DIFFERENTIATED IMPACTOR SIGNATURE IN APOLLO 16 IMPACT MELT ROCKS. P. Gleißner[1] and H. Becker[1], [1] Freie Universität Berlin, Institut für Geologische Wissenschaften, Malteserstr. 74-100, 12249 Berlin, Germany (gleissner@zedat.fu-berlin.de)

Introduction: Early work on ancient lunar impact rocks from all Apollo and Luna landing sites has shown that significant quantities of highly siderophile elements (HSE) were added to the lunar crust after core formation and magma ocean crystallization [e.g., 1-3]. Most of the HSE in the lunar crust were supplied during the basin forming impact events, between 4.5 and 3.8 Ga. The exact ages of the basins and the existence of a "late heavy bombardment" event at 3.75-3.95 Ga are still debated [e. g., 4-6].

Since differentiated pristine rocks of the lunar crust are very low in highly siderophile elements [7] the budget of these elements in impact melt rocks is dominated by the composition of the impactors. Hence, the compositional record of ancient lunar impact rocks provides constrains on the composition and timing of the impact flux to the moon, with important implications for the inner solar system dynamics and late accretion history of the terrestrial planets [8-10]. This information is also the key to understand the observed excess abundance of highly siderophile elements in the earth's mantle and the slight deviation from chondritic ratios [11].

The compositions of siderophile, chalcophile and volatile trace elements were used to tentatively assign ancient lunar impact rocks to specific basins and impactor signatures [e.g., 1,2]. Recent work on HSE compositions of lunar impact rocks, using precise isotope dilution methods combined with osmium isotopic compositions as a time-integrated measure of the Re/Os ratio, highlight similarities and differences of lunar impact rocks to known chondritic and non-chondritic meteorite groups [12-16]. At present, the majority of such data are available from the Apollo 17 landing site. Most Apollo 17 impact rocks were interpreted as ejecta of the impact that formed the Serenitatis basin (assumed by some to have formed 3.89 Ga [e.g., 17]). These rocks display a dominant impactor signature which overlaps with ordinary chondrites [12,13,15].

Here, we represent the results of an ongoing study on HSE abundances and osmium isotopic composition of ancient lunar impact melt rocks from the Apollo 16 landing site. The new data together with results from the recent studies of [14] and [16] shed new light on the composition of late accreted material that contributed to the impact rocks sampled at the Apollo 16 landing site.

Apollo 16 impact melt rocks: Sample 62295 was collected near Buster crater and is a fine-grained, mesostasis-rich basaltic impact melt rock with a variolitic texture. The spinel troctolite with plagioclase and olivine clasts contains metal-schreibersite-troilite intergrowths up to 200 µm. An age of 3.86 ± 0.01 Ga was determined with the Ar-Ar technique [18].

Sample 60335 was collected close to the Lunar Lander. It is a pokilitic impact melt rock that exhibits a variety of melt textures and contains lithic clasts, which were identified as granoblastic highland rocks [19]. Metal occurs as up to 1 mm sized grains. A concordant Pb-Pb model age of 4.08 Ga was reported [20].

Sample 61016, found on the rim of the Plum crater, indicates the complexity of impact generated rocks. A cap of shocked ferroan anorthosite is attached to a troctolitic impact melt rock, which is covered by a crust of anorthositic to noritic glass [21]. The rock is interpreted as ejecta of the South Ray crater but displays shock and crystallization features of at least 3 cratering events [21]. An age of 3.97 ± 0.26 Ga was inferred from U, Pu - ^{136}Xe data of the impact melt rock portion [22].

Analytical techniques: In general we followed the analytical procedure of [14]. The samples were crushed into coarse-grained chips and some metal grains were separated from 62295 and 60335. Mixed ^{185}Re-^{190}Os and ^{191}Ir-^{99}Ru-^{194}Pt-^{105}Pd spikes were added to multiple aliquots of ~100 mg rock and ~5 mg metal and digested in 1 ml conc. HCl + 2 ml conc. HNO_3 for 16 h at 320°C in a high-pressure Asher.

Os was extracted by solvent extraction and back extraction into HBr followed by microdistillation. Os isotopic ratios were measured by negative TIMS (ThermoFinnigan Triton) on an electron multiplier or faraday cups at FU Berlin. Measured ratios were corrected for isobaric oxide interferences and mass fractionation. The rest of the HSE were separated by cation exchange chromatography from the matrix and analyzed by ICP-MS (Element XR) at FU Berlin. Total analytical blanks contributed generally less than 0.5 % for Os, 1 % for Ir, Ru and Rh, 2 % for Au, 5% for Pt and Pd and 10 % for Re. Due to significantly lower concentrations in 61016 the blank contributions were about 4 times higher in some aliquots of that sample.

Results and Discussion: Subsample aliquots of all three impact melt rocks define linear trends in HSE vs. Ir diagrams and y-intercepts of regressions are statistically indistinguishable from zero. Metal grains display

HSE concentrations generally two orders of magnitude higher than corresponding rock samples. Their HSE ratios generally overlap with regression values. Exceptions are some metal grains with higher Re/Ir and Re/Os. The measured $^{187}Os/^{188}Os$ ranges from 0.129 to 0.147 with the highest values measured in some metal aliquots with higher Re/Os ratios.

