LROC OBSERVATIONS OF THE MARIUS HILLS. S. J. Lawrence[1,2], J. D. Stopar[1], B. R. Hawke[3], L. R. Gaddis[4], M. S. Robinson[1], B. W. Denevi[1], T. A. Giguere[5], B. L. Jolliff[6], S. E. Braden[1], and the LROC Team. [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ [2]sjlawren@asu.edu [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, HI [4]United States Geological Survey, Astrogeology Program, Flagstaff, AZ [5]Intergraph Corporation, Honolulu, HI [6]Department of Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, MO

Introduction: The Marius Hills (MH) are located in Oceanus Procellarum (~13.4°N, 304.6°E), and represent the largest concentration of volcanic features on the Moon (including domes, cones, sinuous rilles and pyroclastic deposits)[1]. Previous studies used telescopic, Lunar Orbiter, Apollo, and Clementine data to investigate the morphology and composition of the volcanic features in the MH region [e.g., 1-7]. High-resolution Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images provide new insight into volcanic features in MH. Here, we present initial results of morphologic and topographic studies based on NAC images including a Digital Terrain Model (DTM) derived from stereo NAC imagery.

Methods: LROC consists of three instruments: a Wide Angle Camera (WAC) and two NACs [8,9]. NAC frames of the MH used in this study have resolutions of ~1.3 m/pixel (from the 220x30km commissioning phase orbit) and ~0.5 m/pixel (from the 50km nominal orbit). During the commissioning phase (the first 90 days) of the LRO mission, over 30 NAC frames of the MH region were acquired. LRO can be rolled off-nadir to acquire a limited number of stereo observations[10]. NAC images with offset viewing geometries (offset angle of 14°) were used to create a 5m/pixel uncontrolled DTM of a region in the MH with the SOCET SET toolkit [11] for morphometric measurements of specific features (including heights, profiles, and slopes). The DTM extends from 14.2°N, 12.1°N and 303.7°E, 304.2°E.

Results: *Domes and Cones:* Two types of domes were observed: small steep-sided domes (with diameters from 1-2 km) and larger, more irregularly-shaped domes, consistent with previous observations [1-7]. Portions of the observed MH domes are characterized by rough surfaces, often with large low-reflectance boulders up to 6 meters in diameter at the dome summits. One of the small steep-sided domes has a summit crater. This feature has an outer diameter of ~2.0 km and a summit crater diameter of ~0.6 km, giving a ratio (outer/inner) of 3.3.

A third type of volcanic construct in the MH is steep-sided and roughly circular in shape with positive-relief and a central depression. These features were previously termed "cone" by [1-7] and were suggested as pyroclastic features. High-resolution NAC images will be used to test that hypothesis. One example of these steep-sided volcanic features lies within the LROC DTM and has a slope of 10.3°, a width of 1.8 km, and a height of 100 m. These measurements are consistent with those of previous investigators [1-7].

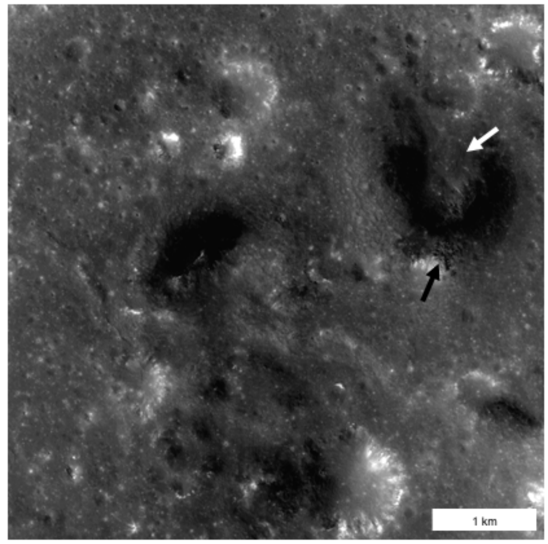

Figure 1: Subset of a high sun (incidence angle 25.2 degrees), map-projected LROC NAC frame (M107235870R) showing a dense region of volcanic features in MH. A breached, steep-sided, cone-shaped feature is at top right of image. Image resolution is 0.92 m/pix, which provides enough detail to resolve boulders (3-6 m) on the flanks of the construct. The south flank of the structure is covered with large blocks (black arrow), which may be either related to volcanic activity or the remnants of a now partially buried impact crater. There are fine ridges (white arrow) seen at the limits of the image resolution that may be volcanic flow features emanating from the center of the feature and flowing off to the north..

A second example of the circular, steep-sided cone-shaped features is shown in Fig. 1. This feature was visible previously in Lunar Orbiter images; it has an outer diameter of ~1.6 km and an inner diameter of ~0.6 km, yielding a ratio of 2.7. Both low-reflectance boulders and higher-reflectance blocks up to 6 m in diameter are resolved on the flanks of the cone-shaped structure. Fine ridges are seen (at the limit of the image resolution) that may represent fluidized flow textures on a volcanic flow emanating from the center of the cone and flowing northward.

