Estimates of Cryptomare Thickness and Volume in Schiller-Schickard, Mare Humorum and Oceanus Procellarum Areas; I. Antonenko, J. W. Head, Dept. Geol., Brown Univ., Providence, RI 02912 USA

Summary: Minimum cryptomare thickness estimates in selected areas were refined using the relationship depth of excavation (d_e) is equal to one third the crater depth (d), or d_e=.33d (5), and were found to be approximately 500 m. DHC distributions were used to estimate cryptomare areas, and thus calculate minimum volumes. The cryptomare were found to be significant, representing 2% of the total known mare volume and 6% of the presently exposed mare area. These volumes were used to draw conclusions about the duration and timing of mare volcanism in the area.

Background: Dark halo impact craters (DHCs) in the highlands provide evidence for the presence of ancient mare deposits, or cryptomare (1,2). The distribution of DHCs can be used to delineate the boundaries of the cryptomare. Their size and geometry can offer clues to the 3-D geometry of cryptomaria and the deposits that overly them. Small craters that do not penetrate to the cryptomare will not produce a dark halo; large craters that penetrate through the cryptomare to underlying highland material will contain highland ejecta, which will obscure the dark halo signature. Thus, in any given area, the smallest observed DHC should define the top of the cryptomare, and therefore the thickness of the overlying ejecta, while the largest observed DHC should define a minimum estimate of the bottom (Fig. 1). The thickness of the cryptomare can be estimated from the difference between the depth of the mare base and the thickness of the overlying ejecta (3). Generally, such estimates will tend to be minimum values, since the largest DHCs observed may not neccesarily be reaching the cryptomare bottom. For example, an extrapolation from (5) shows that DHCs on the order of 100 km in diameter would be required to sample the bottom of mare 1 km thick.

Previous cryptomare estimates have been approximate calculations, where the depth of the crater was obtained from diameter measurements (4) and approximated as the depth of excavation (3). The actual relationship is more complex (Fig. 2), where depth of excavation (d_e) is one third of the crater depth (d), thus d_e=.33d (5). Here, we further refine our previous estimates for the Schiller-Schickard, Mare Humorum and Western Oceanus Procellarum areas using this relationship. The depth of penetration into the mare layer which is required before a dark halo becomes visible (d_m) is a value that is still unknown and requires further study.

Schiller-Schickard Area: In the Schiller-Schickard area, 44 DHCs were found, located approximately 1400 km SE of Orientale, which is interpreted as the source of the overlying ejecta for this region. The DHCs are distributed somewhat evenly, ranging in distance 1000-1900 km from the center of Orientale, and appear to define a basin. Depths of excavation were calculated for the DHCs. Minimum depths are plotted as a function of distance from Orientale (Fig. 3). Column heights represent the thickness of the overlying Orientale ejecta deposit as determined from the size of the smallest DHC in each 100 km distance interval. These results are compared to theoretical ejecta decay models for Orientale diameters of 900 and 620 km (6). The data are generally consistent with theoretical predictions for ejecta from Orientale and thus support an Orientale source for the ejecta. However, it is unclear whether the data supports a 900 or 620 km diameter for Orientale.

Minimum cryptomare thickness estimates can be plotted as a function of distance from Orientale (Fig. 4). Column heights represent the maximum depths minus the minimum depths for each 100 km distance interval. If a distance interval contains only one DHC, no value is thus entered. Minimum cryptomare thickness can be seen to vary from about 300-700 m, with an average of 500 m. This is somewhat lower than typical mare thicknesses (7), suggesting that the largest DHCs observed may not be reaching the cryptomare bottom.

The area of the cryptomare, based on the distribution of DHCs, was calculated to be 2.7 x 10^5 km^2. Using this area and the average minimum mare thickness, we estimate the minimum cryptomare volume to be 1.4 x 10^5 km^3, which is approximately half of the volume of Mare Humorum. These values correspond to approximately 4% of the total known mare area and 1.4% of the total known mare volume (8).

