MODELING THE SOURCE OF IMPACT MELT AT THE APOLLO 14-17 SITES. A. M. Blevins, D. A. Minton, Y. H. Huang, J. Du, M. M. Tremblay, Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, Indiana 47907, USA (blevins2@purdue.edu), Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA.

Motivation: Besides being an extremely important geologic process, impact cratering is essential to understanding the history and evolution of the Solar System. Obtaining radiometric ages of samples linked to regions with relative crater-counting ages allows for the construction of a chronology function [1]. Since the Moon is the only planetary body with available data for both, chronology functions for other planets in the inner Solar System have been extrapolated from the lunar chronology function [1].

In contrast to the mare-dominated periods sampled by the Apollo 11 and 12 missions, impactor flux for early lunar history (t ~ 3.8 Ga) is poorly constrained [1]. This period was dominated by impacts that formed large craters (D > 200 km) known as basins [2]. Because impacts, especially large impacts, redistribute material throughout the lunar surface, it is extremely difficult to correlate an impactite sample with the crater that formed it [3]. The Apollo 14-17 missions collected many samples believed to be from basins, yet none have been directly correlated to a basin of origin [2].

A large number of samples returned from the Apollo 14-17 missions have been radiometrically dated to ~3.9 Ga [3]. Over the past five decades, there has been speculation about which craters produced these samples [4]. Since the amount of ejecta emplaced scales with crater diameter and almost all lunar basins formed prior to the emplacement of the large mare units, it has long been believed that the impactites returned from Apollo 14-17 originated from large basin-forming events [4]. The Imbrium basin is the youngest and largest basin on the nearside and has been theorized to be the source of much of the material at Apollo sites [5], though other basins have also been theorized to contribute significantly to the Apollo sample record [4].

While prior models have estimated the contribution of certain basins to the Apollo sites [6,7], none have examined the role of post-Imbrium sub-basins. These craters are smaller than basins, but large enough to have emplaced material at the Apollo 14-17 sites [8]. Because they are younger than basins, they should either overlay or overlap with basin ejecta in a stratigraphic sequence. This work seeks to determine how significant such deposits are via global bombardment modeling.

Modeling the Lunar Bombardment: The Cratered Terrain Evolution Model (CTEM) [9,10] was used to simulate 4.31 Gyr of impact bombardment. Each of the Moon’s 74 basins was emplaced at a location corresponding to its true location [11]. Several sub-basins were also emplaced in this manner. The time of emplacement of basins was found by taking a model basin sequence [12] and anchoring it by absolute model ages based on the Neukum cratering chronology [13], with some changes made to basin order based on these model ages. The time of emplacement of sub-basins was estimated based on the closest mare model age [14]. All other craters were emplaced randomly via the Monte Carlo method. Numerous simulations were run and aggregated to account for the variance of this method.

Of the many different types of Apollo samples, impact melt is the most important for dating craters because the age of an impact melt sample should date the impact that formed it [15]. A percentage of melt formed is transported out of the crater as ejecta, while the rest forms an impact melt sheet inside the crater [16]. CTEM calculates these percentages from scaling laws [17]. After ejecta is emplaced via a modified version of the Maxwell Z-model [10,18], the top layers are homogenized to simulate impact gardening [10]. The amount of melt from each crater, as well as the age of the melts, was tracked throughout each simulation.

A New Model for Distal Ejecta:

![Figure 1: Percentage of melt from the Iridium sub-basin in the top 5 m of regolith at all pixels in a 1000x1000 pixel simulation. The most melt is found in the melt sheet (green to yellow), while the ray pattern is apparent from the regions of elevated melt in the distal ejecta.](image)

Distal ejecta takes the form of heterogeneous crater rays [2]. Because the percentage of impact melt is higher in distal ejecta than in proximal ejecta [16], modeling rays (Fig. 1) is key to accurately simulating distal ejecta.
emplacement. Rays are formed by secondary craters, so the distribution of secondary craters around Orientale basin [19] was used to calibrate the distribution of distal ejecta for craters emplaced by CTEM. This results in a ray pattern model that represents the spatial distribution of distal ejecta based on that of secondary craters.

**Origin of melt at the Apollo 14-17 sites:** Large basins play a major role in shaping the composition of impact melt at the Apollo 14-17 sites. Preliminary model results show that melt at pixels corresponding to each of these sites originates primarily at either large basins or small, local craters (Fig. 2). Melt from post-Imbrium sub-basins is most prominent at the Apollo 15 site, but still composes a minority of impact melt compared to large, older basins.

Fig. 3 shows that a large amount of pre-Imbrian melt should be expected for Apollo 17; similar results were also found for Apollo 16. Preliminary results for Apollo 14 and 15 indicate a spike at the time of the Imbrium impact, which is consistent with the Apollo sample record. In these simulations, “local” melt refers to melt that originates from neither a basin nor sub-basin. Instead, local melt comes from the craters that were randomly emplaced in the model using the Monte Carlo method (D < 200 km). The early periods in the Moon’s history when basin formation occurred experienced many more smaller impacts than recent lunar geologic history. The majority of local melt seen in these simulations is thus likely to have been formed early in lunar history and excavated as ejecta by the large basins. Radiometric ages of these melts are likely to have been influenced by these excavations and may even be completely reset to the age of the last basin to affect the sample [20]. These preliminary results support the idea that large basins, especially Imbrium, redistributed melt from older basins and craters [5]. Conversely, younger craters, including sub-basins, may have also transported basin melt to the Apollo sites. Whether radiometric ages of these melts are expected to be partially or fully reset due to impact heating and associated isotope loss is a question to be explored in future work.