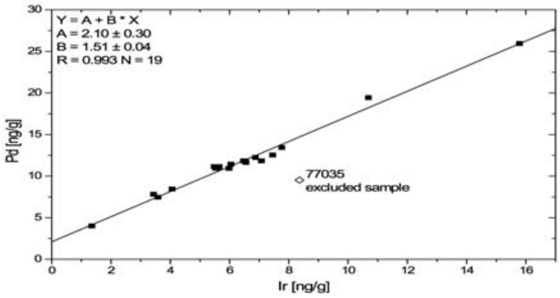
LL-ORDINARY CHONDRITE IMPACT ON THE MOON: RESULTS FROM THE 3.9 GA IMPACT MELT AT THE LANDING SITE OF APOLLO 17. Roald Tagle, Inst. Mineralogy, Nat. History Museum, Berlin, 10115 Berlin, Germany, Roald.Tagle@rz.hu-berlin.de

Introduction: The Moon allows a view to the past of Earth, offering a unique opportunity to study the ancient impact history of our planet. Since the first impact melt (IM) samples were brought back by the Apollo missions, controversies existed regarding the ancient impact population and the projectile types involved in the late heavy bombardment [e.g. 1,2,3]. The intention of this paper is first to re-evaluate PGE data on lunar rocks using the newest methods of impactor identification based on linear correlation [4] and second to discuss the various problems related to the identification of an impactor component given the special conditions present on the Moon.

Data: As a case study for the impactor identification on the Moon, chemical data from IM samples collected during the Apollo 17 mission were used. The platinum group elements (PGE) composition of poikilitic IM rocks was taken from [3]. Additionally, a set of samples including analyses of Ir, Ni and Au from Boulder 1 at station 2 [5] will be discussed. The identification of the projectile based on elemental ratios will draw on a database of the composition of chondrites compiled by [6].

Methods: The characterisation of the impactor follows the procedure applied for the identification of the projectile responsible for the Popigai crater, Siberia [4]. The method is based on the principle that the IM is a mixture of target material, in this case lunar rocks, and meteoritic material. The projectile elemental ratios (PER) can be calculated from the slope of the mixing line. There is practically no influence of the target on the slope of the mixing line, when elements with large meteorite/target ratios as PGE are used. The resulting PER are plotted together with the elemental ratios obtained from the different types of chondrites.

Results: The PGE plotted on Fig 1-2 show an extraordinary correlation. The correlation coefficients are for all element combinations R>0.99, strongly supporting a single source for the PGE-rich component. The sample 77035 that does not correlate with the others was excluded because of a different composition for main and trace elements [3]. The slope of the linear regression (B) represents the PER, and can be calculated in the same way for all combinations of the analysed elements (Ir, Ru, Pt, Pd and Re). For a clear identification of the projectile type it is fundamental to choose the elemental ratios, that allow the best discrimination. Condensation processes in the solar nebula control fractionation of PGE in chondrites. Therefore, elements with large differences in the condensation temperature present stronger variations. The lowest condensation temperatures among PGE are found for Rh and Pd. Ratios including one of these elements and one of those with higher condensations temperatures allows better discrimination. As a consequence, Rh and Pd



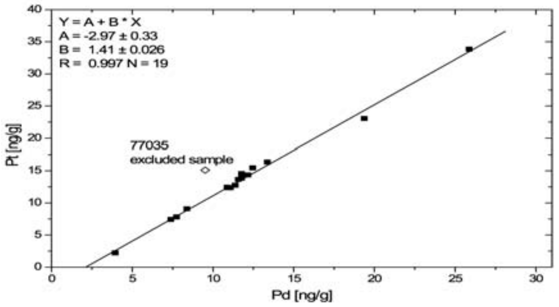


Fig.1 a, b. Linear correlation of Pd vs. Ir and Pt vs. Pd on the lunar impact melt rocks, concentrations values from [3].

the most relevant elements for the impactor identification (see Fig. 2. a). The determination of PGEs by isotope dilution, as used by [3] for the data discussed in this paper does not allows the determination of Rh, since it is a mono isotopic element. For the identification of the projectile the values obtained from the correlation, as shown on Fig. 1, are plotted on Fig 2 a & b. Since there are no measurements for Rh it was not possible to determine the Ru/Rh PER. Therefore, only a range is given (dashed lines). However, the range defined is only overlapping with the composition of LL-ordinary chondrite (OC). On Fig. 2b, ratios from three measured elements are plotted. The diagram shown here is only a section, the ratios for carbonaceous chondrites (CC) are outside of the area shown. In this case there is also a correlation of the Pd/Ir PER with the elemental ratio of the LL-OC. The projectile signature found in the lunar samples appears to be consistent with the composition of the LL-OC and not with a EH as proposed before [3]. Since Rh was not measured, alternative approaches in order to clarify the controversy had to be tested. In order to check the hypothesis of a LL-OC, the results from [5] were used. Au does not belong to the PGEs but shares some characteristics with those elements. Like Rh and Pd, Au has a low condensation temperature resulting in a fractionation among the chondrites. Analyses performed by INAA on samples collected from boulder 2 at the Apollo 17 landing site were use [5]. Among the elements analyzed Ir, Au and Ni are relevant for impactor identification. These elements also correlate. The PER for Ni/Ir ~

22 ± 4 similar to the values from H-, L- and LL-OC with 22, 26 28, respectively, and from EH and EL with 31 and 25. The slope of the mixing line is representative for the PER in case of a high meteorite/target ratio of the element. With decreasing ratio of an element e.g. Ni (target concentration ~ 44 µg/g, see (A) on Fig. 3 a) the slope becomes flatter. Therefore, the original PER should be slightly higher for Ni/Ir as the value obtained from the linear regression. This means that, based on the Ni/Ir, we can exclude all chondrites with similar or smaller ratios than the slope (H and EL).

