

**UNWRAPPING LUNAR PITS: HORIZONTAL VIEWS FROM ORBIT.** R. W. Wagner and M. S. Robinson, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (rvwagner@asu.edu).

**Introduction:** Lunar pits are a type of collapse feature, usually <100 m wide, that can expose vertical cross-sections through many tens of meters of mare basalt flow deposits [1,2]. Building on our method of creating 3D models from orbital images described in [2], we have produced a method of rendering a modeled pit's vertical walls as if viewed from the side. We used this method to identify features in the walls of lunar pits, following up on and confirming our previous work on measuring layers from uncorrected oblique images [3].

**Methods:** The method has two main steps: 1) Create a textured 3D triangle mesh in an industry-standard format, and 2) Use ray-tracing to render that mesh onto a cylindrical surface approximating the pit wall (Fig. 1).

In [2], we used individual pairs of off-nadir LROC NAC images to create multiple 3D point clouds of the walls of a pit and merged several of those sub-models to form a complete point cloud of the pit interior. Our new method creates textured meshes and wall maps for the individual sub-models, but cannot yet create a textured mesh version of the combined model.

**Textured 3D Meshes:** The models created in [2] are unconnected point clouds, rather than meshes. To calculate connectivity and make a triangle mesh, we first reprojected the points of a given wall model onto a cylinder centered on the pit. Then, we ran a 2D Delaunay triangulation algorithm using *matplotlib* [4] on those reprojected points to build a 2D network (Fig. 1B). This network was then applied to the 3D coordinates of those points to create a 3D triangle mesh (Fig. 1C).

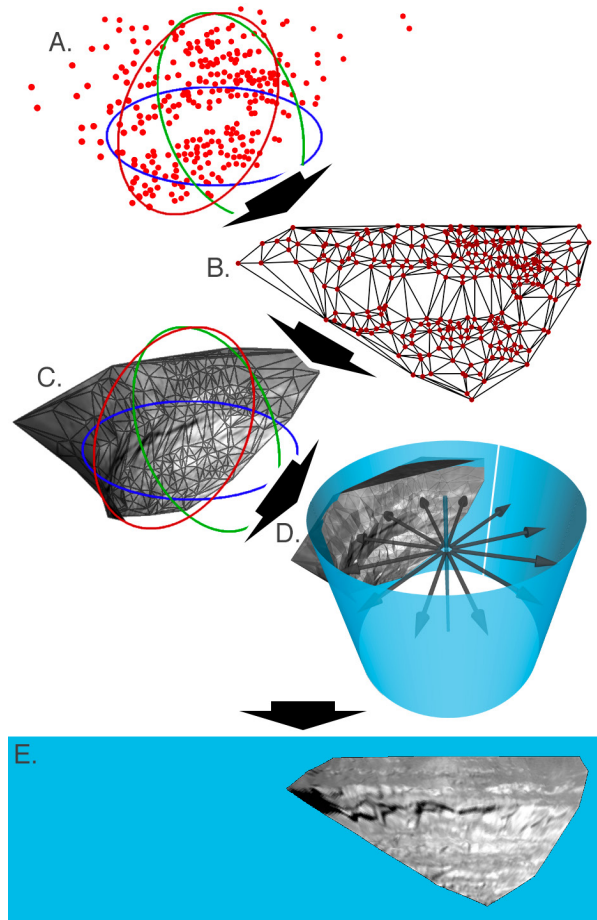
The textures we applied to this mesh were the same images used to produce the point cloud from stereophotogrammetry. We extracted the image-space coordinates from the original point correspondence network and added them to each vertex as UV coordinates (the standard method of mapping images onto triangle meshes). We saved this textured model in Wavefront OBJ format, with one OBJ file for each source image. The coregistration accuracy between the reprojected images from the two textures indicates the quality of the mesh: an inaccurate mesh will leave sections of the wall misplaced differently in each image.

Additionally, we exported textured 3D meshes of terrestrial pit craters we had previously modeled in Agisoft Metashape [5,6] to verify the next step (Fig. 2).

**Image Reprojection:** We used the *trimesh* Python library [7] to load the textured OBJ files. This library supports ray-mesh intersection calculations and provides programmatic access to texture color information. These features allowed us to build a simple ray-tracing renderer that takes a set of rays and creates an image

from the colors where they intersect the mesh, allowing us to render the mesh in any projection. The currently supported projections are orthographic (to aid in aligning the projection surface to the model) and “cylindrical orthographic,” where the pit wall is projected from a vertical line down the center horizontally out to a cylindrical projection plane (Fig. 1D, E). All calculations use physical units and produce output with uniform scaling and square pixels (to the greatest extent possible given the irregular geometry of pit walls).

