OSMIUM ABUNDANCE & ISOTOPE SYSTEMATICS OF LUNAR CRUSTAL ROCKS AND MARE BASALTS.

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Introduction: The lunar crust is considered to have formed as early as 4.4 billion years ago as a consequence of a large-scale magma ocean differentiation event [1, 2]. It has been argued that this thick, ancient crust was an effective barrier to additions to the lunar mantle by post-core formation accretion [3, 4]. There is corresponding physical and chemical evidence that brecciated crustal materials have experienced significant re-working and contamination via impact events (e.g., [5-7]). However, our understanding of lunar formation processes, the composition of the Moon and the flux of post-core formation accretion materials to it, is hampered by a still-limited knowledge regarding the abundances of highly siderophile element (HSE) in the lunar crust. Based on the apparently low HSE content of the lunar mantle [3] and knowledge of HSE partitioning, ancient, pristine crustal samples should have extremely low HSE concentrations, yet analysis of some impact melt breccias may indicate anomalously high abundances of some HSE components after mathematically removing meteoritic additions from the samples [7]. This could point to high indigineous concentrations of some HSE in crustal components. In order to place better constraints on the HSE inventory of the Moon, we present an initial characterization of lunar pristine crustal rocks, as well as new analyses for Apollo 12 olivine-normative basalts.

Methods: We have analysed 2 Apollo 12 Olivine-normative basalts (12009, 136; 12040, 200), 1 troctolite (76535, 16), 3 ferroan anorthosites (65315, 145; 62255, 181; 60025, 851) and 3 norites (15455, 297; 77215,233; 78235, 143). All crustal samples were requested from CAPTEM without melt veins and brecciated materials to avoid exogenous meteoritic components. We also measured two Apollo 15 basalts (15555, 955; 15555, 958) to confirm inter-laboratory consistency [3]. Osmium analyses were performed at the Univeristy of Maryland and other HSE measurements were in progress as the time of writing. 0.18 to 0.35 g aliquots of sample were dissagregated and spiked with isotopically-enriched HSE tracers, the amounts of which were estimated based upon previously published INAA Ir data [8]. Osmium was purified using standard digestion and extraction techniques (e.g., [3, 4, 7]) and Os isotopic and elemental compositions were measured via N-TIMS. Os blanks (*n* = 4) averaged 0.22 pg with a $^{187}Os/^{188}Os$ = 0.158.

Results: Aliquots of 15555 are within error of $^{187}Os/^{188}Os$ reported in [3] and [9], but Os concentrations (8 to 12.4 ppt) are somewhat (~10%) lower. We attribute this to 'nugget'-effects, especially considering the limited sample mass (~250 mg) analysed here. Olivine-normative cumulate (12040) and vitrophyre (12009) basalts from the Apollo 12 site have Os concentrations of ~10 to 30 ppt, in the range of Apollo 15 and 17 samples. They are also characterized by present-day $^{187}Os/^{188}Os$ of ~0.142, consistent with generally low, long term Re/Os. Ferroan Anorthosite (FANs) samples have very low Os abundances (≤ 1.4 ppt) and suprachondritic present-day $^{187}Os/^{188}Os$ ratios that extend to as high as 0.20. Two of the high-Mg suite (HMS) samples also have low Os concentrations (0.4 to 15.3 ppt) and present-day $^{187}Os/^{188}Os$ ranging from 0.16 to 0.17. An additional HMS, 77215, has a present day $^{187}Os/^{188}Os$ of 0.124, that is within the range of chondrites, and a relatively high Os concentration of 144 ppt.

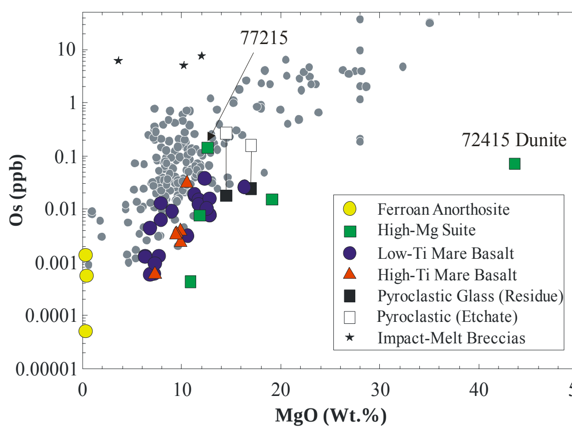

Figure 1. *MgO versus Os concentration (in ppb) for typical terrestrial lavas (grey circles) and lunar rocks. Lunar mare basalts plot at systematically lower Os concentrations than terrestrial lavas of comparable MgO contents. New pristine lunar crustal data, and data for lunar dunite 72415 point to a lunar crust that has very low abundances of Os. Lunar data from this study, [3], [4] and [7].*

