**LUNAR BOULDER FIELDS AS AN INDICATOR OF RECENT TECTONIC ACTIVITY.** C. A. Nypaver[1], B. J. Thomson[1], T. R. Watters[2], C. M. Elder[3], J. T. Cahill[4], J. D. Clark[5], S. L. Pérez-Cortés[6], A. M. Bramson[6]. [1]The University of Tennessee, Knoxville (cnypaver@vols.utk.edu). [2]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC. [3]Jet Propulsion Laboratory, California Institute of Technology. [4]JHU Applied Physics Laboratory, Laurel, MD. [5] School of Earth and Space Exploration, Arizona State University. [6]Purdue University, West Lafayette, IN.

**Introduction:** The Moon's complex deformational history has resulted in the formation of numerous tectonic surface features [e.g., 1]. Wrinkle ridges are one such class of tectonic features that has primarily resulted from load-induced subsidence and flexure in an isostatic response of the lunar lithosphere to the emplacement of the nearside lunar basalts [e.g., 2]. However, a newly identified population of lunar wrinkle ridges has been inferred to be reactivated by residual, antipodal stresses from the SPA impact event [3]. These wrinkle ridges exhibit fields of meter-scale boulders on their scarps and were thus inferred to be recently active based on the lifetime of meter-scale lunar boulders (~300 Ma, [4]). Such an interpretation is supported by past work indicating that wrinkle ridge boulder fields are primarily controlled by slope, regionality, and recent tectonic activity [5].

A more recent study separately identified a new population of small (~0.05–0.5 km-wide) lunar wrinkle ridges deemed recently active based on their crisp morphologies and cross-cutting relationships with other lunar surface features [6]. The small, recently active wrinkle ridges in that investigation (hereafter referred to as NT2022) were generally observed to lack boulders on their scarps and topographic crests, despite their cross-cutting small impact craters. Hence, the use of boulder fields as definitive indicators of recent tectonic activity on the Moon remains unclear. The objective of the work presented here is to quantify the presence and cause of boulder fields on small, recently active lunar wrinkle ridges – thereby determining the value of boulder fields as markers of recent tectonic activity.

**Methods:** In the work presented here, we analyze the full database of 1,149 small, recently active ridges from NT2022. These small wrinkle ridges are generally narrow (~0.05–0.5 km) in width, <60 km in length, and are clustered in discrete, dendritic networks. We utilize the Diviner rock abundance (RA) dataset [7] to measure boulder populations over the aforementioned ridge systems. Rock abundance represents the percentage of the lunar surface covered by meter-scale rocks and is derived by assuming a two-component model of rocks and regolith to explain the observed lunar nighttime surface anisothermality [7].

Discrete 600-m-wide polygon buffers were built along the topographic crest of each ridge from the NT2022 database using the ArcGIS buffer tool. The ArcGIS zonal statistics tool was used to extract median RA values under each primary ridge buffer. The median values were weighted by the area of each RA pixel covered by the ridge buffers using a 10m sampling grid under each buffer polygon. Areas of wrinkle ridge/impact crater interaction were excluded from the data collection buffers to mitigate the influence of rocky crater interiors and ejecta on measured RA values. The RA values corresponding to each wrinkle ridge segment were compared to the surface unit age [8] and Diviner H-parameter [9] in the region immediately surrounding each wrinkle ridge. The H-parameter data are sensitive to the density (pore space and small rock content) of the upper layers of lunar regolith. The age and H-parameter data were collected using terrain buffers extending to 1.3 km beyond the primary ridge crest, excluding the RA collection buffer zone (0–300 m from the ridge crest).

**Results:** All recently active wrinkle ridges measured here exhibited RA medians <0.07. Of the 1,149 ridge segments measured, 13.9% of the ridges exhibited RA medians >0.01, 55.3% of ridges were >0.005, and 94.9% of ridges were >0.002. The wrinkle ridges exhibiting the highest 5% RA are primarily concentrated in S. Mare Procellarum, Mare Tranquillitatis, Mare Humorum, and Mare Cognitum. Ridges with the lowest 5% RA are concentrated in Mare Imbrium (**Fig. 1a**). Loose correlations exist between wrinkle ridge RA values and surface age (**Fig. 1b**) and Diviner H-parameter data (**Fig. 1c**) of the surrounding terrain.

**Discussion:** The RA values reported for the wrinkle ridges studied here indicate that not all recently active wrinkle ridges exhibit dense boulder fields, and some recently active ridges may be devoid of boulders all together. Such an observation is contradictory to the prior understanding that the presence of boulder fields indicates recent tectonic activity or shifting of the host ridge [3, 5]. There are two potential explanations for the low RA values observed here. First, the slopes and magnitude of seismic shaking associated with small wrinkle ridge formation/activation may be insufficient to cause the same degree of boulder exhumation present at larger ridges. Alternatively, the presence of boulder fields on a wrinkle ridge may not be indicative of recent tectonic activity and instead may be caused by some other aspect of the underlying or surrounding geology.

A loose correlation with surface age (**Fig. 1b**) indicates that recently reactivated wrinkle ridges on younger surfaces have a higher propensity for surface boulders. This relationship with surface age could result from the thinner and less mature (higher rock content) regolith commonly associated with younger surfaces, but further work is necessary to confirm that interpretation. The inverse correlation between ridge RA and the H-parameter of the surrounding terrain (**Fig. 1c**) indicates that ridges with enhanced boulder populations occur in regions with decreased pore space or enhanced small rock content in the upper regolith layers. However, such a correlation with regolith density may also just be an inherent attribute of the younger surfaces that host high RA ridges [9].