Mare Humorum: In the region surrounding the western portion of Mare Humorum, 52 DHCs were found. Here, the DHCs are distributed unevenly, and some appear to be aligned concentrically around Mare Humorum. The DHCs are located approximately 1100 km west of Orientale and range in distance 600-1600 km from Orientale. Once again, minimum excavation depths are plotted as a function of distance from Orientale (Fig. 5), with column heights representing the Orientale ejecta thickness. The data are generally consistent with theoretically predicted values for Orientale ejecta and tend to support a 620 km diameter for Orientale. The ejecta in this area is thinner than in Schiller-Schickard, which may be due to the presence of an ejecta lobe in the latter area (9).

Minimum cryptomare thickness estimates are again plotted as a function of distance from Orientale (Fig. 6), with column heights representing maximum minus minimum depths for each 100 km distance interval. Minimum cryptomare thickness here varies from 200-600 m, with the average of 400 m, again lower than typical mare (7). Cryptomare area, based on DHC distribution, was calculated to be 1.7 x 10^5 km^2, giving a minimum volume estimate of 6.6 x 10^4 km^3, or one quarter the volume of Mare Humorum. These values correspond to approximately 2% of the total known mare area and 0.7% of the total known mare volume (8).

Oceanus Procellarum: Ten DHCs were located west of Oceanus Procellarum. These DHCs are located approximately 800-1100 km west of Orientale and are arranged in two clusters and one solitary crater. These DHCs probably correspond to small mare patches, since the size distribution of DHCs found here corresponds to that of the other areas, thus a paucity of DHCs due to a proposed thicker ejecta deposit in this region (3) can be ruled out. The minimum depth of these mare patches is estimated to be 400-600 m. Investigations are currently underway to constrain the boundaries of the cryptomare patches by considering similar sized, fresh craters which don't exhibit dark halos. Once this is accomplished, area and volume estimates can be calculated.

Conclusions: Ongoing analysis confirms earlier studies suggesting that mare volcanism is an areally and volumetrically significant process in this area, prior to the Orientale basin forming event. Cryptomare in this region are on the order of 500 m thick, and represent 2% of the total known volcanic mare volume and 6% of the presently exposed mare area. The cryptomare thicknesses are low compared to typical mare and may indicate that post-Orientale craters have not been large enough to penetrate to the mare bottom. The fact that these cryptomare represent significantly smaller percentages of known mare volume, as compared to area, supports the interpretation that mare thickness estimates are low. Conversely, these values may mean that early mare deposits are characterised by thin, broad deposit morphologies. This question can be addressed by a search for large, relatively young, non-DHCs in the cryptomare regions, a direction we intend to pursue.

Our data suggest that the three study areas exhibit different geometries of mare emplacement (8). The Schiller-Schickard area appears to be an example of basin-fill cryptomare. The area west of Mare Humorum may be a basin-concentric cryptomare. The area west of Oceanus Procellarum is probably an example of isolated crater fill volcanism.

This study also suggests some implications for the duration and timing of mare volcanism (9). In the Schiller-Schickard area, volcanism was primarily confined to before the Orientale event, with a significant volcanic volume represented by the cryptomare, and only small post-Orientale mare patches present. In the Humorum area, volcanism began before the Orientale event, but was more significant after. This is evidenced by the relatively low volume of pre-Orientale cryptomare volcanism as compared to the post-Orientale Mare Humorum. This type of analysis provides important data on the onset and location of the earliest mare volcanism and is significant for petrologic models. We are presently working on further refining the cryptomare depth estimates and boundary delineations, and plan to extend this analysis to other regions, to develop a global census of cryptomaria deposits.

References: 1) P. Schultz & P. Spudis, *PLPSC* 10, 2899, 1979; J. Bell & B. Hawke, *PLPSC* 12, 665, 1981. 2) I. Antonenko *et al.*, *submitted to EMP*, 1994. 3) I. Antonenko & J. Head, *LPSC* 25, 35, 1994. 4) R. Pike, *GRL*, 1, 291, 1974. 5) D. Stöffler *et al.*, *JGR*, 80, 4062, 1975. 6) T. McGetchin *et al.*, *EPSL*, 20, 226,1973; P. Schultz *et al.*, *PLPSC* 12, 181, 1981. 7) R. Dehon, *PLPSC* 10, 2935, 1979; J. Head, *Moon and Planets*, 26, 61, 1982. 8) J. Head, *Origin of Mare Basalts & their Implications for Lunar Evolution*, LPI, Houston, TX, 66, 1975; ibid., 61, 1975. 9) D. Wilhelms, *USGS Prof. Pap. 1348*, US Gov. Washington, D.C., 1987.

