ALPHONSUS-TYPE DARK-HALO CRATERS – MORPHOMETRY AND VOLUME REASSESSMENTS AND IMPLICATIONS FOR ERUPTIVE STYLE. J. A. Skinner, Jr., L. R. Gaddis, L. Keszthelyi, T. M. Hare, E. Howington-Kraus, and M. Rosiek, Astrogeology Team, U. S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001 (jskinner@usgs.gov).

Introduction: Dark-halo craters located along floor-fractures in Alphonsus crater (108 km diameter; ~13ºS/357ºE) are considered type localities of small lunar pyroclastic deposits. Much of our understanding of the processes involved in smaller pyroclastic eruptions comes from morphometric analysis and deposit volumes in Alphonsus crater performed by Head and Wilson [1]. These authors used high-resolution photographs and topographic data to map the distribution and estimate the volume of materials in the pyroclastic cones. They concluded that juvenile materials were present in nearly all of the dark-halo crater deposits.

Additional information on the nature of the magmatic or juvenile components at Alphonsus has come from Earth-based spectral data, which indicated that these deposits were compositionally diverse and that several of the pyroclastic cones may have olivine components [2, 3]. Recent results based on Clementine UVVIS data were less conclusive, supporting the existence of compositional diversity among the Alphonsus and other pyroclastic deposits but not clearly identifying an olivine component [4-7].

This study complements previous compositional analyses through the use of stereomapping and GIS methods to refine volume estimates of volcanic materials in the Alphonsus deposits. We use digital reproductions and analysis of previous topographic data [8] to update geomorphic and volumetric measurements of the deposits. Preliminary results are being further improved via photogrammetric processing of Apollo metric and Lunar Orbiter photographs to derive better quality topographic data for the Alphonsus crater floor. These data will help refine our understanding of the parameters that controlled the formation of the Alphonsus-type dark-halo craters, with application to other lunar dark mantle deposits.

Geologic Setting: Alphonsus is a Lower Imbrian-age crater located in the Fra Mauro highlands east of the Upper Imbrian-age Mare Nubium [9]. The crater has a flat, heavily cratered floor, a central peak, and a broad rim. The crater floor is covered with Upper Imbrian mare basalts at near-equivalent elevations to Mare Nubium. North-south trending rilles dissect the crater floor and are interpreted to have formed as tension fractures in response to isostatic rebound or thermal contraction of the intra-crater mare basalts [9]. The dark-halo craters are located in and adjacent to the floor rilles, indicating the fractures likely provided conduits for volatile accumulation and subsequent pyroclastic eruption.

Alphonsus contains 11 dark-halo craters, ten of which are located within 25 km of the basin rim (**Figure 1**). These small craters are characterized by non-circular rims <2 km in diameter and dark halos that extend up to 6 km from the crater center, and they are interpreted as endogenic in origin [1]. Head and Wilson modeled the formation of these pyroclastics by the accumulation and explosion of volatiles that collected in a cap above a rising magma body. Here we verify and update morphometric and volumetric analyses of the vulcanian-type pyroclastic deposits at Alphonsus.

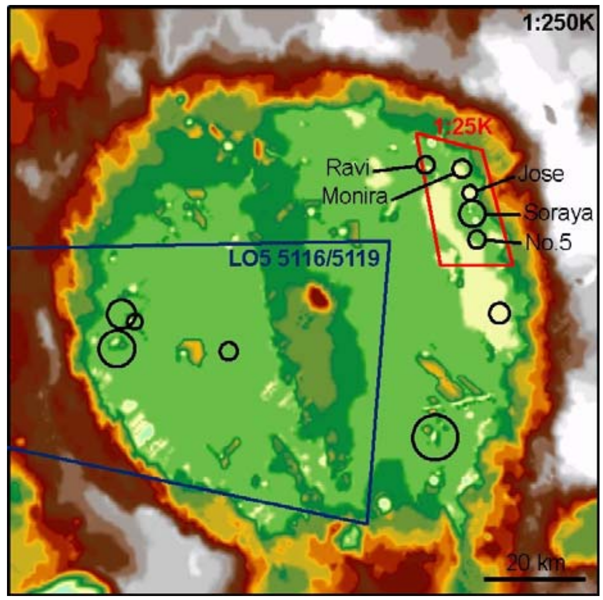

Figure 1. 1:250K reconstructed DEM showing the 1:25K map boundary (red outline), the LO5 DEM boundary (blue outline), and the locations of 11 dark-halo craters.

Methods: We scanned hardcopies of 1:250K and 1:25K scale topographic maps that were originally generated from Apollo 16 metric photos (frames 2477/2478) and panoramic photos (frames 9383/9378 and 5380/5385) in an analytical stereoplotter [8]. Each map was scanned at full-scale, ingested into ArcGIS as an uncontrolled, 8-bit raster image, and cleaned and vectorized using the ArcScan toolbox. We registered the resulting linework to a matched, Clementine mosaic in Mercator projection using transformation and rubbersheet spatial adjustments. The arbitrary datum originally applied to the 1:25K map was stripped and the data was tied to the 1:250K map. We attributed vector linework with elevations, converted the lines to points with 100-meter spacing, and generated DEMs using a 12-pt. tensioned spline algorithm (0.1 weight). We digitized dark-halo boundaries in ArcGIS using

Clementine 750-nm and color ratio data, which highlighted the low-albedo and high iron content of the dark-halo deposits (e.g., [10]).

