THE THICKNESS OF MARE BASALTS IN IMBRIUM BASIN ESTIMATED FROM PENETRATING CRATERS.

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Introduction: Approximately 16% (6×10^6 km^2) of the Moon's surface is covered by basaltic lava flows [1], and although the total areal extent of these flows is easily determined, their thicknesses are more difficult to constrain. The total volume of lunar lava provides basic constraints on the Moon's thermal and petrogenetic evolution. Previously, thickess estimates have been obtained from gravity, seismic, and radar data [e.g., 2-4]; measurements of impact craters partially filled with basalt [5,6]; comparisons of lunar basins filled with mare deposits to unfilled basins [7]; and spectral analysis of impact craters that have completely penetrated the mare [8-10].

Here we report thicknesses estimates of basalt in Imbrium Basin derived from analyses of high resolution (~100 m/pix) Clementine UV-VIS multispectral images of large craters that penetrate (or failed to penetrate) the mare. Because the thickness of basalt in Imbrium Basin is one of the least well constrained of the western mare [6], it is a prime target for further study. Previous results from Apollo gamma ray data suggest that at least two craters in Imbrium, Timocharis and Lambert, have penetrated through the mare and excavated sub-mare, Th-rich material [11].

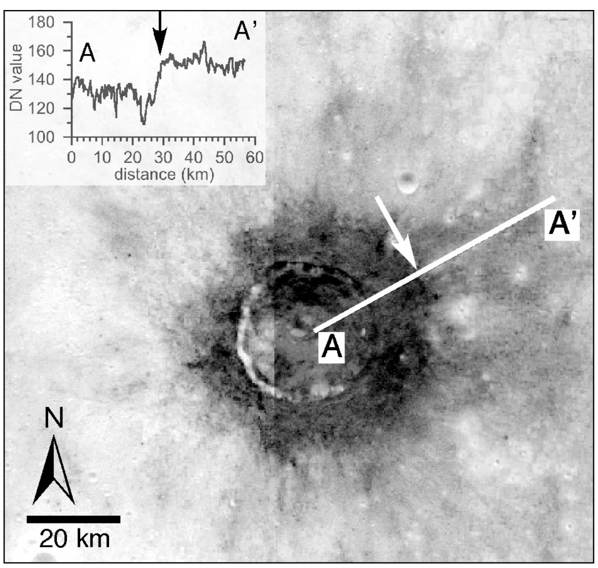

Figure 1. Iron concentration map of Timocharis Crater (33 km in diameter) derived from Clementine UV-VIS data [12]. Radial profile A-A' shows distinct step (arrow) from low iron ejecta inferred to represent the transition from sub-mare basement material to more iron-rich basaltic ejecta.

Method: To estimate basalt thickness using craters that have penetrated through the mare, we use compositional data derived from Clementine UV-VIS images to identify and quantify the signature of basement highland materials in their ejecta. First, Clementine UV-VIS data are processed to derive maps of the estimated iron (FeO) weight percent of the craters of interest [12]. Crater morphometric and topographic data are then used to determine the maximum excavation depth using a geometric scaling model [e.g., 13]. Finally, we use the iron compositional maps to determine the radius of the low FeO basement material emplaced in the craters' ejecta blankets (Fig. 1). Further details of the conversion of these measurements into basalt thickness estimates are given in [14].

Results: We examined all 23 craters in Mare Imbrium >10 km in diameter. As indicated by their surrounding halos of low FeO ejecta (e.g., Fig. 1), six craters (Aristillus, Autolycus, Brayley B, Euler, Pytheas, and Timocharis) clearly penetrate into the mare and excavate low iron basement material. Nine others lack a low iron ejecta component and we infer that they fail to penetrate through the mare/highland interface; thus these craters provide only minimum estimates of basalt thickness. Six craters are flooded with lava to a degree such that only their rims remain, making it impossible to determine whether they excavated basement material. Finally, two additional craters (Delisle and Lambert) have a low iron component exposed in their central peak regions but not in their ejecta. This suggests that the mare/highland interface is close to, but below, each crater's maximum excavation depth, and that the exposures of basement material were brought up to the surface due to rebound during the modification stage of crater formation.

Measured thickness values from this study are combined with thickness data points derived from partially flooded craters to create a basalt isopach thickness map (Fig. 2a). A simplified version of the previous isopach map made using partially flooded crater data alone [6] is given in Fig. 2b for comparison.

Discussion: By comparing the revised and original maps of mare basalt thickness (Fig. 2a-b), it is apparent that the basic spatial pattern remains consistent. Mare Imbrium consists of a circular central thick lens that is surrounded by an annular zone of thinner basalt (some of which is presumably located over a buried Imbrium Basin ring and ring shelf [15]).

