IMPROVED METHOD FOR ESTIMATING LUNAR VOLCANIC DOME VOLUMES. F. Baum[1], M. Zanetti[2], B. L. Jolliff[1], [1]Washington University in St. Louis and the McDonnell Center for the Space Sciences, St. Louis, MO 63130 (FBaum@TapestrySolutions.com; bjolliff@wustl.edu), [2]University of Western Ontario, Department of Earth Science, 1151 Richmond St., London, Canada N6A 5B7 (Michael.Zanetti@uwo.ca).

Introduction: Volume estimates of lunar volcanic domes usually approximate their topography with basic three dimensional shapes, such as paraboloids or cones, so that a simple volume equation can be used. For example, volume estimates of the Gruithuisen and Mairan domes calculated in 2003 [1] treated each dome as a simple paraboloid. More recent volume estimates [2] used a circular truncated cone approximation. However, more robust volume estimates and other dimensional measurements can be calculated using Digital Terrain Models (DTMs) and various Geographical Information System (GIS) tools. Here we discuss the tools and methods for determining volumes of volcanic constructs on the Moon using DTMs, common ArcGIS [3] tools, and the GeoEVE (Geologic Event Volume Estimator) tool [4]. We present the results from case studies of these tools with respect to putative lunar silicic volcanic constructs [5].

Methodology: We use Lunar Reconnaissance Orbiter Camera (LROC) Wide and Narrow Angle Camera (WAC, NAC) imagery and their DTMs [6][7] with various GIS tools strung together using ArcGIS ModelBuilder and ArcPy scripting software to help improve defining and verifying the outlines of lunar volcanic domes and to measure their lengths, widths, heights, volumes and 3D surface areas. All GIS tools mentioned below are ArcGIS built-in tools or custom tools/scripts, developed by the authors, for use with ArcMap 10.2.2 or later (the GeoEVE tool is available on request from the authors). The following steps were performed to calculate the dimensions and volume estimates for several lunar volcanic domes.

Create contour lines: To find the approximate base height and approximate outline of a given volcanic dome, first contour lines were generated (Figure 1A) using NAC DTM rasters [7] that covered the dome and surrounding area. Image and topography interpretation at the discretion of the geologist were also used.

Adjust dome outline: A dome's approximate outline can be modified with a buffer, to uniformly extend the dome's outline, or modified manually to account for geologic features (e.g., craters).

Verify base outline with topographic profiles: To help verify and refine the dome's outline, an ArcPy script was written that executed the following steps:

- Located the highest elevation DTM pixel within the dome's outline and created a point there.

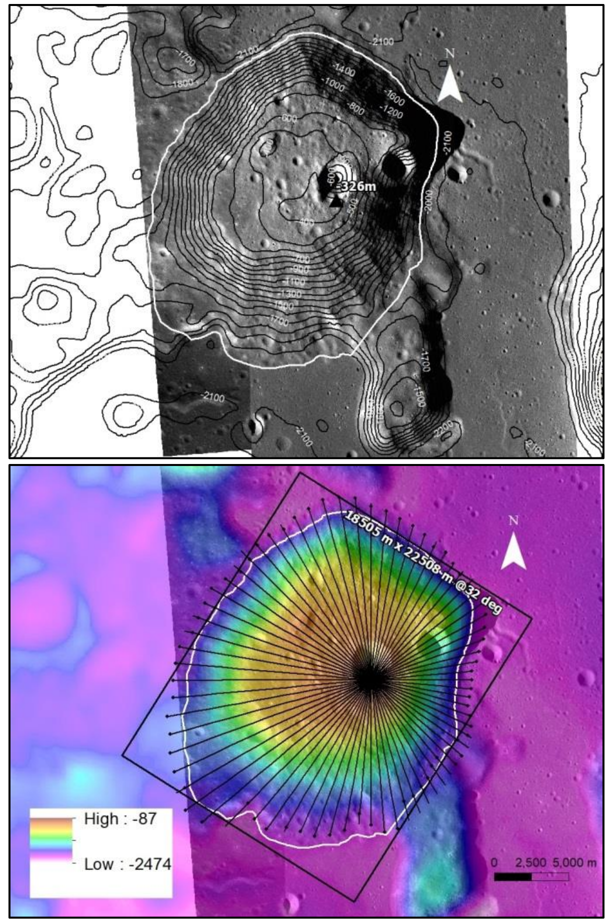

Figure 1: Gruithuisen-Gamma dome topographic extent (solid white line) with A) 100m contour lines; dome summit at -326m (black triangle); NAC image; and B) MBG extent (black rectangle); azimuth cross-section lines (black lines); minimum elevation points along topographic profiles (black points); WAC DTM [6].

- Created many azimuth cross-section lines radiating from this summit point out to the edge of a buffer surrounding the dome's outline.
- Generated topographic profile tables and graphs, using the Stack Profile tool [8], along each azimuth cross-section line.
- Determined the horizontal distance from the summit to each topographic profile's minimum elevation.
- Created feature points, in the NAC DTM's coordinate system, at these horizontal distances by using ArcGIS' Linear Referencing [9] capability.

