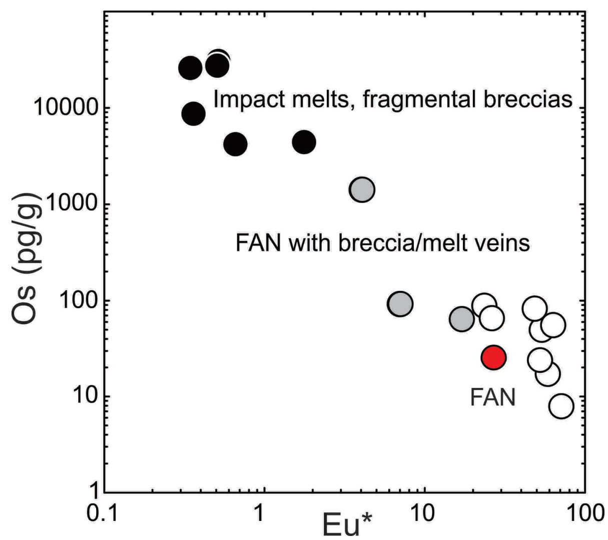

Figure 4: Eu versus Os content for Apollo 16 samples and 15415 (red circle). Symbols same as for Fig. 1.*

Acknowledgments: NASA Solar System Workings program (80NSSC19K0932). **References:** [1] Elardo, S.M. et al. (2023) *Rev. Min. Geochem.* **89**, 293; [2] Wood, J.A., et al. (1970) *Science*, **167**, 602; [3] Renggli, C.J., et al. (2017) *GCA*, **206**, 296. [4] Srivastava, Y. et al. (2025) *LPSC,* this volume; [5] Srivastava, Y. et al., (2025) *LPSC*, this volume; [6] Day, J.M.D. et al. (2018) *Nat. Comm.* **9**, 4799; [7] Day, J.M.D., Walker, R.J. (2015) *EPSL* **423**, 114; [8] Fischer-Gödde, M., Becker, H. (2012) *GCA* **77**, 135; [9] Puchtel, I.S. et al. (2008) *GCA* **72**, 3022; [10] Liu, J. et al. (2015) *GCA* **155**, 122; [11] Glieβner, P., Becker, H. (2017) *GCA* **200**, 1; [12] Glieβner, P., Becker, H. (2019) *MAPS* **54**, 2006; [13] Norman, M.D. et al. (2002) *EPSL* **202**, 217; [14] Day, J.M.D. et al. (2010) *EPSL*, **289**, 595; [15] Ganapathy, R., et al. (1973) *PLSC*, **4**, 1239; [16] Taylor L.A. et al. (1973) *PLSC*, **4**, 829; [17] Taylor, L.A. et al. (1974) LPSCP, **5**, 743.