In general the HSE/Ir ratios are suprachondritic except for Os/Ir, which displays slightly subchondritic ratios (Fig. 1). The impact melt rock portion of 61016 shows a HSE pattern (Fig. 1) and $^{187}Os/^{188}Os$ ratios (Fig. 2) similar to Apollo 16 impact melt rocks analyzed by [14]. Basaltic impact melt 62295 is different. It shows lower HSE/Ir ratios and $^{187}Os/^{188}Os$ within the upper range of Apollo 17 impact rocks [13,15]. Both samples fall close to the magmatic fractionation trend for IVA iron meteorites. According to the model proposed by [14], the observed strongly suprachondritic HSE/Ir and $^{187}Os/^{188}Os$ ratios of Apollo 16 impact melt rocks point to the admixture of a fractionated metal phase that experienced liquid metal-solid metal fractionation in the parent body.

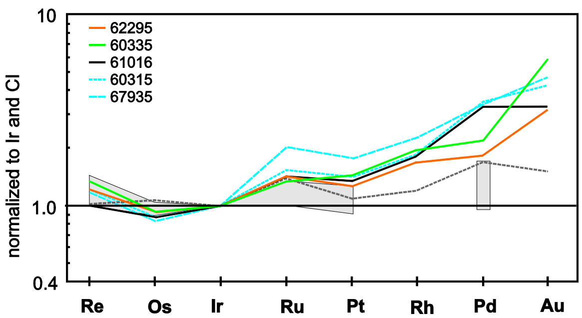

Fig. 1. Double normalized HSE diagram for Apollo 16 impact melt rocks [14, this study]. The range of Apollo 17 pokilitic impact melt rocks (grey field) [12,13] and PUM (grey dotted line) [11,23] are displayed for comparison.

Pokilitic impact melt rock 60335 displays a fractionated HSE pattern (Fig. 1) but a distinctly more radiogenic $^{187}Os/^{188}Os$ (Fig. 2). Such characteristics do not fit the IVA iron meteorite fractionation trend and point to the presence of a distinct, differentiated impactor signature at the Apollo 16 landing site, or a process that preferentially has fractionated Re/Os. The frequency of fractionated impactor signatures in the Apollo sample suite suggests important contributions of differentiated material during the late accretion period of the earth-moon system.

References: [1] Morgan J. W. et al. (1976) *Proc. Lunar Sci. Conf.* 7, 2189-2199. [2] Hertogen J. et al. (1977) *Proc. Lunar Sci. Conf.* 8, 17-45. [3] Korotev R. L. (1994) *GCA*, *58*, 3931-3969. [4] Neukum G. et al. (2001) *Space Sci. Rev.*, 96, 55-86. [5] Norman M. D. (2009) *Elements*, *5*, 23-28. [6] Fernandes V. A. et al. (2013) *Met. Planet. Sci.*, *48*, 1-29. [7] Day J. M. D. et al. (2010) *EPSL*, *289*, 595-605. [8] Bottke W. F. et al. (2007) *Icarus*, *190*, 203–223. [9] Bottke W. F. et al. (2010) *Science*, 330, 1527-1530. [10] Bottke W. F. et al. (2012) *Nature*, 485, 78-81. [11] Becker H. et al. (2006) *GCA*, *70*, 4528-4550. [12] Norman M. D. et al. (2002) *EPSL*, *202*, 217-228. [13] Puchtel I. S. et al. (2008) *GCA*, *72*, 3022-3042. [14] Fischer-Gödde M. and Becker H. (2012) *GCA*, *77*, 135-156. [15] Galenas M. G. et al. (2012) *ESSIB II*, Abstract #4003. [16] Liu J. G. and Walker R. J. (2013) *LPS XLIV*, Abstract # 1837. [17] Norman M. D. et al. (2010) *GCA*, *74*, 763-783. [18] Norman M. D. et al. (2006) *GCA*, *70*, 6032-6049. [19] Ryder G. and Norman M. D. (1980) *Curator's Office pub.*, #52. [20] Barnes I. L. et al. (1973) *Proc. Lunar Sci. Conf.* 4, 1197-1207. [21] Stöffler D. et al. (1975) *Proc. Lunar Sci. Conf.* 6, 673-692. [22] Eugster O. et al. (1999) *Met. Planet. Sci.*, *34*, 385-391. [23] Fischer-Gödde M. et al. (2010) GCA, 74, 356-379. [24] Walker R. J. et al. (2002) GCA, 66, 4187-4201. [25] Horan M. F. et al. (2003) *GCA*, *73*, 6984-6997. [26] Brandon A. D. et al. (2005) GCA, 69, 1619-1631. [27] Meisel T. et al. (2001) GCA, 65, 1311-1323. [28] McCoy T. J. et al. (2011) *GCA*, *75*, 6821-6843.

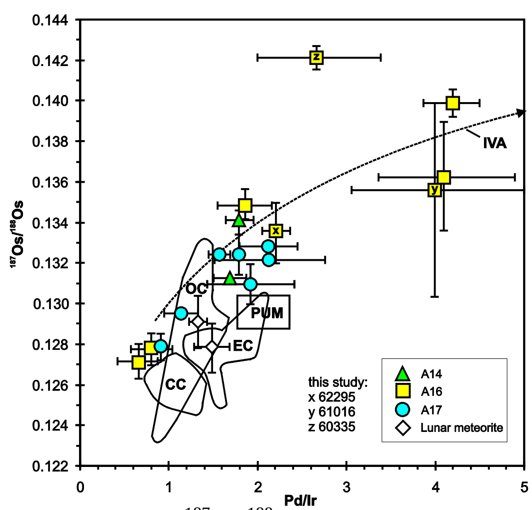

Fig.2. Average $^{187}Os/^{188}Os$ versus slope-derived Pd/Ir ratios of lunar impact melt rocks, granulites and lunar meteorites [13-16, this study). Ratios of chondritic meteorites [23-26], the terrestrial primitive upper mantle [11,27] and magmatic differentiation trends of IVA iron meteorites [28] are shown for comparison.

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