To help verify and manually adjust each dome's outline, 72 azimuth cross-section lines were used, spaced 5 degrees apart. (Figure 1B).

Measure dome's horizontal dimensions: To measure the length, width, and orientation (i.e., azimuth of the longer side) of a dome's outline, the Minimum Bounding Geometry (MBG) tool [10] was used to create a rectangle of the smallest width enclosing the input feature (Figure 1B).

Estimate dome's 3D surface area and volume using a flat, horizontal reference plane as its base: These were calculated using the Surface Volume (SV) tool [11] with NAC/WAC DTMs clipped to the dome's outline and a base height value derived from the contour line that most closely followed the dome's outline.

Model pre-event surface and estimate dome's volume: To calculate more robust volume estimates of each dome, our custom-built GeoEVE tool [4] was used to model the dome's base (i.e., pre-event surface) as a flat, sloped plane interpolated from the surrounding topography and then calculate a volume estimate of the clipped DTM located above this plane.

Case studies of lunar volcanic domes. Using the methods and tools described above, we measured the dimensions and volume estimates of various lunar volcanic domes (Table 1), including Gruithuisen (Gh) Gamma, Delta and Northwest (NW), Mairan Northwest (M-NW), and Compton-Belkovich (CB) volcanic complex's Beta. For comparison, Table 1 lists in parentheses the dimensions and volume estimates for the Gruithuisen domes from [2], which also used WAC/NAC images and DTMs. The Gruithuisen domes' volume estimates in [1] were not used for comparison because their dimensions were derived from lower resolution Lunar Orbiter IV imagery and their paraboloid volume calculations used a dome's estimated maximum radial extent. Also, the Gh-Delta and Gh-NW domes' volume estimates in [1] were each partitioned into multiple dome components (e.g., lower and upper domes), making comparisons even less consistent. Volume estimates based on the paraboloid and truncated cone, using our dimension estimates, were also calculated and are included in Table 1.

Results: The first three volume estimates in Table 1 use a flat, horizontal plane for the dome's base. Of these, given a roughly circular dome, the paraboloid seems to overestimate the volume and the truncated cone underestimates it. For a dome that is more rectangular (e.g., CB-Beta), its mean base radius misrepresents the dome's basic shape and causes these two 3D-shape volume equations to give high volume estimates. Since the Surface Volume and GeoEVE tools use the actual DTMs, their volume estimates are closer to the true volumes and, because the GeoEVE tool models the dome's base from the surrounding topography using multiple Monte-Carlo-like runs, we suggest that its volume estimates are more robust.

References: [1] Wilson, L. and Head, J. W. (2003) JGR, 108(E2), 5012, 6-1-6-7 [2] Ivanov, M. A., et. al. (2016) Icarus 273, 262-283 [3] ArcGIS® 10.x software by Esri, (http://esri.com) [4] Baum, F. and Zanetti, M. (2017) LPSC XLVIII, 2779 [5] Glotch, et. al. (2010) Science, 329(5998), 1510-1513 [6] Scholten, F., et. al. (2012) JGR 117, E00H17 [7] Henriksen, M. R., et. al., (2017) Icarus 283, 122-137 [8-11] ArcGIS Help: [8] Stack Profile [9] What is linear referencing? [10] Minimum Bounding Geometry [11] Surface Volume

Table 1: Summary of dimension and volume estimates for lunar volcanic domes

	Dome Latitude (°) / Longitude (°)	Gh-Gamma ([2]) 36.56/-40.72	Gh-Delta ([2]) 36.07/-39.59	Gh-NW ([2]) 37.1/-41.1	M-NW 43.7/-49.9	CB-Beta 61.8/99.6
Length/m		22508 (~24500)	31646 (~35000)	8284 (~8000)	2962	4334
Width/m		18505 (~19000)	20971 (~18000)	8121 (~6400)	2854	2216
Orientation/deg		032	172	021	169	176
Mean base radius (R_b)/m		10245	11914	3955	1462	1579
Mean summit radius (R_s)/m		5603	3827	~0 (N/A)	~0 (N/A)	184
Base Elevation (E_b)/m		-1900	-1900 (~-2000)	-1750 (~-1600)	-2582	-2210
Summit Elevation (E_s)/m		-326	-87 (~300)	-532 (~-600)	-2390	-1984
Dome Height ($H=E_s-E_b$)/m		1574 (~1400)	1813 (~1700)	1218 (~1000)	192	226
3D Surface Area from SV tool (A_{sv})/km^2		316.31	487.37	60.17	6.84	7.84
Volume Estimates /km^3	paraboloid (V_p) [a]	238.03	404.23	29.93	0.65	0.89
	truncated cone (V_{tc}) [b]	284.06 (~290)	383.86 (~470)	19.95 (~20)	0.43	0.67
	Surface Volume tool (V_{sv})	229.96	322.28	20.90	0.58	0.64
	GeoEVE tool (V_g)	265.67	399.64	25.53	0.61	0.43

[a] paraboloid volume $V_p = [(\pi/2)R_b^2H]$; [b] truncated cone volume $V_{tc} = [(\pi H/3)(R_b^2 + R_bR_s + R_s^2)]$