A ^{187}RE-^{187}OS AND HIGHLY SIDEROPHILE ELEMENT STUDY OF THE KREEP-FREE YAMM BASALTS.
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Introduction: The study of highly siderophile element (HSE: e.g., Re, Pd, Pt, Ru, Ir, and Os) abundances and $^{187}Os/^{188}Os$ in lunar rocks is useful in understanding the formation and evolution of the Moon [1-3]. Due to the absence of true mantle materials in the lunar sample collection, mantle HSE abundance estimations have largely been based on HSE contents in mare basalts, regressing to an assumed bulk mantle MgO concentration [1,3]. The mantle source of mare basalts, despite being heterogenous in terms of trace element abundances and Sr-Nd-Hf-Pb isotopes [4, 5], is considered to be homogeneous, with a low HSE abundance of ~0.0002 × CI and a chondritic $^{187}Os/^{188}Os$ composition [1,3]. Another important aspect of estimation of the HSE in the Bulk Silicate Moon (BSM) is that most of the samples analyzed for the HSE are returned mare basalts samples, which were brought from an anomalous region – particularly enriched in potassium (K), rare earth elements (REE) and phosphorous (P), (KREEP) – known as the Procellarum KREEP Terrain (PKT). To overcome this issue, previous studies [1,3,6] have utilized lunar meteorites to compliment the BSM budget estimate for the HSE. Notwithstanding, there is a continued need to analyze further samples, especially from regions other than PKT, to constrain the BSM HSE content as well as to understand the nature and quantity of late accretion materials on the Moon [2,6,7].

Here we present a comprehensive geochemical study of A-881757 along with other meteorites from the YAMM (Yamato-793169, Asuka-881757, Miller Range 05035 and Meteorite Hills 01210) basalt clan, including analysis of HSE abundances and Os isotope ratios. The YAMM meterorites range from unbrecciated gabbros (A-881757 and MIL 05035), to unbrecciated basalt (Y-793169), to a polymict regolith breccia (MET 01210), that have the most depleted Sr-Nd isotope compositions and crystallization ages (~3.9 Ga). These ages coincide with the putative late heavy bombardment, make them ideal samples with which to study both exogenous and endogenous processes on the Moon.

Methods: Analysis of major element compositions of minerals and BSE imaging were conducted at the National Institute of Polar Research (NIPR), Japan. The 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 remaining sample powder with appropriate amounts of 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., [3]).

Results:

Metal grains in A-881757 and YAMM basalts: Two distinct associations of metal grains were found in A-881757. One occurs as relatively coarse ~100 µm anhedral grains associated with pyroxene and troilite (Type-I) and the other as small grains (~10-20 µm) occurring between spinel and ilmenite (Type-II) (Fig. 1). Other than A- 881757, only MET 01210 has

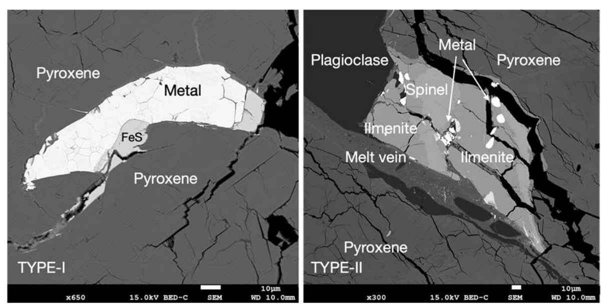

Figure 1: *Backscattered image of metal grains showing two distinct associations in A-881757, 88 thick sections.*

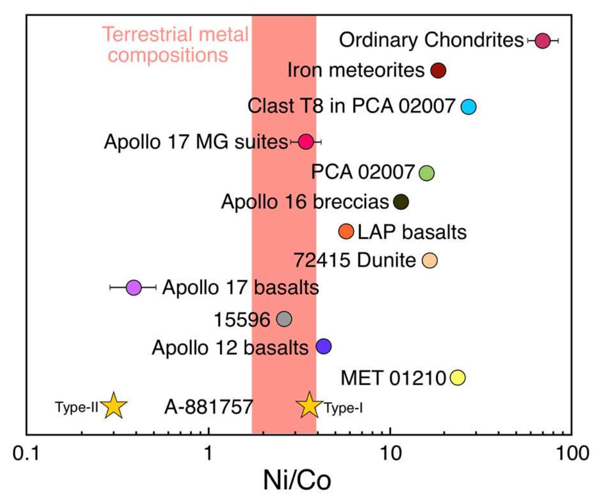

Figure 2: *Ni/Co ratio in metal grains of A-881757 compared with MET 01210, mare basalts, MG suite, chondrite, iron meteorites and terrestrial metals. Data sources: this study, [9] and references therein.*

anhedral metal grains [8, 9]. The Ni/Co composition of metal grains can record the effect of impact contamination as most plausible impactors (chondrites and iron meteorites) have relatively high Ni/Co [9]. The average measured Ni/Co composition of metals in A-881757 is 3.6 for Type-I and 0.3 for Type-II (Fig. 2). Day [9] measured the average Ni/Co composition of metals in MET 01210 to be ~23.6, indicative of exogenous input of chondritic material. Our measured Ni/Co for A-881757 metal grains suggest them to be pristine, free from impactor contamination. Therefore, A-881757 can be used to estimate BSM HSE contents in non-PKT regions.

