CONSTRAINTS ON HIGHLY SIDEROPHILE ELEMENT ABUNDANCES IN THE LUNAR CRUST FROM REGOLITH BRECCIA METEORITES Y 981031, Y 983885 AND Y-86032.

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Introduction: Impactor-contaminated rocks such as impact melt breccias (IMB), lunar regolith breccia meteorites and impact melt coats (IMC) have been analyzed to understand the flux, nature and highly siderophile element (HSE) characteristics of impactor materials that were accreted after the Moon formed [1-5]. Studies on IMB samples have reported that Re-Os isotopic compositions in several cases are super-chondritic with high Pt/Ir, Pd/Ir and Ru/Ir that differ significantly from the present-day composition of chondrites sampled on Earth [1-5]. It has been suggested that super-chondritic $^{187}Os/^{188}Os$ and high Pt/Ir, Pd/Ir and Ru/Ir in some Apollo IMB demarcates changes in the composition of impactors striking the Moon before and after 3.5 Ga, possibly following the Late Heavy Bombardment (LHB) [5]. Some apparently non-converging controversial explanations are that these HSE characteristics could reflect (1) a combination of chondritic and differentiated impactors [3]; (2) mixing of endogenous lunar crustal components with fractionated HSE relative to chondrites [6], or (3) fractionation of the HSE within impact melts sheets [7].

In this work, we studied the abundances of the HSE and $^{187}Os/^{188}Os$ for lunar meteorites Y-86032, Y 981031, and Y 983885. Further, these three regolith breccia meteorites enable examination of the nature, flux and composition of the materials striking the unexplored lunar surface away from the PKT [8]. Most importantly, these results help to provide a robust constraint on the abundance of the HSE in the lunar crust, globally.

Methodology: Back-scattered electron imaging, X-ray mapping and mineral chemical analysis were carried out using an electron probe microanalyzer at the Physical Research Laboratory. Bulk major and trace element analyses were performed on the powdered bulk rock using an iCAP-Q ICPMS at the Scripps Isotope Geochemistry Laboratory (SIGL). Highly siderophile elements and Os isotopes were measured by digesting the remaining sample powder with appropriate amounts of reagent and isotopically enriched spikes in Carius tubes at the SIGL. Osmium isotope dilution (ID) concentration and isotopic composition was analyzed by N-TIMS while the remaining HSE were analyzed for ID concentrations by ICP-MS (e.g., [5]).

Results: *Composition of metal grains:* Among the studied sections of regolith breccia meteorites, only Y 981031 and Y 983885 contain numerous FeNi metal grains. Sample Y 981031 has metal grains embedded in matrix as isolated mineral fragments (**Fig. 1a**). The Ni and Co composition of metal grains show restricted composition of 3.53-6.91 wt.% Ni and 0.39-0.60 wt.% Co. The metal grains in sample Y 983885 exists as anhedral grains of size ranging from 100-200 µm (**Fig. 1b**). The compositional range of Ni and Co in Y 983885 metal grains vary from 2.86-10.59 wt.% and 0.32-0.78 wt.%, respectively.

