Introduction

The Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) consists of two line-scan cameras aimed side-by-side with a combined 5.7° field of view, with a nominal resolution of 0.5 m/pixel from the original mission altitude of 50 km. To date, over 300 vertically-walled lunar pits have been discovered, all but three from analysis of NAC images [1,2], and recent measurements suggest some may be associated with large underground void spaces [3,4]. LROC can acquire off-nadir images by slewing the spacecraft to the east or west, giving views of vertical and overhanging surfaces, and has done so for many of the larger pits. We used multiple oblique images of the same walls to produce 3D models of the Mare Tranquillitatis, Mare Ingenii, Marius Hills, and Laciuc Mortis pits, and plotted layer boundaries in 3D to follow up on previous studies of overhanging void spaces and meter-scale layering in the walls interpreted as mare flows [2,5,6].

Producing Pit Models

As the LROC NAC is a line-scan camera, we first rectified all images by scaling them such that the down-track scale matched the cross-track scale in a plane parallel to the sensor. We then used the USGS ISIS tool to manually place tie points on a pair of images (automatic feature-based tie point selection usually failed or required manual correction for non-horizontal surfaces). Next, we calculated the 3D position of each tie point using both the ISIS bundle-adjustment tool figaro and a custom trigonometric solver. Differences between the figaro and trigonometric point clouds were typically < 1 m.

Once a point cloud was produced for a given pair of images, we aligned it to a NAC DEM of the surrounding surface [5,9] using 4-7 control points to correct the orientation and align multiple single-wall models together (Figure 1).

Model Verification

To test the accuracy of the models, we created renderings from them with identical lighting and viewing angles to LROC NAC images of the pits [6]. To produce these synthetic NAC images, we used the NASA SPICE data associated with NAC images of pits to determine the camera and Sun positions and orientations relative to the pit, and reproduced those conditions in Blender using a virtual camera that matched the NAC optical parameters (Figure 2). These synthetic images do not contain any albedo information; we used a generic 3D modelling photometric model.

As an additional check of the method, we produced synthetic NACs of a model of a terrestrial pit crater, and created a model using those images. The resulting point cloud aligned with the original model to within 1 m.

New Morphologic Observations

Preliminary floor measurements (Figures 1, 3) suggest that the floor of the Mare Tranquillitatis pit is flat in the center of the pit, but slopes down sharply under the east rim. We have not yet confirmed that our model of the center of the floor (Figure 3, faded orange line) is accurate, as in this case the jigsaw model does not converge. The floor of Mare Ingenii slopes down smoothly towards the south-west, until it reaches a wall ~15 m past the rim, under a roof at least 50 m thick. A non-stereo observation suggests that the wall continues northward, but we have not yet observed the lower wall due south, so we cannot rule out an opening to a larger void space.

We have confirmed the previously-reported overhang in the Marius Hills pit [5], but have located a wall-floor contact at several points along the back end of the overhang. The west side of the pit has not yet been imaged obliquely.

Stratigraphic Analysis

All mare units are interpreted as outcrops of individual mare flow layers, with thicknesses ranging 1-15 m at the Mare Tranquillitatis [5], Mare Ingenii and the West walls of Mare Tranquillitatis (Figure 6). We previously found that mare NAC images of high-resolution 3D models of terrestrial pits show that lava flow layers can produce morphologic layering visible in orbital images [6]. To map layers in three dimensions, we selected tie-points from our models that fell on apparent layer boundaries (usually either the upper bounds of bands of bright material, or protruding edges above vertical or overhanging surfaces). These points were assigned to provisional layers based on apparent continuity. We then refined these layer assignments based on calculated depths, by merging layers with matching depths, splitting up layers with divergent depths, and verifying that the new layer assignments did not split up visually continuous layer segments.

With layers on both walls of a pit modelled, we found that in many cases we had identified layers with matching depths on both east and west walls of a pit (Table 1). Near the surface, some of these matching layers can be traced from one side to the other, confirming that they are continuous and that the models align. By assuming that all layers are continuous and horizontal across the pit, we can combine both walls to produce a more complete record of layers.

Table: Identifiers in the Mare Tranquillitatis and Mare Tranquillitatis pit walls. All measurements are in meters.

Depletions are below mean regolith surface. “Offset” is vertical offset between layers identified as matching between walls. “Thickness” is distance to nearest identified layer on either wall. Figures show points used for layer measurements on each wall (only one of the two models used for east Mare Tranquillitatis is shown), color-coordinated with the table rows.

Poster in 60 seconds

The Problem: In LROC NAC images, pits are usually <100 pixels wide, making it difficult to directly observe their internal morphology.

The Question: Can we produce accurate 3D models of pit interiors from orbital images, and what can we learn about mare flow units from them?

The Method: We used multiple oblique images of pit walls to produce stereo models, and used tie points located on layer boundaries to map flow units within each pit wall.

Model Results: We created 3D models that accurately reproduced wall morphology (left) and found that layers identified in the models could be correlated between walls for a more complete record (below). We found that layer thicknesses appear to be thin and fairly uniform, with a median layer thickness of ~3.5 m at both the Mare Ingenii and Marius Tranquillitatis pits.

Abstract

Scan this code to view the abstract for this poster online.

References

[10] (Background: Upper wall of Devil’s Throat pit crater in Hawai’i.)

Figure 1: Point cloud anaglyphs of the Mare Tranquillitatis pit (left, ~90 m wide by ~125 m deep) and Mare ingeni pit (right, ~90 m wide by ~100 m deep), merged with subsections of NAC DEMs of the surrounding surface (DEM point spacing is 2 m).

Figure 2: Creation of a synthetic NAC image. Left: Geometry of original slewed image (top) and actual image M155023632R (bottom). Right: Blender scene with matching parameters (top), and rendered synthetic NAC view of Mare Tranquillitatis pit model (bottom). Distances/sizes not to scale.

Figure 3: East-west profiles through the center of each pit. Horizontal and vertical scales are the same. Horizontal lines mark measured layer boundaries, and faint lines mark interpolated surfaces that have been seen, but have not been measured. Note that the Marius Hills model is not well-controlled due to low resolution DEM orthophotos [8].

Figure 4: Layers in Mare Tranquillitatis west wall. Left: Layers identified in [5], recolored to roughly match this work. Right: Layers identified in the table below. Dots mark layer boundaries used in this work.

Detailed Floor Measurements

East Wall

West Wall

North Wall

Figure 5: West Wall of Mare Tranquillitatis pit showing apparent strata marked on wall above and below its top.

Layers in Mare Tranquillitatis west wall.

Layers in Mare Tranquillitatis east wall.

Layers in Mare Tranquillitatis north wall.

Figure 6: East-west profiles through the center of each pit. Horizontal and vertical scales are the same. Horizontal lines mark measured layer boundaries, and faint lines mark interpolated surfaces that have been seen, but have not been measured. Note that the Marius Hills model is not well-controlled due to low resolution DEM orthophotos [8].

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