HOW MUCH IMBRIUM MATERIAL SHOULD BE PRESENT AT THE APOLLO 17 SITE? Larry A. Haskin, Bill E. Moss, and William B. McKinnon, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130

Photogeologists have not found universally compelling evidence for disturbance of the Taurus Littrow region by Imbrium ejecta [1], although that location is only ~4.1 to ~2.8 transient crater radii from the center of the Imbrium Basin (based on the extreme estimates of 335 km and 485 km [2] for the Imbrium transient crater). The principal materials at the site are mare basalt plus volcanic ash on the valley floor, surrounded by highland masses regarded by most investigators [3] as mainly Serenitatis ejecta. Here, we ask what average thickness of Imbrium-derived ejecta we might expect on the basis of modern cratering theory, as adapted by Moss et al. [4] to estimate average thicknesses of basin ejecta (primary fragments, PriFrgs) and average proportions of PriFrgs in ejecta deposits as a function of distance from a large crater or basin. The calculations provide the average thickness of basin primary ejecta (PriFrgs) falling onto a "square of interest" (SOI) and the depth to which the PriFrgs erode. A SOI is the selected member of the set of adjacent (approximate) squares that form a ring at the chosen distance from the center of a basin or crater. The resulting regolith layer will not be uniform over the SOI; the calculations also yield the average distribution of thicknesses and depths.

Our model results agree with secondary crater populations around Imbrium [4], ejecta deposition near Orientale [5], ejecta thickness for deposits outside the Ries Crater [7], and average surface density of Copernicus secondary craters ≥0.5 km in dia. at a distance of ~6 crater radii from the rim of Copernicus [4]. Figure 1 shows estimates of depths of the regolith layer (PriFrgs mixed with eroded substrate) and the proportions of PriFrgs contained in the layer as a function of distance from the center of Imbrium. Calculations are sensitive (most importantly in this case) to the assumed Imbrium transient crater diameter and excavation depth/diameter ratio (1/10), which control the mass of material ejected.

For modelling, we place the Taurus-Littrow Valley at the center of a 100 × 100 km SOI 1,350 km from the center of Imbrium. Results are shown in Figs. 1 and 2. On average, the SOI is covered with Imbrium-derived regolith to a depth between ≥810 m (small Imbrium) and ≥24 km (big Imbrium) at the 50% coverage level (i.e., 50% of the SOI is covered to that depth or greater). Proportions of Imbrium PriFrgs in the deposits range from ~29% (small Imbrium) and ~52% (big Imbrium); proportions of Serenitatis PriFrgs in the Imbrium-produced layer are 48% and 33%. Based on these averages, the Imbrium event would have produced substantial thicknesses of deposits containing substantial proportions of Imbrium PriFrgs at Apollo 17. If so, it should be present in the materials sampled. Should the site be average one?

The distribution of observable secondary craters in the northern half of the Copernicus ejecta field [4] enables us to estimate rough probabilities of deviations from the average value for individual SOIs in the same ring. We were able to make unambiguous crater counts only between ~145 km, barely inside the outer edge of the continuous ejecta deposits, and 210 km, beyond which we were unable to distinguish with confidence Copernicus secondary craters from primary craters. Calculated values are higher than observed values at the shorter distance, owing to mutual obliteration of larger secondary craters, but they agree well at greater distances (Fig. 3). The 15 × 15 km SOIs around Copernicus were chosen to be roughly equivalent in scale to 100 × 100 km SOIs at the Apollo 17 site relative to the Imbrium Basin. The shortest distance (145 km) is ~4.5 transient crater radii from the center of Copernicus, greater than the 2.8 to 4.1 transient crater radii distance between the center of Imbrium and the Apollo 17 landing site. We observed an average of 27.5 Copernicus secondary craters ≥0.5 km in diameter at a distance of 4.5 transient crater radii from Copernicus. This ignores the apparently missing secondary craters (presumed obliterated). None of the 33 SOIs at that distance contained fewer than half the average amount (i.e., <14 observable craters) (Fig. 3). Based on this estimate, and particularly considering that the Apollo 17 site is only 2.8 to 4.1 transient crater radii away from the center of Imbrium, the probability that the SOI centered on the Taurus-Littrow Valley contains less than half the estimated thickness of Imbrium deposit is extremely low. The SOI is close enough to the Imbrium Basin that, on average, 95% of its area should have developed Imbrium-derived deposits at least 270 m (Imbrium small) to 1.2 km (Imbrium large) deep or greater. Depths could be greater than average.

Might Imbrium material, although present within the Taurus-Littrow SOI, have been missed in the sampling? The fraction of the SOI traversed by the crew of Apollo 17 is small, of the order of ~10 km, and most of the traverse was in mare plains, where lava and ash cover underlying highland material. The massifs have nevertheless shed material onto the valley floor, and substantial highland material from somewhere (typically 15-30%, [8]) is present in most mare soils. For Imbrium material to be essentially absent from that highland component, although possible, is of low probability, particularly for a large Imbrium event.

What among the Apollo 17 samples might represent Imbrium material? If we take at face value the tight radial distribution of Th concentrations seen by the Apollos 15 and 16 γ-ray experiments [9], high Th concentrations center broadly in the Procellarum region and taper off rapidly outward. Any source of Th beneath Serenitatis is not seen in the highlands to the east (average ~1.5 ppm [10]). Nevertheless, Th-rich materials are common in Apollo 17 highland soils
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and massif breccias. A noritic breccia component containing ~5 ppm Th makes up ~25 to 45% of the highland portion of the soils [8]. Might the Th-rich material in the Apollo 17 collection, mainly noritic melt breccias, represent the Imbrium components, whose overall proportion in Imbrium-derived ejecta deposits we estimate should lie between ~30 and 50%? (Others have considered this; e.g., [11].) Except for a small set of A-17 melt breccias similar to a set from Apollo 15 [12], Th-rich melt breccias are compositionally distinct from mission to mission. Still, noritic melt breccias from Apollos 14, 15, 16, and 17 have similar trace-element relative distributions. PriFrags of relatively shallow origin from more distant Imbrium could have a high proportion of melt, whereas PriFrags of deeper origin from closer Serenitatis would not [e.g., 13]. Can Ir/Au ratios [14] and ages of A-17 impact melt breccias [15] be reconciled with an Imbrium origin?

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REFERENCES:

Figure Captions: 1. Predicted thickness for deposits of small (trans crater dia.=335 km) Imbrium-derived ejecta as a function of distance from the center of Imbrium. Coverage level means fraction of the SOI covered by a deposit that thick or thicker. At 1,350 km, 50% coverage level, the deposit is ~800 m thick, and Imbrium ejecta comprise ~30% of the mixture. For large (485 km) Imbrium, the values are ~2.4 km and ~50%. 2. Pseudo-stratigraphy of the Taurus-Littrow SOI, showing deposit depths at the 50% level for 3 basin events. On average, thick Imbrium-derived deposits would be present; particular areas of the SOI covered by one event at the 50% coverage level would not, however, be the same as the areas covered at the 50% level by the next event, as is implied by the figure. Only the values for the most recent crater in any column are thus correct. 3. The percent of the SOIs in the northern half of the Copernicus ejecta deposit between 4.5 and 6.6 crater radii from the center of the crater that deviate from the observed average by as much as 50%. At 2.8 to 4.1 crater radii, the distance from the center of Imbrium to the Taurus Littrow Valley, few or no SOIs would have 50% thinner Imbrium deposits than the estimated value.