**Results:** The reprojection method produces clear wall maps for fully-modeled terrestrial pits (Fig. 2). Lunar pit wall maps must be spliced together from individual images, and coverage is limited. Still, the resulting images are useful for identifying horizontal features interpreted as flow layers (Fig. 3).



**Figure 1:** Workflow to produce wall images. A) Initial 3D point cloud. B) Triangulation of cylindrical projection of point cloud. C) Triangulated and textured 3D mesh. D) Reprojecting textured mesh onto a cylinder. E) Cylindrically projected image.

We compared the results of this method to our previous work identifying layers in the Mare Tranquillitatis pit [3] (Fig. 3). On the west wall, the same horizontal features are identifiable and appear within  $\sim 1$  m of their locations from [3]. Several do not identifiably span the full wall width, but are still distinct from the features above and below them. On the east wall, not all layers from [3] have more than 1-2 points of identifiable expression. Very few horizontal features are apparent below  $\sim 25$  m depth (3<sup>rd</sup> blue line from top in Fig. 3). This may be an effect of the wall geometry reducing contrast: on the west wall, few parts of the wall are overhung (outside of the poorly-reconstructed regions, red in Fig. 3), allowing dust to accumulate on top of layers, while on the east the wall is largely overhung with irregular geometry, possibly preventing dust build-up and reducing contrast between the tops and sides of protrusions.

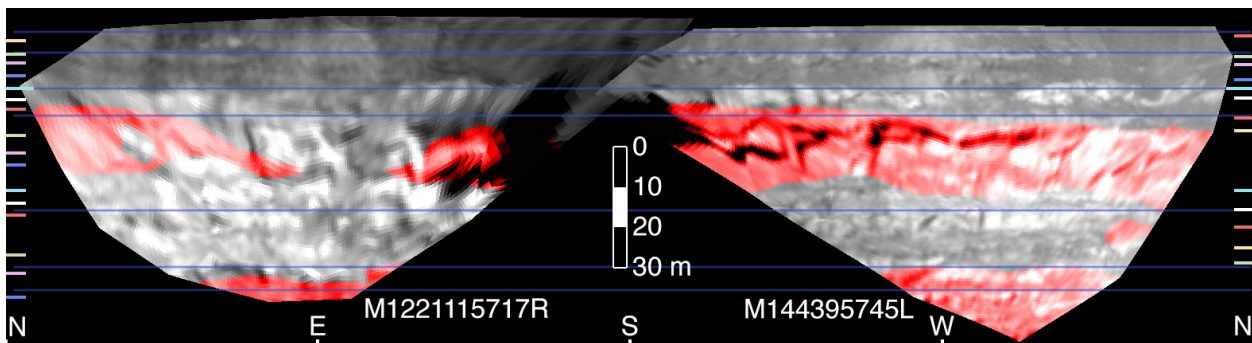
**Summary:** We developed a new method of viewing the walls of lunar pits, which is a significant improve-

ment for unambiguously identifying horizontal features. Working directly on oblique NAC images, we found it difficult to tell if discontinuous features were at the same depth, and we needed to carefully cross-reference measured depths to determine if features were likely related [3]. With this reprojection method, horizontal features appear as horizontal lines, and we have confirmed our previous work indicating layer thicknesses of  $\leq 5$  m. Additionally, this method allows easy identification of inaccurate sections of the underlying model geometry that can be further refined.

**References:** [1] Robinson et al. (2012) doi:10.1016/j.pss.2012.05.008. [2] Wagner and Robinson (2022). doi:10.1029/2022JE007328. [3] Wagner et al. (2019) 50<sup>th</sup> LPSC #2138, abstract and eposter. [4] [https://matplotlib.org/stable/api/tri\\_api.html](https://matplotlib.org/stable/api/tri_api.html) [5] Wagner et al. (2018) 49<sup>th</sup> LPSC #1538. [6] <https://agisoft.com> [7] Dawson-Haggerty et al. (2019). <https://trimsh.org>.



**Figure 2:** The wall of Devil's Throat in Hawai'i Volcanos National Park ( $\sim 40$  m diameter,  $\sim 50$  m deep; horizontal and vertical scales are approximately equal). South is at the center of the image. Note the sinusoidal curvature of the rim, which in reality is horizontal, indicating a tilt in the model. Our rendering code can correct this tilt if the model error is known. Note also that layering is more identifiable in indirect light (right) than direct light (left).



**Figure 3:** The wall of the Mare Tranquillitatis pit ( $\sim 100$  m diameter, section shown is 80 m tall, starting  $\sim 10$  m below the surface; horizontal and vertical scales are approximately equal). Red areas are approximate regions with poor geometric reconstruction based on misregistration between images of that wall. Blue lines mark horizontal boundaries identified on the west wall; colored marks on left/right indicate layer boundary depths identified in [3], colored to match [3]. Both images were acquired  $\sim 51^\circ$  off-nadir with  $\sim 8^\circ$  phase angles.