NEW OBSERVATIONS OF RECENTLY ACTIVE WRINKLE RIDGES IN THE LUNAR MARE: IMPLICATIONS FOR THE TIMING AND ORIGIN OF LUNAR TECTONICS. C. A. Nypaver[1], B. J. Thomson[1], and C. I. Fassett[2]. [1]Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996 (cnypaver@vols.utk.edu). [2] NASA Marshall Spaceflight Center, Huntsville, AL 35808.

Introduction: The onset of lunar wrinkle ridge formation is spatially and temporally correlated with the cooling of the lunar maria and the subsequent mascon loading of the lunar surface (e.g., [1]). The degree to which tectonic features remain currently active on the lunar surface remains a topic of ongoing research, however. The goal of the work presented here is to identify the extent and relative timing of recently active tectonic features in the lunar maria.

From 1972–1977, the Apollo seismic experiments recorded 28 shallow moonquakes that have been interpreted as likely resulting from recent tectonic movement in the lunar lithosphere [2]. Subsequent to those seismic experiments, several studies were successful in using high resolution LROC NAC images to identify scarps on the lunar surface as the likely origins of the recorded shallow moonquakes (e.g., [3–4]). The use of high resolution LROC NAC images has also allowed researchers to identify several lunar wrinkle ridges on the lunar maria that crosscut small (>10 m) impact craters, indicating recent (<10 Ma) movement of those wrinkle ridges [5–6]. Both [5] and [6] identified several recently active wrinkle ridges in Mare Imbrium and Mare Frigoris and suggested that regional stress mechanisms may differ from global patterns in those areas. Those studies were limited in the size of their respective study areas, however. In the preliminary work presented here, we build on the work of [5–6] by identifying several regions of the nearside lunar mare where wrinkle ridges appear to be very recently or currently active based on their morphologies and cross cutting relations with other lunar surface features.

Methods: For this work, we use LROC NAC images (~0.5-2m/px) to map impact craters in the diameter range of ~10m–3km on the lunar maria that have been tectonically deformed (cross-cut) by wrinkle ridges. The mapping was done in the LROC QuickMap web interface [7], and was thus limited to the LROC NAC data that is currently available through that interface. In QuickMap, we manually examined 11,476 wrinkle ridges on the lunar maria that were mapped in a prior study [8], and we flagged each impact crater that had been crosscut by one of those wrinkle ridges. The resulting crater center points were then imported into ESRI's ArcGIS Pro and a kernel density map was created from the resulting shapefile of crosscut craters.

Results: In our mapping, we identified 2,277 impact craters on the lunar maria that have been deformed by wrinkle ridges in some way (**Fig. 1A**). Of the 11,476 wrinkle ridges examined in this work, the majority of the crater deformation occurred at fewer than 15 wrinkle ridge systems, but those crater-deforming wrinkle ridges were present in nearly every nearside mare basin. The ~15 wrinkle ridge systems that crosscut the most craters exhibited narrow, sinuous morphologies (**Fig 1B-D)** – similar to the wrinkle ridges described in [8]. Dense populations of tectonically deformed impact craters in the lunar maria can often be traced back to individual wrinkle ridge systems that display this narrow, sinuous morphology. Larger wrinkle ridges with less distinct crests and muted morphologies deform far fewer impact craters. Hence, we observe a non-uniform distribution of wrinkle ridge morphology and deformation history in the lunar nearside mare basins. Most wrinkle ridges exhibit increased heights and widths with somewhat muted morphologies, but a small percentage of the ridges display sinuous, crisp morphologies. Those narrow, sinuous ridges also deform the majority of the craters accounted for in this work.

Discussion: The non-uniform distribution of wrinkle ridge morphologies and tectonically deformed impact craters on the lunar maria indicates that some areas of the nearside lunar have been more recently active than others. Using our crater deformation density map, we can identify ~15 young wrinkle ridge systems that display the aforementioned crisp morphologies and dense crater crosscutting properties.

Given that decameter-scale lunar surface features become topographically muted relatively quickly due to meteoroid bombardment and regolith overturn, the narrow widths (~10–50 m) and crisp morphologies of the deformation-causing ridges observed is further evidence for their recent formation (e.g., [9–10]). Operating under the assumption that the most recently active wrinkle ridges have crosscut the most impact craters, the areas in the lunar maria which demonstrate the most recent tectonic activity are S. and E. Mare Procellarum, Mare Humorum, N. Mare Imbirum, NE Mare Serenitatus, and Mare Frigoris.

Conclusions: By mapping tectonically deformed craters within the nearside lunar maria, we have created a map of relative wrinkle ridge age and identified the most recently active areas of lunar tectonism in the nearside lunar mare. A non-uniform distribution of wrinkle ridge age and crater deformation history indicates that the stress mechanisms acting on this area of the lunar surface have been neither constant nor of similar magnitudes throughout lunar history. Our results support the Lu et al. [6] hypothesis that late-stage mare cooling is a potential mechanism for recent wrinkle ridge formation locally in several lunar mare basins. The idea of late stage cooling and contraction of some nearside mare basins is also corroborated by the non-KREEP bearing samples recently obtained by the Chang'e 5 mission, which necessitate prolonged cooling and volcanism to explain their relatively young (~2.0 Ga) crystallization age [11]. Our preliminary results highlight the need for more quantitative metrics of wrinkle ridge age and offset. Future work on this project will be focused on conducting buffered crater counts over the recently active wrinkle ridges presented here to establish their absolute model ages.

