LUNAR IMPACT HISTORY FROM METEORITE IMPACT MELT CLASTS AND LESSONS LEARNED FOR LUNAR SURFACE SAMPLING. B. A. Cohen¹, T. D. Swindle², and D. A. Kring³. ¹Marshall Space Flight Center, Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov), ²University of Arizona, Tucson AZ, ³Lunar and Planetary Institute, Houston TX.

Introduction: One of the important outstanding goals of lunar science is understanding the bombardment history of the Moon and calibrating the impact flux curve for extrapolation to the Earth and other terrestrial planets. Obtaining a sample from a carefully-characterized interior melt sheet or a ring massif is a reliable way to tell a single crater’s age. A different but complementary approach is to use extensive laboratory characterization (microscopic, geochemical, isotopic, geochronological) of float samples to understand the integrated impact history of a region. Both approaches have their merits and limitations. In essence, the latter is the approach we have used to understand the impact history of the Feldspathic Highland Terrain (FHT) as told by lunar feldspathic meteorites. Here, we summarize data on impact-melt clast composition and ages in the feldspathic lunar meteorites, and use this work as an example of how this approach is valid for understanding regional lunar bombardment history of areas such as the South Pole-Aitken Basin (SPA).

Impact-melt clasts in lunar meteorites: The feldspathic lunar meteorites are regolith and fragmental breccias with high Al₂O₃ / low Th content relative to the KREEPy, mafic impact-melt rocks of the Apollo collection. The stochastic nature of lunar meteorite launch events implies that these meteorites are more representative of the feldspathic lunar highlands than the Apollo and Luna samples [e.g., 1-3]. More than 100 impact melt clasts from 12 feldspathic lunar meteorites (and two possible nearside lunar meteorites, Calcalong Creek and SaU 169) have been studied [4-10]. The clasts have textures similar to well-known rocks of impact origin, establishing their origins as impact-melt samples. The majority of clasts in the feldspathic meteorites and in Calcalong Creek are themselves highly feldspathic and lack a KREEP component. Based on their composition, we may infer that these clasts were formed by impacts into the feldspathic lunar crust, indicating their origin either before the formation of the Procellarum KREEP terrain (PKT) or far from the Apollo sampling sites.

The meteorite clast ages range from ~4.0 Ga to younger than 2.0 Ga, with a statistical peak around 3.5 Ga (Fig. 1). It appears that impact melt rocks created in post-basin bombardment dominates the very surface of the lunar regolith and is readily incorporated into regolith breccias until the breccia lithification event. No samples are >1.1 σ older than 4.0 Ga, the older limit of the predominant age range among Apollo impact melt rocks. This older age limit is consistent with a resurfacing event in the FHT at that time, such as a global lunar cataclysm. Alternatively, older impact melt rocks may have been gardened back into the regolith column, becoming volumetrically rare. Either way, the impact rate after 4.0 Ga is probably low enough that the impact-melt clasts now at the surface effectively sample the impact flux since 4.0 Ga.

Impact-melt clasts in lunar meteorites show that surface breccias provide a relatively representative sample of the upper lunar surface in the area where they formed. The impact-melt ages within them therefore record of the impact history of that region between the time of the last major resurfacing (or gardening) event and the time of breccia closure, perhaps with a statistically small number of older samples entrained in the upper regolith. Because the samples come from the uppermost surface, we can correlate composition of the clasts with lunar terrains from remote sensing data [11-12] to conclude that the age distribution of clasts in the feldspathic meteorites reflects the impact history of the FHT from ~4 Ga to the closure age of the meteorites.

Sampling strategies for dating lunar craters: The age recorded by the slowly-cooled impact-melt sheet that lines the floors of large craters gives the most reliable date for the formation of the crater (e.g., Sudbury, Manicouagan). Extensive geologic fieldwork is usually necessary to link the impact-melt formations to the crater of origin. Other craters have reliable ages found by dating impact melt blebs that are mixed into breccias in the ejecta (e.g., Ries). In the lunar case, many, if not most, random breccia melt clasts may never be positively linked with their source crater. Nevertheless, the compositional signature of the impact-melt clasts in the meteorites links them to the FHT and precludes their origin in other geochemical terrains. Therefore, these products reflect the composition and age of craters in this particular region. In this approach, a large number of samples must be studied with terrestrial laboratory techniques to build meaningful statistics and correlations.

Several important lunar craters such as Tycho are young, not filled with lava flows, and probably preserve impact melt, if not as lining sheets, at least as extensive melt pools in the bottom of the crater. These craters have well-constrained stratigraphic ages and therefore serve as key benchmarks in defining the lunar flux curve. Such sites are probably less geologically complex than a large old basin such as SPA and it.
has been suggested that they would need less intensive fieldwork to either retrieve, or possibly date in situ. However, the impact-melt rocks even at a geologically simple location are not likely to be simple themselves. Impact-melt rocks from small craters have the same composition as the bulk crust at that location and may have cooled rapidly, making it difficult to distinguish the impact melt of interest from locally-contributed ejected melt from nearby craters.

At the other end of the lunar flux curve, the South Pole–Aitken Basin is the stratigraphically oldest identifiable lunar basin and is therefore the most important target in understanding whether ancient lunar bombardment history smoothly declined or was punctuated by a cataclysm. The interior of SPA retains an anomalously mafic compositional signature relative to the surrounding feldspathic terrain [14], despite billions of years of vertical and lateral mixing from smaller and younger impact basins both internal and external to SPA. SPA near-surface materials are almost certainly a broken-up mixture of original SPA rocks, reworked material from interior basins, and exogenous material. On the lunar near side, mixing of ejecta and local bedrock has led to some ambiguity in the origin of specific impact-melt rock groups, because we do not have definitive information on the composition of the basin floors. In contrast, the unique geochemical signature of SPA materials serves as a proxy to link impact melt rocks found in the region to the SPA basin and subsequent interior basins and craters, giving context to the rocks even without extensive human field activity.

**Conclusions:** Our collection of impact-melt rocks from the extensive FHT has been limited to the lunar meteorites so far. The impact-melt clasts in the meteorites have not yet been linked with specific source craters, but their petrologic identification as impact-created, geochemical affinity to remotely-sensed lunar regions, and age by radiometric techniques provides a statistical knowledge of the impact history of these areas. This experience can be translated to other areas where combinations of techniques such as orbital and regional remote sensing and extensive laboratory analysis of a large number of samples can link samples to specific goals, such as understanding the age distribution of impact craters. This approach is not useful everywhere but is valid for one of the most important science goals – understanding the impact history of the SPA basin.

Fig. 1: Impact-melt clast ages in lunar meteorites [4-10].

![Impact-melt clast ages in lunar meteorites](image)