HSE abundance and $^{187}Os/^{188}Os$: A-881757 has less fractionated and higher HSE abundance when compared to its paired counterpart MIL 05035 (Fig. 3). The absolute and relative abundance of HSE in A-881757 lies at the higher end among previously analyzed mare basalt meteorites while being within the range of values observed for Apollo mare basalts [1, 3]. The $^{187}Os/^{188}Os$ of A-881757 (0.1247 ±0.0003) is slightly sub-chondritic but within error to its pair MIL 05035 (0.1244 ±0.0002). The Re/Os is likely disturbed as has previously been observed for MIL 05035 and LAP basalts (Fig. 3).

Discussion: YAMM basalts have previously been

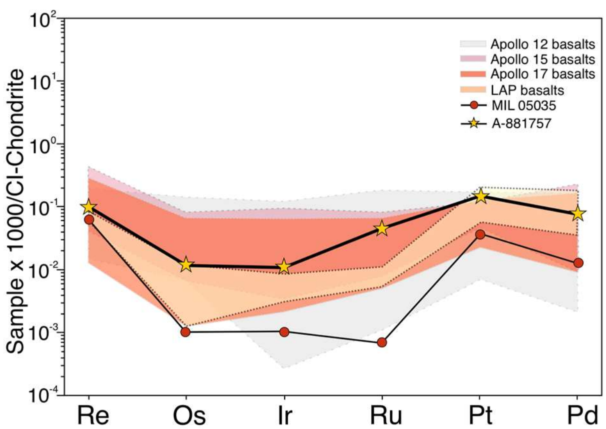

Figure 3: *CI-chondrite normalized HSE abundance patterns for A-881757, MIL 05035 [3], LAP basalts [1], and Apollo 12, 15, 17 mare basalts [3].*

shown to originate from pyroxene-rich mantle at depths shallower than Apollo mare basalts [10]. The observed Sr-Nd isotope heterogeneity between the KREEP-free YAMM mantle source and KREEP-rich Apollo mare basalts is evident in Os isotopes, depicting the insensitivity of ^{187}Re-^{187}Os systematics to Lunar Magma Ocean crystallization and a relatively homogenous distribution of the HSE within the lunar mantle. However, we observe differences in the HSE abundances of MIL 05035 and A-881757. In the absence of impact contamination, a few endogenous

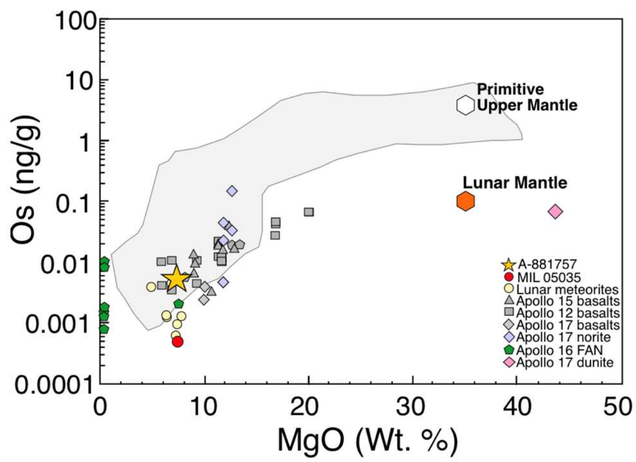

Figure 4: *Bulk Os (ng/g) versus MgO(wt. %) concentration plot for YAMM basalts [this study, 3], Apollo 11, 12, 15,17 [3, 11], low-Ti mare basalt meteorites [11]. The terrestrial lavas are shown as the grey region [11].The values of Earth's primitive mantle [12] and lunar mantle [1] are shown for a similar mantle MgO abundance.*

process may have been responsible for the variation observed between the bulk HSE abundances of A-881757 and MIL 05035, despite having similar $^{187}Os/^{188}Os$. First, the coarse-grained nature of these samples could possibly have led to variable metal or sulfide distribution in aliquots (i.e., more in A-881757 than MIL 05035). Alternatively, sulfide and/or metal fractionation may have occurred during fractional crystallization of parent magmas. The absence of metal grains in MIL 05035 supports this latter view, that the variations reflect fractional crystallization at 3.9 Ga with very limited corresponding Re/Os fractionation. The measured bulk HSE abundance of A-881757 suggest that our present predicted values of BSM lies well within the values estimated by previous studies (Fig. 4) [1, 3].

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References: [1] Day, J.M.D. et al. (2007) Science, 315, 217. [2] Bottke et al. (2010) Science, 330:1527-1530. [3] Day, J.M.D., Walker, R.J. (2015) EPSL, 423, 114. [4] Hallis et al. (2014) GCA, 134:289-316. [5] Neal, C.R., and Taylor, L.A. (1992), 56(6):2177-2211. [6] Day, J.M.D., and Paquet, M. (2021) MAPS, 56(4):683-699. [7] Zhu, M.H. et al. (2019) Nature, 571(7764):226-229. [8] Arai, T. et al. (2010) GCA, 74(7):2231-2248. [9] Day, J.M.D. (2020) MAPS, 55(8): 1793-1807. [10] Srivastava, Y. et al. (2022) Nat. Comm., 13(1):1-9. [11] Day, J.M.D. et al. (2010) EPSL, 289(3-4): 595-605. [12] Becker, H. et al. (2006) GCA, 70:4528-4550.