SECONDARY CRATER DOMINANCE ON THE MOON. M. R. Kirchoff and C. R. Chapman. Southwest Research Institute, Boulder, CO (kirchoff@boulder.swri.edu).

Introduction: The Moon is the only place to analyze the absolute impact crater chronology in the inner solar system. This is due to a combination of relatively minimal geologic activity over the last 3 Gyr to erase craters and radiometric dating of Apollo samples from known regions on the Moon's surface. The Earth, which is the only other planetary surface with radiometric ages of explicitly known cratered regions, has experienced considerable resurfacing erasing most of the cratering record. Meanwhile, most of the Moon's cratering record, since 4 Ga, is still observable (except for those regions affected by crater saturation).

Estimates of the absolute crater chronology on the Moon have dated of surfaces not visited by the Apollo missions [1-9]. Some of these researchers [2, 3, 5, 9] have used the cumulative densities of small craters (diameter, $D < 10$ km) to calculate absolute ages of various geologic units. A concern with these analyses is the extent to which secondary craters from large impacts dominate the small crater population. This question has been studied since images of the Moon were first analyzed in the 60's and continues today [1, 2, 6, 10-18]. Some researchers [1, 2, 6, 17] have argued that secondaries are a minor contribution and do not significantly affect calculations of the absolute ages. Others consider the contamination to be considerable so that calculated ages may be seriously erroneous [11, 12, 14-16, 18].

We are compiling measurements of size distributions of superposed craters on lunar basins and large craters. The goal is to understand the external impactor population(s), which produce primary craters, and their evolution through time. To understand the primary crater population, however, we must first identify the secondary crater population. Here, we report some preliminary results of recording obvious secondaries (methods discussed below) and compare their distribution to the "primary" crater distribution (the distribution of craters that are not obvious secondaries, which will always be designated in quotes) in the same diameter range in the same region. These results indicate that contamination could be substantial for craters with $D < 10$ km. If this result is further substantiated, then the utility of dating surfaces using small craters is reduced and previous results dating surfacing using craters of this size may need to be reconsidered.

Methods: We have measured craters on mosaics created from Lunar Orbiter (LO) VI and V images of Birkhoff and Imbrium basins. LO images are retrieved from the USGS digitization project [19]. We measure the crater diameter, position, and record the degradation state of the crater on a scale of 1-4 with 1 being the freshest (sharp rim) and 4 the most degraded (very little rim remaining and considerable reduction of crater depth). In addition, craters assessed to be secondaries from their appearance in clusters or chains are marked as such. This assessment provides a minimum estimation of the contribution of secondaries in the analyzed region.

Once measurements are completed the data are compiled and examined as relative or R-plot size-frequency distributions [20]. Note the presented size-frequency data are cut off at a minimum diameter larger than where the roll-off due to inadequate resolution begins. To qualitatively determine if contamination of the crater population by indistinguishable secondaries is considerable, we compare the "primary" distribution with the distribution classified as secondaries. In addition, analyzing the shape of the size-frequency distribution may provide insight into the impactor populations.

Preliminary Results and Discussion: The results we present here are for superposed craters in Birkhoff basin (center = 59°N, 147°W, D = 325 km, Pre-Nectarian [4]). In Figure 1 we display the craters recorded on the mosaic of Birkhoff basin. The counting area is shown by the yellow outline. The freshest craters (degradation class 1) are shown in light blue, while

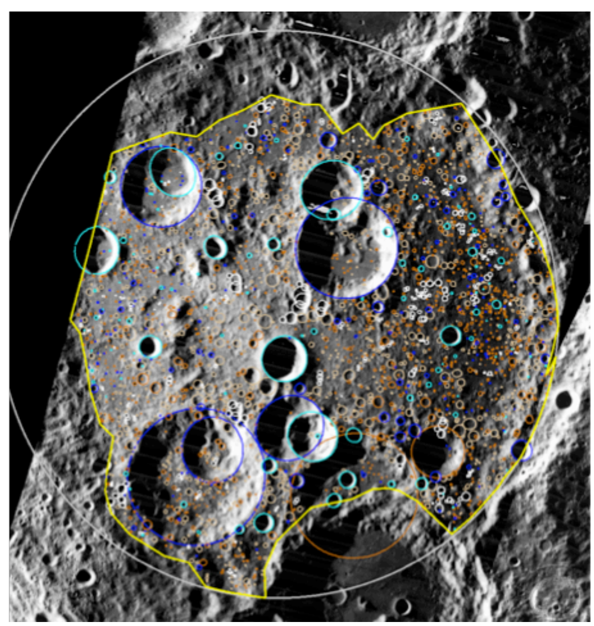

Figure 1. LO mosaic of Birkhoff basin. North is up, resolution is 80 m/pixel, projection is orthographic, the basin center is 59°N and 147°W, and basin diameter is 325 km. Yellow outline indicates the region analyzed. Colored circles represent the crater measurements with a description of the color classification given in the text.