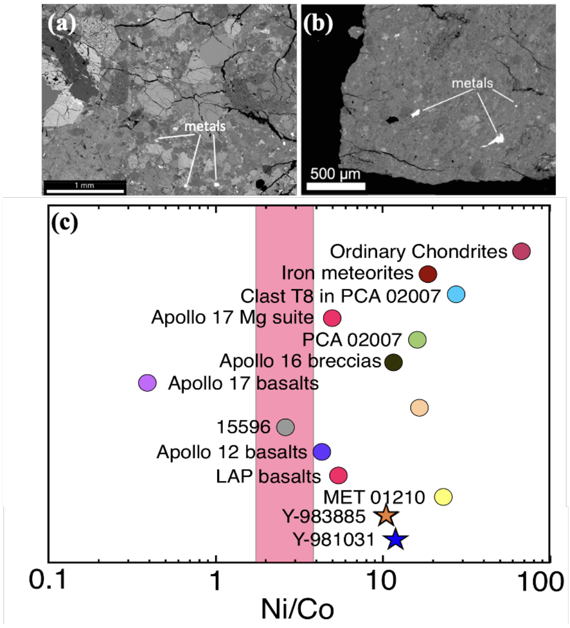

Figure 1. *Fe-Ni-Co Metal grains in studied lunar meteorites. a) Image showing small irregular metal grains in Y 981031. b) Anhedral Fe-Ni metal grains in Y 983885. c) Ni/Co ratio in metal grains of studied lunar meteorites (cf. [9]) Red regions corresponds to Ni/Co ratio in terrestrial metals. Data Source from [9] and references therein.*

Highly Siderophile Element and Re-Os isotopes: Among all three samples, Y-86032 exhibits relatively flat HSE patterns while Y 981031 and Y 983885 patterns display HSE fractionation (**Fig. 2**). Sample Y 981031 shows enrichment of Pt and Pd and Y 983885 has a relative enrichment of only Pd. Sample Y 983885 has the highest absolute abundance of the HSE among the studied samples, suggesting the most significant impactor contamination.

The HSE composition in the studied regolith breccias shows heterogeneity in their (Pt, Pd, Ru)/Ir ratios (**Fig. 3**). Sample Y-86032 shows chondritic ratio of all the HSE (Ru/Ir=1.38; Pd/Ir = 1.26 and Pt/Ir =1.88) and falls in the field of chondrites and impact melt breccias. Sample Y 981031 exhibits non-chondritic ratios of Pd/Ir=5.51 and Pt/Ir=6.96. Similar non-chondritic Pd/Ir=3.51 is observed in Y 983885, however, Pt/Ir value falls within chondritic fields. The non-chondritic Pd/Pt and Pt/Ir, have been observed previously in the case of Apollo 16 impact melt rocks, Apollo 16 impact melt coat 65035 and lunar meteorite MIL 090034 [3,5]. Unlike the inter-element HSE concentrations, ratios of $^{187}Os/^{188}Os$ for the studied regolith breccia meteorites show chondritic ratios ranging between 0.1265 (~3.5 Ga; Y 981031) and 0.1278 (~ 4.4 Ga; Y-86032). All these measured ratios plot within previously measured $^{187}Os/^{188}Os$ of Apollo 16 and 17 impact melt breccias, feldspathic impactites and terrestrial primitive mantle (**Fig. 3**).

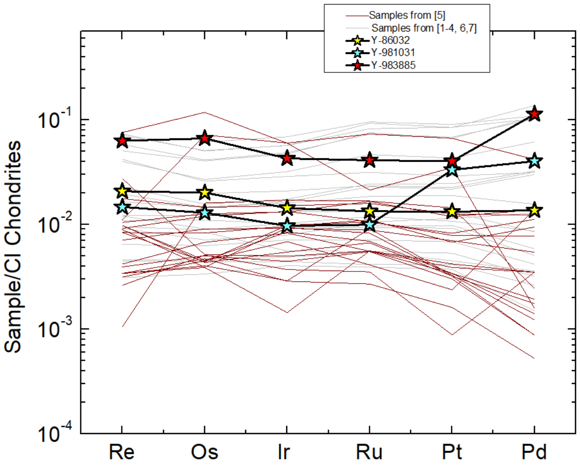

Figure 2 *Carbonaceous Ivuna (CI) normalized highly siderophile (HSE) abundances for studied regolith breccia meteorites, Y 981031, Y 983885 and Y-86032 compared with previously analyzed impact melt rocks. CI chondrite normalization from [10].*

Discussion and Conclusions: Metal grains in regolith breccias Y 981031 and Y 983885 show Ni/Co composition of 10.4±1.5 (n=6) and 11.7±2.8 (n=20), respectively (**Fig. 1c**). These values are similar to Ni/Co compositions of metal grains present in Apollo 16 impact melt breccias (~ 11.6), but lower than the value observed in lunar breccia meteorites MET 01210 (~23.6) and PCA 02007 (~27). The intermediate Ni/Co of Apollo 16 impact melt breccias has been interpreted as a signature of mixing between low Ni/Co endogenous component and high Ni/Co exogenous components [9]. Therefore, sample Y 981031 and Y 983885 likely preserve some evidences of pre-existing lithologies.