Dark-halo crater and deposit volumes: The 1:25K DEM allowed detailed examination of 5 dark-halo craters in the northeast norner of Alphonsus (**Figure 1**). Individual DEMs were constructed for Ravi, Monira, Jose, Soraya, and No.5 (after [1]). "Pre-eruption" topography for each region was constructed by removing elevation points within the rilles (where applicable) and the dark mantle material, based on boundaries identified in Clementine mixed spectral datasets. Where necessary, rilles were reconstructed using elevations outside of the dark-halo deposits. Crater morphometries (e.g., crater and halo widths, deposit thicknesses) and volumes (e.g., volume excavated and deposited) were derived using point elevation comparisons and cut-fill calculations between pre- and post-eruption DEMs in ArcGIS. Selected results are summarized in Table 1.

Table 1 - Alphonsus-type dark halo crater characteristics

Crater name	Excavated volume (km3)	Deposited volume (km3)	Juvenile (% deposited)	Max. halo radial (km)
Soraya	0.14	1.34	90	5.9
Ravi	0.19	0.44	57	4.1
Monira	0.12	0.17	28	3.6
Jose	0.10	0.03	<0	2.8
No. 5	0.06	0.05	<0	2.6

Results: Volumetric data from this analysis show both similarities and differences with past studies of dark-halo crater materials, particularly with respect to eruptive styles and processes. [e.g., 1-2, 9]. The most notable observations and parameter associations are numbered and described below. (1) While small-diameter craters (Jose, No.5) have more material excavated than deposited, larger craters (Ravi and Monira), may contain 30 to 60% of juvenile magmatic and volatile material. Soraya deposits appear to contain a very large amount of juvenile material (>90%). These comparisons suggest that small craters formed exclusively by explosion while larger craters incorporated more significant amounts of juvenile materials. The large size of the Soraya deposit indicates that this eruption was unique for this area. (2) Radial distances of the dark-halo deposits increase with increased deposit volume and amount of juvenile material, showing that as activity progressed from explosions to eruptions, the halo expanded outward reflecting the growth of the crater vent. (3) While Soraya crater and dark-halo deposits conform to some characteristics of similar deposits in this region, its characteristics are significantly varied. For example, while crater rim-to-halo diameter ratios are ~0.3 for other craters, Soraya shows a ratio of 0.2. Other discrepancies include the volume of juvenile material, depth of crater below the pre-eruption surface, and maximum halo radial. These discrepencies may indicate a major shift in the eruption style for Soraya crater.

Implications: The results of these preliminary morphometric and volumetric analyses show interesting physical relationships among the dark-halo craters of Alphonsus. The Alphonsus dark-halo craters are consistent with deposits formed by monogenetic, short-lived terrestrial eruptions [11] (seconds to minutes in duration). The Jose and No.5 deposits likely did not involve the eruption of juvenile material but only redistribution of excavated material. Importantly, there is no albedo, morphologic, or mineralogic evidence that materials that were excavated are chemically different from the juvenile materials erupted from other craters.

These observations and implications affirm the hypothesis of Head and Wilson [1] that the Alphonsus-type dark-halo crater are vulcanian in eruptive style. However, there may be a gradation with larger dark-halo craters where the eruption begins as a vulcanian-style explosive eruption and migrates into a short-lived Strombolian-style of fire-fountaining.

Further studies: Ongoing photogrammetric and mapping efforts will help to validate the results presented above by adding morphometery and volume information for all 11 dark-halo craters on the floor of Alphonsus. We are currently producing DEMs of Lunar Orbiter V (LO5) and Apollo metric stereopairs using BAE Systems's SOCET SET. We anticipate the Apollo 16 metric pair 2677/2678 will cover the entire Alphonsus crater floor and yield a DEM with approximately 30 m/pixel resolution. In addition, we anticipate the LO5 medium-resolution metric pair 5116/5119 will cover the southwest corner of Alphonsus crater (Figure 1) and yield a DEM of approximately 8.5 m/pixel resolution. By completing morphometry and cut-fill analyses for each of these craters, we will compare the implied eruptive proceses and styles of Alphonsus-type dark-halo craters to similar deposits in other lunar regions. In addition, we will document similarities and differences among the Alphonsus-type craters themselves.

References: [1] Head and Wilson (1979) *PLPSC 10th*, 2861. [2] Hawke *et al.*, 1989, *PLPSC 19th*, 255. [3] Coombs *et al.*, 1990. *PLPSC. 20th*, 339. [4] Shoemaker *et al.*, 1994, *Science* 266, 1851. [5] Robinson *et al.*, 1996, *LPS XXVII*, 1087. [6] Gaddis *et al.*, 2000, *JGR*, 105, 4245. [7] Gaddis *et al.*, 2003, *Icarus* 161, 262. [8] Wu et al. (1972) *Apollo 16 Prelim. Sci. Rep.* NASA SP-315. [9] Carr, M.H. (1969) *USGS I-599*, 1:250K. [10] Lucey et al., 2000, JGR 105, 20,297.