References: [1] Melosh H. J. (1978) *PLPSC*, *9*, 35153525. [2] Nakamura Y. et al. (1979) *PLPSC*, *10*, 2299–2309. [3] Watters T. R. et al. (2012) *Nature Geosci.*, *5*, 181–185. [4] Watters T. R. et al. (2019) *Nature Geosci.*, *12*, 411–417. [5] Williams N. R. et al. (2019) *Icarus*, *326*, 151–161. [6] Lu Y. et al., (2019) *Icarus*, *329*, 24–33. [7] https://quickmap.lroc.asu.edu [8] Thompson T. J. et al. (2017) *LPS*, 48, abstract #2665. [9] Fassett C. I. and Thomson B. J. (2014) *JGR*, *119*, 2255–2271. [10] Speyerer E. J. et al., (2016) *Nature*, *538*, 215–218. [11] Tian H. C. et al., (2021) *Nature*, *600*, 59–63.

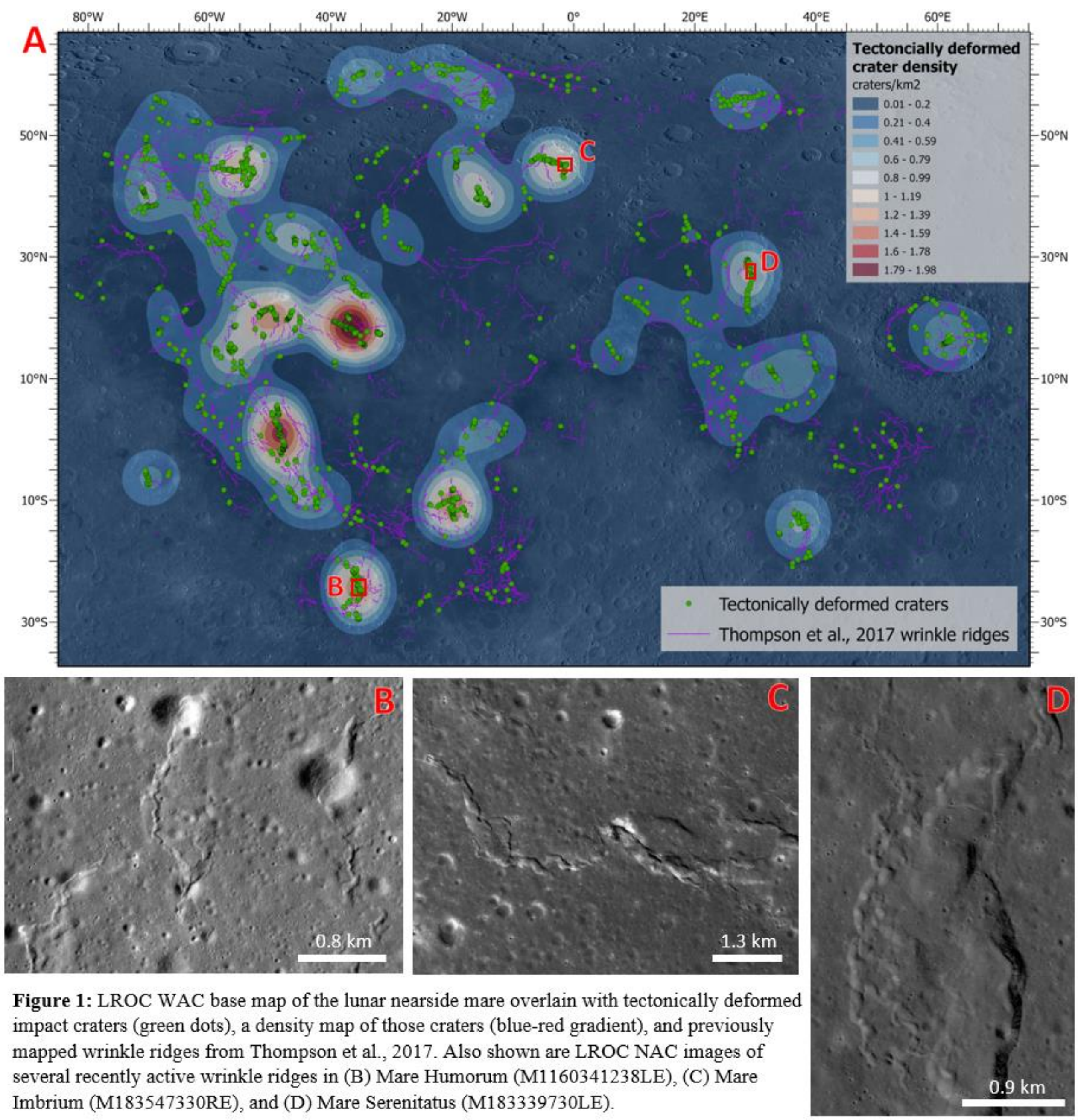

Figure 1: LROC WAC base map of the lunar nearside mare overlain with tectonically deformed impact craters (green dots), a density map of those craters (blue-red gradient), and previously mapped wrinkle ridges from Thompson et al., 2017. Also shown are LROC NAC images of several recently active wrinkle ridges in (B) Mare Humorum (M1160341238LE), (C) Mare Imbrium (M183547330RE), and (D) Mare Serenitatus (M183339730LE).