**PROVENANCE OF BOULDERS ALONG LUNAR WRINKLE RIDGES.** R. A. French[1], D. M. Jurdy[1], M. S. Robinson[2], and T. R. Watters[3], [1]Dept. of Earth and Planetary Sciences, Northwestern University, Evanston, IL, 60208 (renee@earth.northwestern.edu); [2]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85287; [3]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington D.C., 20013.

**Introduction:** Boulders and relatively high reflectance material (typically 5-10% higher but can be as high as ~20%) are observed in patches along the slopes of many wrinkle ridges. Patch sizes vary from ~10 m to a few hundred meters in the short dimension and can be anywhere from 10 m to a couple km in the long dimension. A 2009 Lunar Reconnaissance Orbiter Camera (LROC) Featured Image [1] documented these for the first time as a consequence of higher-resolution imagery with various lighting conditions and improved coverage. Since then, such boulders have been found along most mare wrinkle ridges in a region, but not along the entirety of a ridge (Fig. 1).

Boulders on the lunar surface signify cohesive material that was either ejected by a cratering event or exposed through erosional processes [2]. The high reflectance material typically found with wrinkle ridge boulders (WRB) likely represents either freshly exposed rock and soil [3] or less mafic material. However, with no compelling reason to suspect a compositional difference our preferred interpretation is a simple maturity difference.

We consider three competing hypotheses for the formation of WRB fields: the boulders and high reflectance material (1) originated elsewhere and were transported to their current location (e.g., impact ejecta), (2) were present before deformation and ridge formation, or (3) are disrupted bedrock being exposed and eroded.

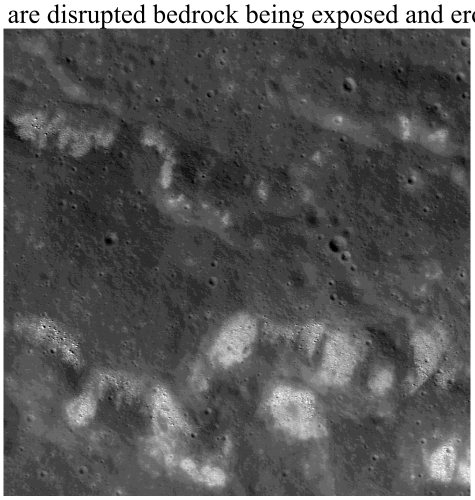

*Figure 1*: Boulders and high reflectance material (bright patches) along a wrinkle ridge in western Mare Serenitatis. Image is ~1.5 km across, LROC NAC frame M106826896LE.

**Method:** LROC Quickmap was used for visual classification of wrinkle ridges (i.e., bouldered, non-bouldered, or unknown) and were mapped using ArcGIS. Ridges were classified as 'unknown' if there was not adequate high-resolution imagery or preferred lighting conditions to determine the presence of boulders and/or high reflectance material. LROC NAC images were processed using the Integrated System for Imagers and Spectrometers (ISIS) [4] and elevation data was obtained from NAC stereo pairs using SOCET SET (average precision error of 4.34 m). Elevations (point spacing of 5 m) were converted to slope estimates using the *Slope* tool in ArcMap.

**Observations:** Of the 65 mapped wrinkle ridge segments examined in Mare Serenitatis (Fig. 2), 57 have boulders exposed on their slopes (red), 11 segments (4 partial) do not have boulders (green), and 7 (6 partial segments) are unknown/unclassified (yellow). Non-bouldered ridges appear to be roughly evenly distributed throughout the entire basin. We also examined wrinkle ridges in Maria Cognitum, Crisium, Fecunditatis, Humorum, Nubium, Oceanus Procellarum, and Tranquillitatis and created similar maps. All of the listed regions are rich in WRB.

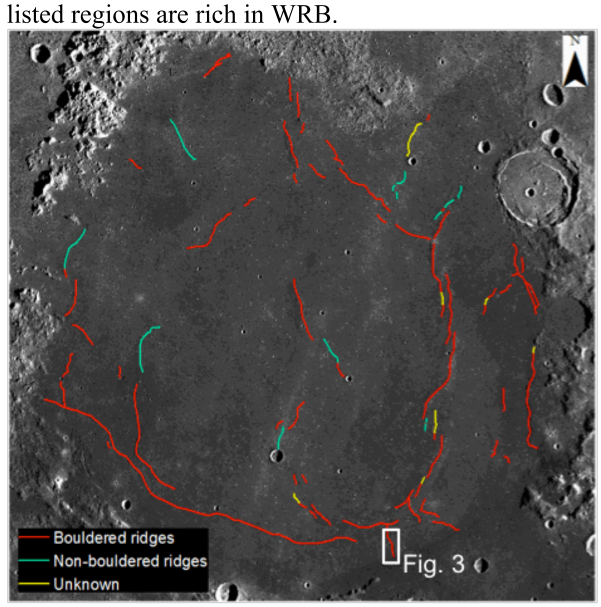


*Figure 2:* Wrinkle ridge classification and distribution map of Mare Serenitatis. Red denotes ridges with boulders; green do not have boulders; yellow are unknown/unclassified.