Discussion: A striking feature of the new lunar crustal data is the very low Os abundances in FAN and HMS rocks (Fig. 1). Only one HMS sample, 77215, has an elevated Os concentration with respect to the other pristine crustal rocks we measured, but the chondritic measured $^{187}Os/^{188}Os$ of this sample (0.124) may indicate exogenous meteoritic addition. Invariably, nearly all 'pristine' lunar crustal samples preserve evidence for meteoritic additions, either to their surfaces, in the guise of glass coatings, or as melt veins within the sample. The great majority of prisitine lunar crustal rocks also preserve Ar release spectra consistent with ages ~3.9 Gyr, the proposed age of a cataclysmic lunar late heavy bombardment event [10]. Lunar impact melt breccias typically have present day $^{187}Os/^{188}Os$ ratios ranging from 0.124 to 0.135. The Os isotope composition measured for 77215 is just at the lower end of this range. Evidently the portion of 77215 that we analysed, for which we saw no surficial evidence for melt veins or glass was compromised by this process (Fig. 2). Further analysis of aliquots of 77215 may allow us to better constrain the igneous HSE inventory for this sample. For the purpose of characterizing the Os isotope composition of the lunar crust, we will not consider the data for 77215 further.

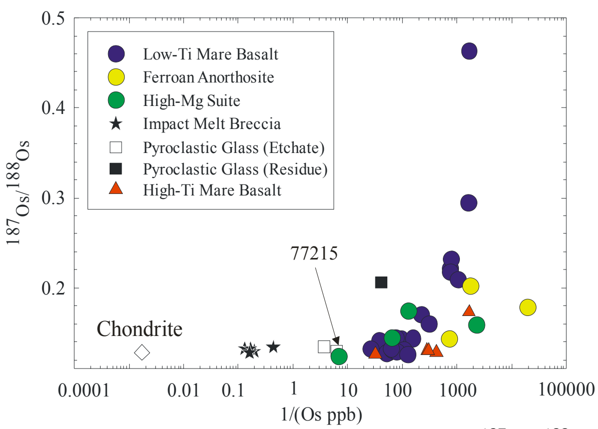

Figure 2: *Reciprocal Os versus measured $^{187}Os/^{188}Os$ for lunar rocks. The observed compositions of pyroclastic glass etchates, 77215, and aphanitic and poikilitic impact melt breccias are consistent with meteoritic contamination. Indigenous lunar Os compositions are reflected in the bulk of mare basalt data, which have been interpreted as originating from a lunar mantle with 20 to 30 times lower HSE content than Earth's mantle [3, 4]. The new prisitine lunar crustal data are consistent with this notion. Data from this study, [3], [4] and [7].*

Using the Os content and $^{187}Os/^{188}Os$ of the samples we have calculated Re* [3], the Re content consistent with the samples having chondritic $^{187}Os/^{188}Os$ at the time of rock formation. Along with Os abundances, the Re* for prisitine crustal rocks indicates that the indigenous (i.e., original) HSE content of the lunar crust is very low, with less than 0.3 ppt Re* and 1.4 ppt Os for FANs and 2 ppt Re* and 15.3 ppt Os for HMS rocks. In the context of the HMS rocks, it is worth noting that the highest Os concentration measured in a sample uncompromised by meteoritic re-enrichment of HSE, is 76535, the classic lunar troctolite.

Our data suggest that the HSE content of pristine lunar crust is extremely low (Fig. 2). Indeed, it is significantly lower than estimates of the terrestrial crust [11] and supports the notion that the silicate portion of the Moon was depleted with respect to HSE via metal-silicate equilibrium and did not witness post-core formation replenishment until after lunar crust formation [3, 4].

Work on poikilitic and aphanitic impact melt breccias has highlighted the requirement for elevated Pd, Ru and Os in some of the original target rocks enriched in HSEs during large impact melt events [6, 7, 12]. High concentrations (as high as 0.36 ng/g Os, 1 ng/g Ru and 2.8 ng/g Pd) calculated from intercept regressions of impact melt breccia data [7], which appear to have relatively constant compositions [12], have been suggested to reflect some portions of indigenous lunar crustal components [13], or multiple impact events [12]. It remains unknown the degree to which the HSE are heterogeneously distributed within the lunar crust. Given the extent of ferroan anorthositic material on the Moon [14], it will be critical to examine additional FANs.

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