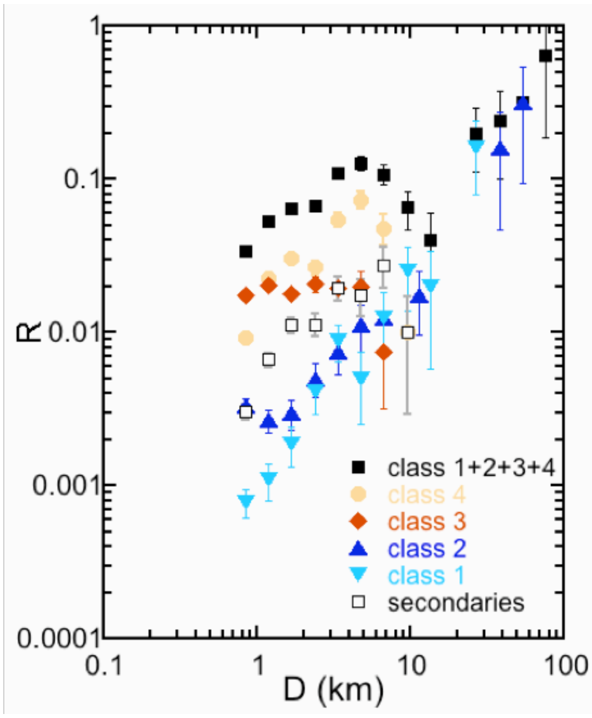

Figure 2. R-plot of distribution shown in Fig. 1 of superposed craters in Birkhoff basin. Bins are √2 and error bars are √*N*, where *N* is the number of craters in each bin.

class 2 is shown in dark blue, class 3 in brown, and class 4 in tan. Craters classified as secondaries are shown in white. The clustering of these craters is very observable.

In Figure 2, we show the size-frequency distribution of the total primary craters (combined degradation classes, black), each individual class, and the secondaries (white with black outlines). The similarity of the total "primary" craters, along with the distributions for class 3 and 4 craters, to the secondary distribution for craters with 1 km ≤ D ≤ 10 km is striking. This would imply that the crater population in Birkhoff basin is considerably contaminated by indistinguishable secondaries in this size range. On the other hand, the distributions for class 1 and 2 craters have some similarities to the secondary crater distribution, but are to some extent different from the secondaries. It is possible that the fresher small craters really are primaries and there are fewer fresh secondaries for 1 km ≤ D ≤ 10 km. The few similarities, however, may still indicate some "hidden" contamination. Furthermore, the relative lack of craters at D ~ 20 km is an interesting feature (Fig. 2). This could represent the features of two combined impactor populations, one having a size distribution decreasing in density for D > 20 km and the other decreasing in density for D < 20 km. Secondary crater populations are always lacking in large craters whereas asteroids responsible for craters a few to a few tens of km in diameter have a shallow size distribution with a relative lack of smaller sizes.

Conclusions and Future Work: The superposed crater distribution on the lunar basin Birkhoff indicates that both generally evident and indistinguishable secondary craters may considerably contaminate the size-frequency crater distribution between 1 km ≤ D ≤ 10 km. Most of these secondaries may be from two large craters ~ 100 km to the southwest of Birkhoff, as indicated by the directionality of the some of the clustered secondaries. There are likely other sources, however, especially for the indistinguishable secondaries.

The result presented here is for a very limited region of the Moon; therefore more work needs to be done to determine if this is a localized or global effect. We are currently compiling data for a region of Mare Imbrium (center ~ 38°N, 18°W, Eratosthenian [4]) and numerous secondary clusters are evident. If the result for Birkhoff is corroborated by the results from Imbrium (and future measurements of superposed craters on other craters and basins around the Moon), then the conclusion of considerable secondary contamination would be global. Therefore, the use of small craters to date lunar surfaces could be severely hindered and previous results using small craters could be in question.

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