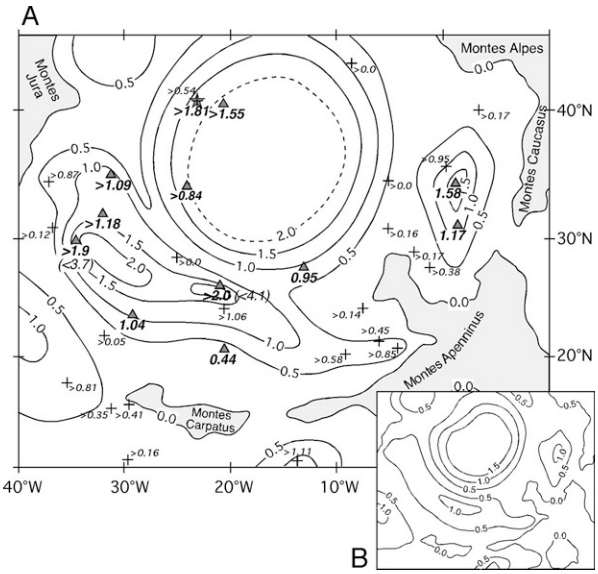

Figure 2. (a) Basalt isopach map of Mare Imbrium. Filled triangles represent craters examined in this study, crosses represent locations of partially flooded craters examined previously [6]. All data labels are given in km; contour interval is 0.5 km. The position of the 2.0 km contour is not well constrained and is depicted with a dashed line to reflect this uncertainty. **(b)** Simplified basalt isopach map of Mare Imbrium determined from partially flooded craters (after [6]).

Outside this annulus, the thickness increases before decreasing to zero at the basin margins. The principal difference between the two maps is that the thickness values for the craters measured in this study are in excess of 0.5 km greater than the thickness values determined from partially flooded craters alone. Mare basalts in the central portion of the basin may exceed 2.0 km in depth (instead of the previously reported 1.5 km), and the regions of closed contours in the southwest and eastern portions of the basin have increased maximum values from 1.0 to 1.5-2.0 km. This 0.5 km excess of thickness values is greater than the uncertainty associated with individual thickness estimates (±~10%).

One example where the results of our study directly contradict previous results is at the crater Helicon (40.4°N, 23.1°W). The crater floor has been partially filled with lava to a depth of ~0.54 km [6]. Although some of the outer portions of the ejecta blanket is partially obscured by later flows, no trace of low FeO highland basement material is detected in the proximal ejecta, indicating that the crater did not penetrate completely through the mare and that the total thickness of basalt in this region exceeds the crater's excavation depth (i.e., >1.81 km).

The example of Helicon Crater illustrates that partially flooded craters, at least in this study area, typically reflect minimum thickness values. Each partially flooded craters only records the thickness of mare fill emplaced after the crater formed; our study indicates that the total basalt thickness may be substantially greater if the flooded craters postdate early mare fill. On balance, the results from our study do not support the assertion that basalt thickness estimates obtained from partially flooded craters are systematically overestimated [16]. While the results support the general approach of using basin scaling to constrain thickness values [e.g., 7], our understanding of Imbrium Basin is significantly advanced by assessing the spatial variability of thickness values using a network of individual thickness estimates.

The results from this study indicate that Mare Imbrium has a total volume of basalt equal to about 1.3×10^6 km^3, a value almost a factor of 2 greater (92%) than the value derived using flooded craters (~6.8×10^5 km^3). Measurements of basalt depth in the basin ring shelf area are well constrained by multiple data points in this study and have a correspondingly high degree of confidence associated with them. However, the total thickness of fill at the center of the basin still cannot be directly constrained by the methods employed in this study—a thickness of 2.0 km is assumed here for the innermost radius of 200 km. This is substantially less than the 9.25 km inferred from Apollo gravity data [17], although this value may be an overestimate since it does not account for an uplifted plug of mantle material [18]. Estimates of basin center fill depths based on Clementine altimetry range from 3-4 km [19] to 5.24 km [20]. If central thicknesses in the range of 3.0 to 5.24 km are assumed, the resulting total volume of basalt in Imbrium ranges from ~1.4 to 1.7×10^6 km^3, which represents only a small change (8-30%) from the value reported here.

References: [1] Wilhelms D.E. (1987) The Geologic History of the Moon, *USGS Prof. Paper 1348*. [2] Talwani M. *et al.* (1973) *Apollo 17 Prelim. Sci. Rep.*, 1-13. [3] Cooper M.R. *et al.* (1974) *Rev. Geophys. Space Phys.*, *12*, 291-308. [4] Sharpton V.L. & Head J.W. (1982) *JGR*, *87*, 10983-10998. [5] De Hon R.A. & Waskom J.D. (1976) *PLPSC*, *7*, 2729-2746. [6] De Hon R.A. (1979) *PLPSC*, *10*, 2935-2955. [7] Head J.W. (1982) *The Moon & Plan.*, *26*, 61-88. [8] Andre C.G. *et al.* (1979) *LPSC*, 38-40. [9] Budney C.J. & Lucey P.G. (1998) *JGR*, *103*, 16855-16870. [10] Rajmon D. & Spudis P. (2004) *MAPS*, *39*, 1699-1720. [11] Metzger A.E. *et al.* (1979) *LPSC*, 833-835. [12] Lucey P.G. *et al.* (2000) *JGR*, *105*, 20297-20306. [13] Melosh H.J. (1989) *Impact Cratering: A Geologic Process*, 245 pp. [14] Thomson B.J. *et al.* (2009 submitted) *GRL*. [15] Spudis P.D. (1993) *The Geology of Multi-Ring Impact Basins*, 263 pp. [16] Hörz F. (1978) *PLPSC*, *9*, 3311-3331. [17] Solomon S.C. & Head J.W. (1980) *Rev. Geophys. Space Phys.*, *18*, 107-141. [18] Neumann G.A. *et al.* (1996) *JGR*, *101*, 16841-16864. [19] Spudis P.D. & Adkins C.D. (1996) *LPSC*, 1253-1254. [20] Williams K.K. & Zuber M.T. (1998) *Icarus*, *131*, 107-122.