**Conclusions:** In this work, we measured Diviner rock abundance values for 1,149 small, recently active ridges on the lunar mare and compared those RA values with various geologic attributes of the surrounding terrain. Our results indicate that >50% of small, recently active wrinkle ridges within the lunar mare exhibit areal rock fractions that are equal to or lower than the background maria terrain. And alternatively, those wrinkle ridges that do exhibit boulder fields appear to be loosely correlated with surface age. These results indicate that the presence of wrinkle ridge boulder fields may instead be either heavily dependent upon the scale of tectonic activity or controlled by some age-dependent regolith characteristic.

**Future work:** Given the scale discrepancy between Diviner RA pixel resolution and many of the wrinkle ridges studies here**,** a quantitative comparison of wrinkle ridge boulder fields in Diviner RA and LROC NAC data is necessary to validate the results presented in this work. Quantitative metrics representing slope, regolith thickness, and rock content are necessary to provide a complete understanding of wrinkle ridge boulder field formation. The latter will be measured using ground-based P-band radar data and X-band bistatic radar data from the Mini-RF instrument onboard LRO. Regolith thickness will be assessed via the morphology of small craters that are local to the ridge in question, and a slope comparison will be derived using LOLA+SELENE Kaguya DEM elevation data [11].

**References:** [1] Watters, T. R., & Schultz, R. A. (2010). Planetary tectonics (Vol. 11). *Cambridge Univ. Press*. [2] Melosh H. J. (1978) *PLPSC, 9*, 3513–3525. [3] Valantinas A. and Schultz P. (2020) *Geology, 48(7),* 649–653. [4] Basilevsky A. T. et al. (2013) *PSS, 89,* 118–126. [5] French R. A. et al., (2019). *JGR, 124(11),* 2970–2982. [6] Nypaver C. A., and Thomson B. J. (2022). *GRL, 49(17).* [7] Bandfield J. L. et al. (2011) *JGR, 116(E12).* [8] Hiesinger H. et al. (2011) *GSA special paper, 477,* 1–51. [9] Hayne P. O. et al. (2017) *JGR, 122(12)*, 2371–2400. [10] Lemelin M. et al. (2015) *JGR, 120(5)*, 869–887. [11] Barker, M. K., et al. (2016) *Icarus, 273,* 346-355.

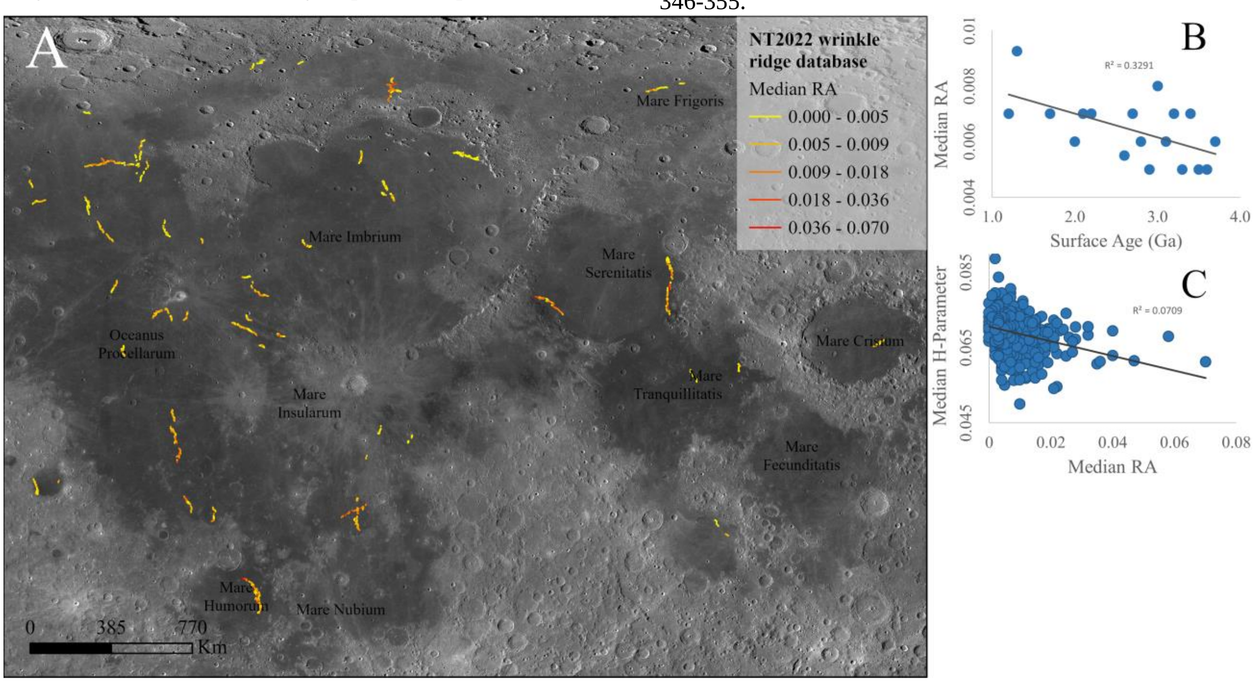


**Figure 1: (a)** NT2022 wrinkle ridge database [6] colorized by median rock abundance value overlaid onto an LROC WAC global monochrome mosaic (~100 m/px). **(b)** Median wrinkle ridge rock abundance [7] as a function of increasing surface age of the surrounding terrain [8]. **(c)** Median H-parameter [9] of the region surrounding each wrinkle ridge as a function of increasing RA value of the corresponding ridge.