Landforms resembling lobate lava flows were observed in association with several volcanic constructs in MH (e.g., Fig. 2). The breached, arcuate volcanic feature in Fig. 2 has an outer diameter of ~1.8 km, and the central depression has a diameter of ~0.5 km, yielding a ratio of 2.1. The ratios derived in this study are somewhat higher than reported for domes by [7] whose values are roughly between 4 and 7; however, more measurements of domes and cones derived from LROC NAC images are needed to provide statistically significant metrics. In Fig. 2, rough-surfaced, lobate flows extend northward from the center of the volcanic feature to a maximum distance (within the image) of 2.7 km. Terminal ends of

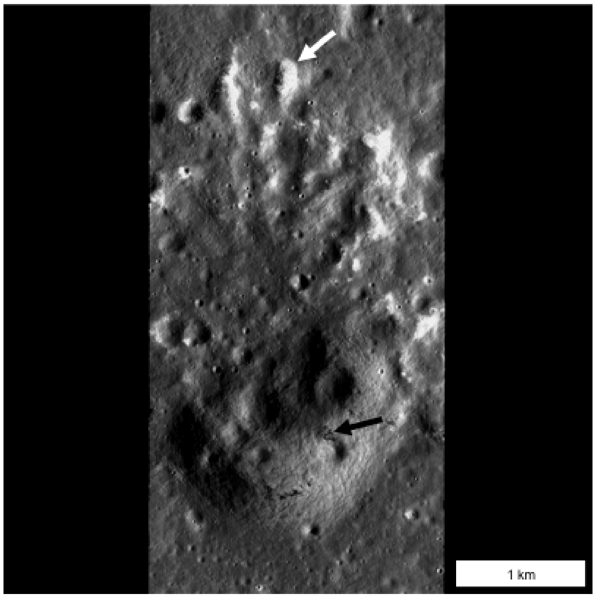

Figure 2: Subset of LROC NAC frame M114308099R showing a volcanic feature with rough-surfaced flows that extend northwestward (top) from a breached volcanic construct to a distance of ~2.7 km. This image was acquired at an incidence angle of 61.4 degrees and resolution of 0.5 m/pix. Terminal ends of rough flows are densely covered in large, higher reflectance boulders (e.g., white arrow). Boulders up to 10 m in diameter are exposed on the southern flanks (e.g., black arrow).

these rough flows appear bright and they are covered in large, higher reflectance boulders.

Rilles: Portions of Sinuous Rilles A and B of [2] are within the LROC DTM. Layers and large boulders are exposed in the walls of the rilles. For Rille A (Fig. 3), the average relative depth is ~250 m, the width ranges from 0.8 to 1.1 km, consistent with previous measurements [2].

Discussion: A wrinkle ridge that trends roughly N-S in the MH region and cuts across both Rilles A and B was noted earlier [2]. The NAC DTM shows a topographic rise (~150m) on the floor of Rille A as it crosses the ridge, indicating that the wrinkle ridge post-dates the formation of the rille.

Volcanic domes, cone-shaped structures, and lava flow margins in MH are associated with both low and higher reflectance blocks and boulders. LROC observations of large boulders at the summits of some of the domes and cones in the MH region, as well as observations of rough, blocky lava flows originating from within domes and cone-shaped structures in the MH region, are consistent with the conclusions of [12], who used Earth-based radar observations to determine that volcanic features in the MH have rough surface textures covered by several meters of regolith.

The bright boulders along flow margins suggest a blocky, more silicic lava. However, the FeO content of the MH domes as determined from Clementine data does not support a high silica content [6]. The lower albedo boulders studied thus far are often found in association with a thin, apparently surficial layer of lower reflectance material. Preliminary inspection suggests that

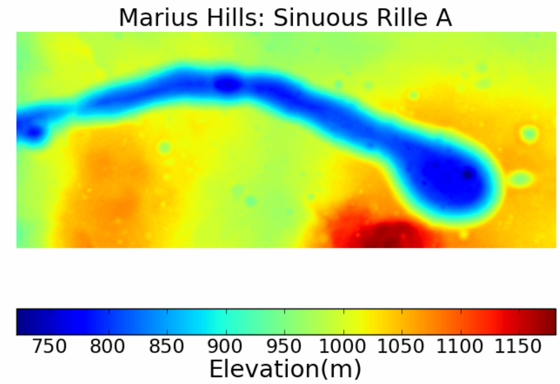

Figure 3: DTM showing Sinuous Rille A (after [2]). Note the wrinkle ridge near the western edge of the rille. Image width is 3.6 km.

there may be two layers of material present in many domes: a thinner, darker upper surface covering a brighter, thicker material. This thin upper layer could be a quenched, glassy surface veneer with brighter materials beneath [e.g., 13]; however, more LROC NAC images are needed to test this hypothesis and determine its extent in the MH region as a whole. Alternatively, this thin upper layer might be explained by pyroclastic eruptions with a high density of blocks, spatter-cone style eruptions, or a surface coating of pyroclastic material that mantles otherwise higher reflectance materials. The relatively smooth surface and low albedo of some regions, such as the breached cone-shaped feature in Fig. 2, could be a dark mantling of pyroclastic materials on the surface. Our ongoing study will test these possibilities.

Future Work: Future work will include analysis of additional high-resolution NAC images and derived stereo photoclinometric products. LROC DTMs controlled to the LOLA basemap will enable detailed volcanic modeling as necessary to further investigate the morphology and rheology of these and other mare domes, as well as comparisons to non-mare domes [14]. NAC images will be coordinated with WAC multispectral data to measure color variations and provide compositional insights into the volcanic features in MH.

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