Detailed topographic analysis was undertaken for two WRB ridges: Dorsum Nicol in southern Mare Serenitatis (Fig. 3) and an unnamed ridge in eastern Mare Tranquillitatis. Comparing slope maps with corresponding NAC images yields a few key observations: (1) the highest abundance of boulders occurs along the part of the ridge with the greatest slopes (20-30°), (2) boulders are definitely exposed along slopes ≥15°, (3) boulders are commonly exposed along slopes between 10 and 15°, and (4) boulders are rarely exposed on slopes between 5 and 10°. Boulders and high reflectance material are not observed on flat (<5° slope) surfaces.

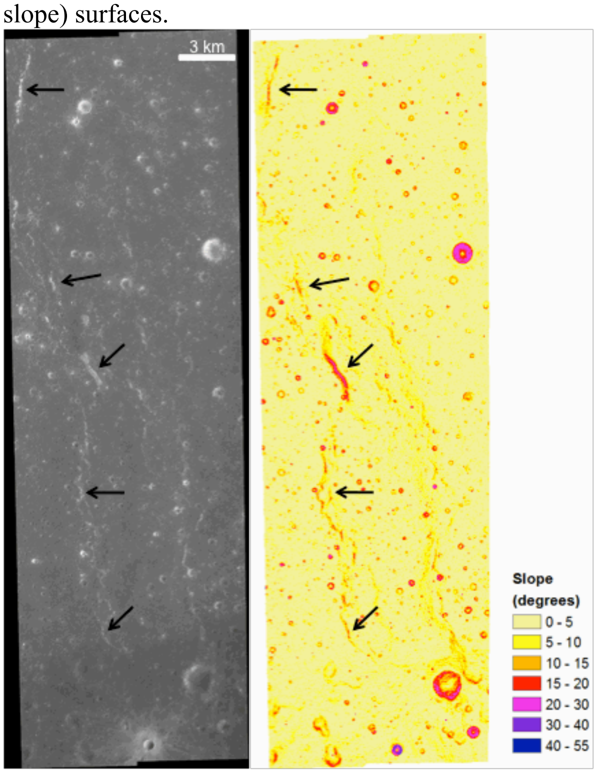


*Figure 3:* LROC NAC M1105773947 (left) and slope map (right) of the Dorsum Nicol ridge in southern Mare Serenitatis (see inset in Fig. 2 for location). Arrows point to areas of notable boulder outcrops and corresponding slope.

**Discussion:** The correlation between the location of boulder outcrops and areas of steep slope on a wrinke ridge allow two formation hypotheses to likely be ruled out. Hypothesis 1 (transport) would suggest either isolated pockets of boulders traceable to a crater or a continual ray of boulders; neither is observed. We would not expect to see a strong correlation with ridge slope or outcrops that follow the trace of the wrinkle ridge. Hypothesis 2 (present before formation) would not suggest a preferential location along wrinkle ridges and boulders should be observed elsewhere in the maria.

Preliminary observations suggest that WRB and associated high reflectance material along mare wrinkle ridges are formed as a consequence of down-slope movement of material on steeper slopes. Down-slope movement could be related to seismic activity from impacts and recent tectonic activity [5, 6]. So far, there are no apparent rock ledges that could be attributed to boulder sources.

**Outlook:** Comparison of boulder locations and density with slope and ridge morphology may provide constraints on regolith and basalt layer (upper layers) thicknesses across the maria. Maximum boulder height constrains maximum layer thickness and thin layers will deform and break for smaller slopes much more readily than thick layers of the same material. Additionally, boulder sizes and the minimum slope angle at which we begin to see boulder outcrops may provide insight into material strength.

If the boulders and high albedo material are due to recent erosion of the ridge, as suggested by observations presented here, these areas would make good targets for future sample return missions.

**Summary**: Wrinkle ridge boulders (WRB) and associated high reflectance material have been observed throughout the maria along wrinkle ridges. Comparisons of NAC imagery with corresponding slope maps indicate that WRB are preferentially exposed along wrinkle ridge slopes >10°, likely originating as a result of down-slope movement. Seismic activity from impacts and recent tectonic activity could be a mechanism for this movement.

**References:** [1] Lawrence, S. (2009). *LROC Featured Image 12/29/2009*. [2] Ostrach, L. R. (2011) *LROC Featured Image 03/24/2011*. [3] Matson, D. L., et al. (1977). *Proc. 8th Lunar Science Conference*, 1001-1011. [4] Anderson J. A., et al. (2004) LPSC XXXV, Abstract #2039. [5] Watters, T. R., et al. (2010). *Science*, 329, 936-940. [6] Watters, T. R., et al. (2012). *Nature Geosci*., advanced online pub.