A stark contrast in HSE abundances between the impactor (ng/g level) and lunar crustal lithologies (pg/g level) enable constraints to be placed on the putative impactor composition and crustal evolution with time [3-5]. Inter-elemental HSE ratios are considered to be important in diagnosing the possible impactor [1-7]. The HSE and $^{187}Os/^{188}Os$ composition of the studied samples highlights three distinct varieties (**Fig. 3**): the anorthositic regolith breccia Y-86032 has a relatively flat HSE pattern with chondritic Os isotopic composition; the coarse-grained fragmental regolith breccia Y 981031 has a non-chondritic HSE pattern with highly fractionated Pt and Pd but chondritic $^{187}Os/^{188}Os$ composition; and the very fine grained regolith breccia Y 983885 has a chondritic Os composition and nearly flat HSE pattern with only slight Pd fractionation. The HSE inter elemental ratio of Y-86032 consistently points toward an ordinary chondrite like composition, with elevated abundance of either Pd and Pt in Y 981031 or only Pd in Y 983885. We suggest that the elevated HSE ratios could possibly be the result of overprinting processes within impact melt sheets which compromises the preservation fidelity of impact signatures.

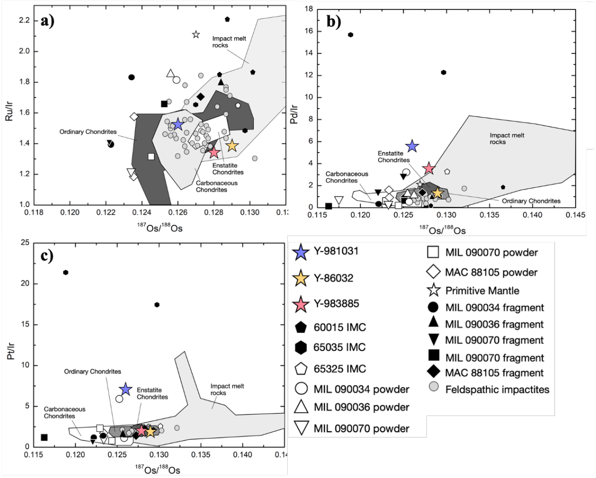

Figure 3 *Plots of $^{187}Os/^{188}Os$ versus a) Ru/Ir b) Pd/Ir and c) Pt/Ir for studied regolith breccia meteorites, Y-981031, Y-983885 and Y-86032, impact melt rocks, lunar anorthositic regolith breccia, impact melt coats and chondrites (cf. [5]).*

References: [1] Walker R. J., et al., (2004) *EPSL* 224, 399–413; [2] Puchtel I. S., et al., (2008) *GCA* 72, 3022–3042; [3] Fischer-Gödde M. and Becker H. (2012) *GCA* 77, 135–156; [4] Gleißner P. and Becker H. (2017) *GCA* 200, 1–24, [5] McIntosh E. C., et al., (2020) GCA *274*, 192–210. [6] Norman M. D. et al., (2002) *EPSL* 202, 217–228. [7] Day J. M. D., et al, (2016) *RIMG* 81, 161–238. [8] Srivastava et al., (2023) *LPSC* (this year) [9] Day, J. M. D. (2020) *MAPS*, 55(8), 1793-1807. [10] Horan, M. F., et al., (2003). *Chem. Geol.* 196(1-4), 27-42.