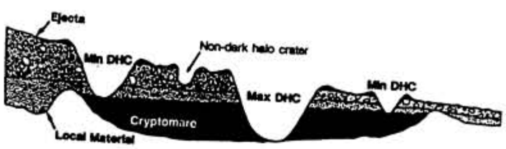

Fig. 1. Scematic diagram illustrating how the smallest DHCs define the top of the cryptomare, and thus the thickness of the overlying ejecta, while the largest DHCs define the bottom.

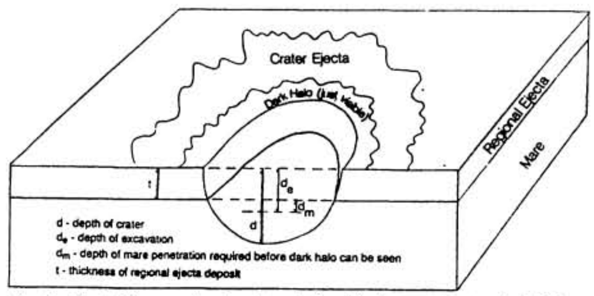

Fig. 2. Block diagram showing the relationship between crater depth (d) and depth of excavation (d_e).

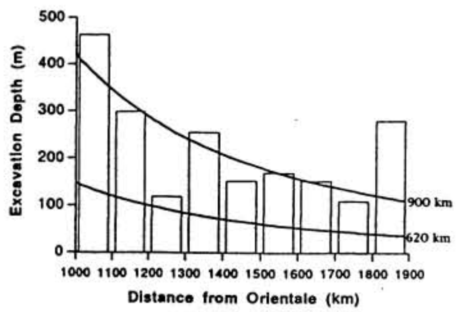

Fig. 3. Refined estimate of ejecta thickness overlying the Schiller-Schickard cryptomaria, from minimum DHCs.

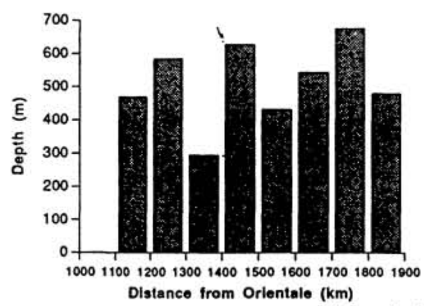

Fig. 4. Refined estimate of cryptomare thickness in the Schiller-Schickard area, from DHC excavation geometry.

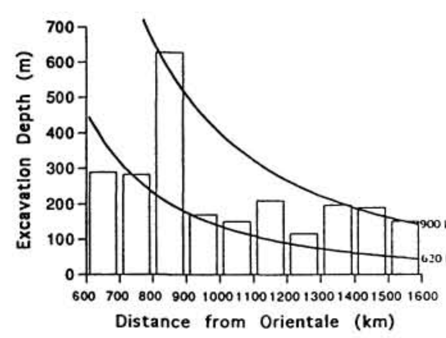

Fig. 5. Refined estimate of ejecta thickness overlying the cryptomare W of Mare Humorum, from minimum DHCs.

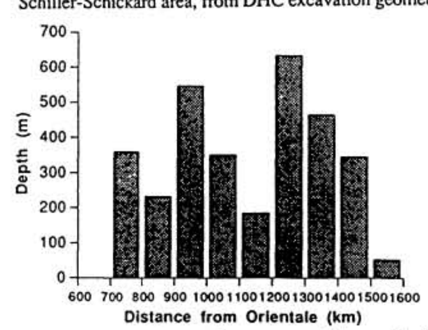

Fig. 6. Refined estimate of cryptomare thickness W of Mare Humorum, from DHC excavation geometry.