INSIGHTS INTO IMPACTOR POPULATIONS STRIKING THE MOON FROM MELT COAT AND REGOLITH METEORITE COMPOSITIONS. E. Carrie McIntosh[1], James M.D. Day[1], Yang Liu[2] [1]Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093-0244, USA; e-mail: ecmcinto@ucsd.edu; [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

Introduction: Lunar impact melt coats (IMC) and impact melt breccias (IMB) can provide insights into the composition of impactors that were striking the Moon after the formation of the lunar crust. The highly siderophile elements (HSE: Re, Au, Ir, Os, Ru, Rh, Pt, Pd) are sensitive tracers of impactor contributions due to the virtue of low HSE contents in pristine lunar crustal rocks [1], and the leverage from elevated HSE concentrations in impactor populations that are assumed to have been broadly similar to chondrites or iron meteorites [2]. Prior work has shown both HSE abundance and Os isotope variability in IMB, demonstrating diversity in impactor populations [3-6]. Here we present HSE abundances and $^{187}Os/^{188}Os$ of late accreted materials by analyzing IMC and anorthositic regolith breccia meteorites.

Methods: Polished sections of 60015,116, 60015,805, 65325,18, and 65035,176 were analyzed for HSE abundances using a *New Wave* UP-213nm laser ablation system coupled to a *ThermoScientific* iCAPq inductively coupled plasma mass spectrometer (ICP-MS). Chips of IMC 65035,192, 65325,24, and 60015,791, and a mixture of powders and fragments of regolith breccia meteorites Miller Range (MIL) 090034,22, MIL 090036,14, MIL 090070,16, MIL 090075,15 and MacAlpine Hills (MAC) 88105,180 were analzed for major- and trace-element abundances, ^{187}Re-^{187}Os, and highly siderophile element abundances [7]. We measured both bulk rock powders and fragments of the meteorites in order to examine variation between homogenous powders and fragments.

Results: *Impact Melt Coats:* IMC on average have higher Pd, Pt, Ru, Ir, and Os abundances compared to anorthositic regolith breccia meteorites measured in this study. Analyses of separate fragments of 65035 IMC have high Pd and Pt abundances compared with Re, Ru, Ir and Os. 65325 IMC has the highest overall HSE abundances, with a relatively flat CI-chondrite normalized pattern (*Figure 1*). The $^{187}Os/^{188}Os$ values for IMC range from 0.1283 to 0.1366, with one exception: one glass fragment analysis of 65035 has a $^{187}Os/^{188}Os$ ratio of 0.1189 (*Figure 2*). IMC have higher $^{187}Os/^{188}Os$ ratios than the anorthositic regolith breccias measured in this study.

Anorthositic Regolith Breccia Meteorites: MIL 090075 and 090034 have Pd depletions outside of the range of published data on IMB, and Re abundances for the anorthositic regolith breccias vary over several orders of magnitude. An analysis of MIL 090036 has higher abundances of Pd, Pt, Ru, Ir, and Os than other anorthositic regolith breccia meterorite analyses and likely reflects metal nuggeting. The $^{187}Os/^{188}Os$ values for the anorthositic regolith breccias range between 0.1164 (MIL 090075) and 0.1284 (MIL 090036) (*Figure 2*). In general, anorthositic regolith breccia meteorites have lower HSE abundances than IMC or IMB, and have Os isotope compositions similar to present day chondritic values. Powders of the anorthositic regolith breccias tend to be fairly homogenous in composition; however, fragments show significant HSE abundance variations, as shown for IMB (e.g., [4,5]).

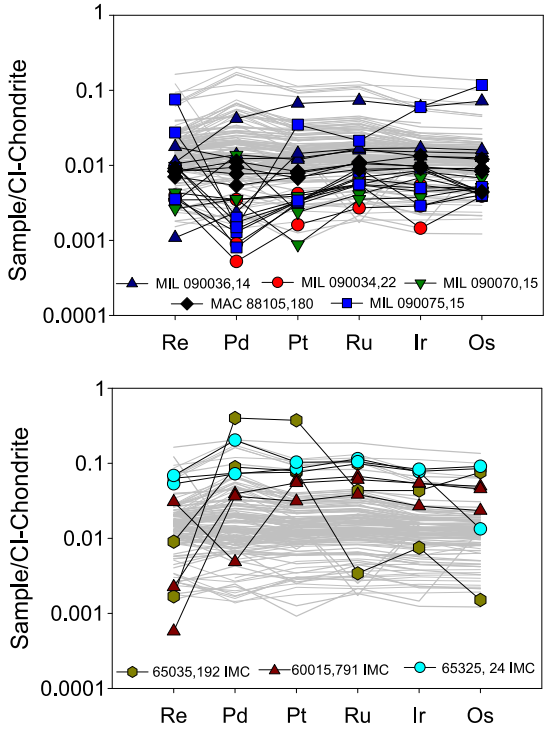

Figure 1: *CI-Chondrite normalized HSE abundances for IMC and anorthositic regolith breccia meteorites. Previous data for IMB are shown in grey [3,4]. CI chondrite normalization from [8].*

Metal and Schreibersite in IMC: Samples 60015, 65035, and 65325 IMC contain metal and schreibersite, and were analyzed for HSE abundances by LA-ICP-MS (*Figure 3*). Metal B from 60015 shows a Pd depletion, which is similar in magnitude to observed Pd depletions in some IMC and IMB. Metal A in 60015 has a flatter pattern, which corresponds to relatively flat

Pd, Pt, Ru, Ir, and Os in some 60015 fragments. Both the metal and schreibersite in 65035 and 65325 are intergrown with troilite and have lower abundances of HSE than those in 60015. Schreibersite from 65035 has much lower Pt and Ru abundances than other metal and schreibersite grains. The metal-schreibersite-troilite segregations in IMC lead to significant HSE fractionation.