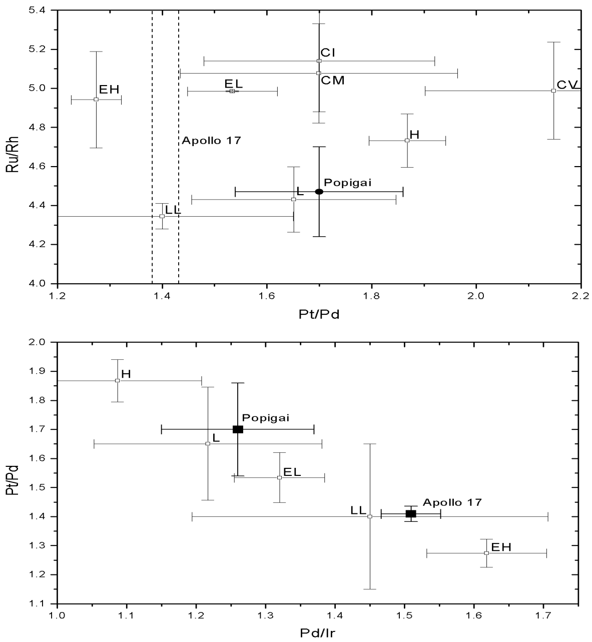


Fig. 2 a, b. PER of Apollo 17 and Popigai impact melt [4] compared to different types of chondrites [7].

The Au/Ir is 0.37 ± 0.4 and the concentrations on the target are around 0.15 ng/g (Fig. 3b). EC are enriched in Au compared to CI and other chondrites, the ratios for OC (H, 0.28; L, 0.30 and LL, 0.34) are lower than the values found for EC (EL, 0.44 and EH, 0.57). The Au/Ir ratios found in the lunar impact melt are similar to those found in LL-OC. This fact, together with the results from the PGE, strongly supports the hypothesis of a LL-OC impactor.

Discussion: The points illustrated in this paper show some of the problems be present when identifying a projectile. The use of elemental ratios calculated from single samples does NOT allow the determination of the PER, without subtracting the unknown indigenous composition. However, by calculating the PER from the slope of a set of related samples it is not necessary to know or determine the indigenous component. The approaches so far used in which single element ratios were used are all significantly disturbed by the composition of the target. Another problem, especially for the Moon, is that it cannot be assumed that all impact melt found in particular location belong to the same impact event,

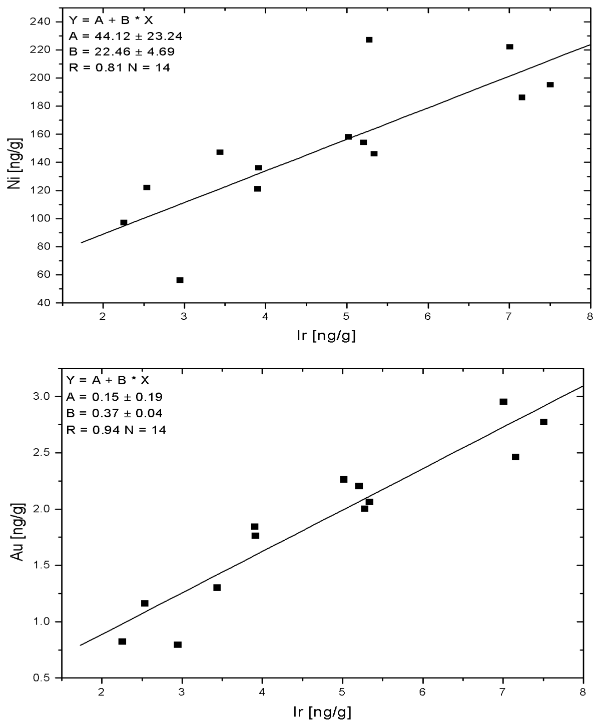


Fig. 3 a, b Linear correlation of Ni vs. Ir and Au vs. Ir on the Boulder 1 Apollo 17, concentrations values from [5].

as can be assumed for Earth. It needs to be demonstrated that the samples share characteristics other than the provenance, such as age and composition in order to be grouped. The lack of water on the Moon reduces possible weathering effects and allows a more precise regression of the elements compared to the results obtained for terrestrial craters such as Popigai and Morokweng [4,7]. This allows even the use of relatively mobile element as Au for the identification.

Conclusions: Under the assumption that the samples analyzed by [5] and the samples from Boulder 1 analyzed by [6] are IM from the same event, the projectile responsible for this major impact, interpreted as the Serenitatis impact 3.9 Ga. ago [8] was produced by an LL-OC. Furthermore it is to be noticed that the Phanerozoic impactor population on Earth appears to be dominated by OC, representing the most common type of projectile found so far [4]. The discovery of more OC impactors in the ancient projectile population will imply that there were no changes in the projectile type since the time of the early bombardment.

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