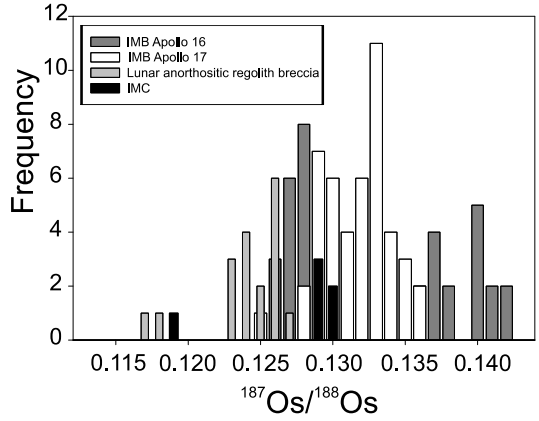

Figure 2: *Histogram of measured $^{187}Os/^{188}Os$ for Apollo 17 IMB (white) [4], Apollo 16 IMB (dark gray) [5], anorthositic regolith breccia meteorites (light gray), and IMC (black).*

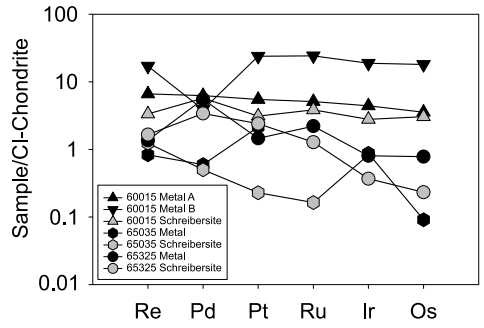

Figure 3: *Metal and schreibersite compositions within Apollo 16 IMC. CI normalization from [8].*

Discussion: In our analysis of IMC, we find that they are elevated in Pd, Pt and Ru compared to IMB, MIL 090034/36/70/75, and MAC 88105. Nugget heterogeneity within the IMC is significant, due to the heterogeneous distribution of metal-schreibersite-troilite blebs. Heterogeneity is also evidence within the anorthositic regolith breccia meteorites, with fragment showing a greater range in relative and absolute HSE concentrations, as also observed for IMB (e.g., [4,5]).

Previous work has demonstrated that breccias and impact-melt rocks contain geochemical signatures of chondrite- or iron meteorite-like impactors [2-6]. The IMC that we have analyzed are interpreted to be younger that IMB [9] and have inter-element HSE ratios that are closer to chondritic than IMB [3,4] or the anorthositic regolith breccias that we have analyzed. This is illustrated in *Figure 4* where the new data for IMC and anorthositic regolith breccias fall within range of modern day chondrites [8]. IMC tend to have compositions closer to ordinary chondrite and enstatite chondrite compositions, versus anorthositic regolith breccia meteorites, which are more consistent with the composition of a carbonaceous chondrite impactor population.

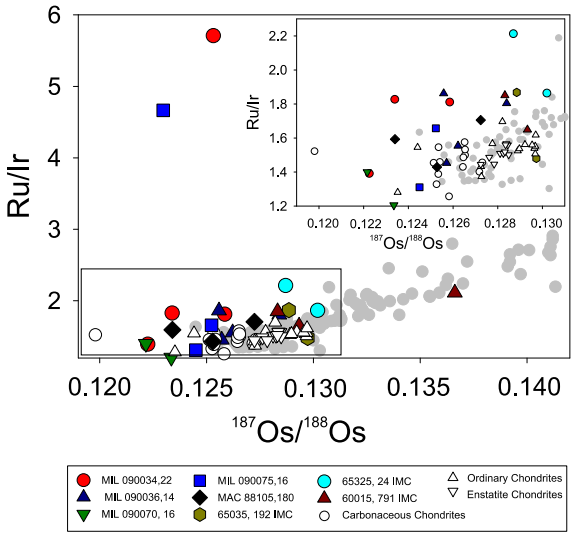

Figure 4: *Plot of Ru/Ir versus $^{187}Os/^{188}Os$ for IMC, lunar regolith breccias, IMB, and chondrites. Previously plotted IMB data plotted in gray are from [3,4] and chondrite data are from [8]. The box highlights the enlarged inset.*

New $^{187}Os/^{188}Os$ and HSE abundance results from IMC and anorthositic regolith breccia meteorites are significant for several reasons. First, these samples reveal significant fractionation of the HSE due to segregation of metal and sulfide during impact melt recrystallization, and during processes responsible for regolith breccia formation. Second, younger IMC and anorthositic regolith breccia meteorites do not possess the high Pd/Ir and Ru/Ir observed in IMB and that suggest an earlier population of impactors striking the Moon with distinct compositions compated with modern-day chondrite meteorites.

References: [1] Day, J.M.D. et al (2010) *EPSL*, **289**, 595-605. [2] Day, J.M.D. et al. (2016) *RIMG*, **81**, 161. [3] Norman, M.D. et al (2002) *EPSL*, **202**, 217; [4] Puchtel, I.S. et al (2008) *GCA*, **72**, 3022; [5] Fischer-Godde, M. & Becker, H. (2012) *GCA*, **77**, 135; [6] Korotev, R.L. (1994) *GCA*, **58**, 3931; [7] Day, J.M.D. et al. (2016) *GGR*, **40**, 49; [8] Horan, M.F. et al. (2003) *Chem. Geol.*, **196**, 5-20. [9] Day, J.M.D., Liu, Y. (2017) *LPSC*, **48**, 2808.