ASSESSING THE TIMING OF A RECENTLY ACTIVE WRINKLE RIDGE ON THE LUNAR MARE.
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Introduction: Although Earth's Moon does not experience crustal recycling via plate tectonics, it is not tectonically inert. Understanding the nature and timing of tectonic features on the lunar surface remains the subject of active research [e.g., 1]. High-resolution images from the Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) have allowed past work to constrain the timing and scale of the most recent tectonic activity on the lunar surface [e.g., 2–3]. Much of this evidence for recent (<50 Ma) lunar tectonism has come in the form of absolute model age dates for small scale lobate scarps in the lunar highlands [4–5], or rates of infilling of shallow, small-scale graben associated with the scarps [3]. The orientations and spatial distribution of those lobate scarps indicates formation by orbital recession, global contraction, and solid body tides [e.g., 6].

Recently, several studies have identified a population of wrinkle ridges in the lunar mare that are similar to lobate scarps in both scale and morphology [7–8]. These features were estimated to be recently active due to their superposition over other lunar surface features. However, the variable morphology and complex distribution patterns of these small, recently active wrinkle ridges have prohibited the establishment of an absolute model age date for any such feature until now [9].

In the work presented here, we report the first absolute model age (AMA) date for an isolated, recently active wrinkle ridge on the lunar mare using buffered crater counting methods. In doing so, we provide a standard procedure for age dating similar, morphologically complex, pseudo-linear features on the lunar surface. The AMA provided for the wrinkle ridge in this work allows for a more quantitatively complete comparison of wrinkle ridge and lobate scarp formation timing and mechanics

Data and Methods: The wrinkle ridge chosen for analysis in this work is located in Eastern Mare Procellarum (18.72°N, 321.76436°E). The ridge is ~450 km in length and <18 km in width with small, <100 m-wide tertiary ridges that branch off from primary ridge structure (Fig. 1a). This specific ridge is one of many mapped in a prior investigation and considered recently active based on cross-cutting relationships with surrounding lunar surface features [8]. This ridge was noted to have caused enhanced surface deformation relative to the other features mapped in that work.

A total of 42 high incidence angle (60–75°) LROC NAC images (~2.0 m/px) were downloaded and processed for our analysis using the Integrated Software for Imagers and Spectrometers (ISIS3). Those images were then map-projected and mosaiced in ESRI's ArcMap 10.8. The ArcMap CraterTools plugin [9] was used to define count areas and superposing craters along the scarp of the ridge.

Buffered crater counts were conducted over two separate south-facing scarps of the ridge. The count areas were defined and bounded by the topographic transition points at the head and toe of the scarp (i.e., the boundaries between the steeply-sloping scarp and the surrounding, flat-lying terrain). The craters included in the counts superposed either the head of the scarp, the toe of the scarp, or both. Craters on the face of the scarp and within the defined scarp boundaries were also included in the count under the assumption that any seismic shaking associated with fault movement would have erased pre-existing craters. Once all craters were marked and area polygons were established for each scarp, the CraterTools buffered crater count option was used to export the respective .scc files into the IDL-based CraterStats software package, where cumulative size-frequency distribution plots were produced for the individual count areas using the Neukum et al. [10] production function.

Results: Buffered crater counts were conducted over two separate sections of the south-facing ridge scarp. The first count area was located at the SE tip of the ridge covering 1.57 km^2 with a count of 279 superposing craters (D >0.003 km; **Fig. 1b**). The second count area was located over the NE portion of the ridge covering 59.8 km^2 with 132 craters (D >0.003 km) (**Fig. 1c**). The best-fit isochrons for both of the scarp SFD plots yielded AMAs of ~8.0 $Ma^{+3.0Ma/-5.0Ma}$ for each count area (**Fig. 2**).

Discussion: Until now, buffered crater counting methods have only been applied to lobate scarps in the lunar highlands and large, km-scale wrinkle ridges in the lunar maria [4–5, 11]. Our work provides the first AMA for a small, recently active wrinkle ridge on the lunar maria. This derived age indicates that the wrinkle ridge analyzed here is among the most recently active tectonic features on the lunar surface. Given that prior work has identified and mapped a maria-wide population of small-scale wrinkle ridges that are similar in morphology and size to the one investigated in here [8], it is reasonable to expect that those wrinkle ridges would exhibit age dates of the most recent activity that are similar to the one presented here.

The geologic relationship between lunar wrinkle ridges and lobate scarps is the subject of ongoing research. Prior work cited the spatial distribution and overall orientations of small lunar wrinkle ridges as evidence that the stress mechanisms responsible for lobate scarps in the lunar highlands may also contribute to the reactivation and formation of small wrinkle ridges [8]. In comparing the absolute model age estimated here with previously published ages on lobate scarps, we find temporal similarity between the two tectonic feature classes. The work presented here therefore adds to the body of evidence supporting the hypothesis of a temporal and mechanical relationship between lobate scarps and small lunar wrinkle ridges.

Conclusions: In this work, we use buffered crater counting methods to provide the first AMA for a recently active lunar wrinkle ridge in E. Mare Procellarum. The size-frequency distribution of impact craters superposing the ridge scarp provides an age of ~8.0 Ma$^{+3.0 Ma/-5.0 Ma}$. This age is interpreted to represent the cessation of the most recent activity associated with the ridge. This age is also similar to those derived for lobate scarp ages in past work. Such a similarity indicates that the compressional stresses responsible for lobate scarp formation may also be responsible for the formation of small wrinkle ridges on the nearside lunar maria. However, further age dating as well as dislocation modeling and detailed mapping of small, recently active wrinkle ridges on the lunar maria is necessary to fully decipher the relationship between these two tectonic feature classes.

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References: [1] Watters T.R. and Schultz R.A. (2010) *Planetary Tectonics,* Cambridge UP. [2] Watters T.R. and Johnson C. (2009) in *Planetary Tectonics,* 121–182. [3] Watters T.R. et al. (2010) *Science, 329,* 936–940. [3] Watters T.R. et al. (2012) *Nature Geosci., 5,* 181–185. [4] van der Bogert C. et al. (2018) *Icarus 306,* 225–242. [5] Clark J. et al. (2017) *Icarus, 298,* 78–88. [6] Watters T.R. et al. (2019) *Nature Geosci., 12,* 411–417 [7] Williams N.R. et al. (2019) *Icarus, 326,* 151–161 [8] Nypaver C.A. and Thomson B.J. (2022) *GRL, 49*(17). [9] Kneissl T. et al. (2011). *PSS, 59*(11-12), 1243–1254. [10] Neukum G. et al. (2001) in *Chronology and evolution of Mars*, 55–86, Springer, Dordrecht. [11] Yue Z. et al. (2015) *JGR Planets, 120, 978*–994.

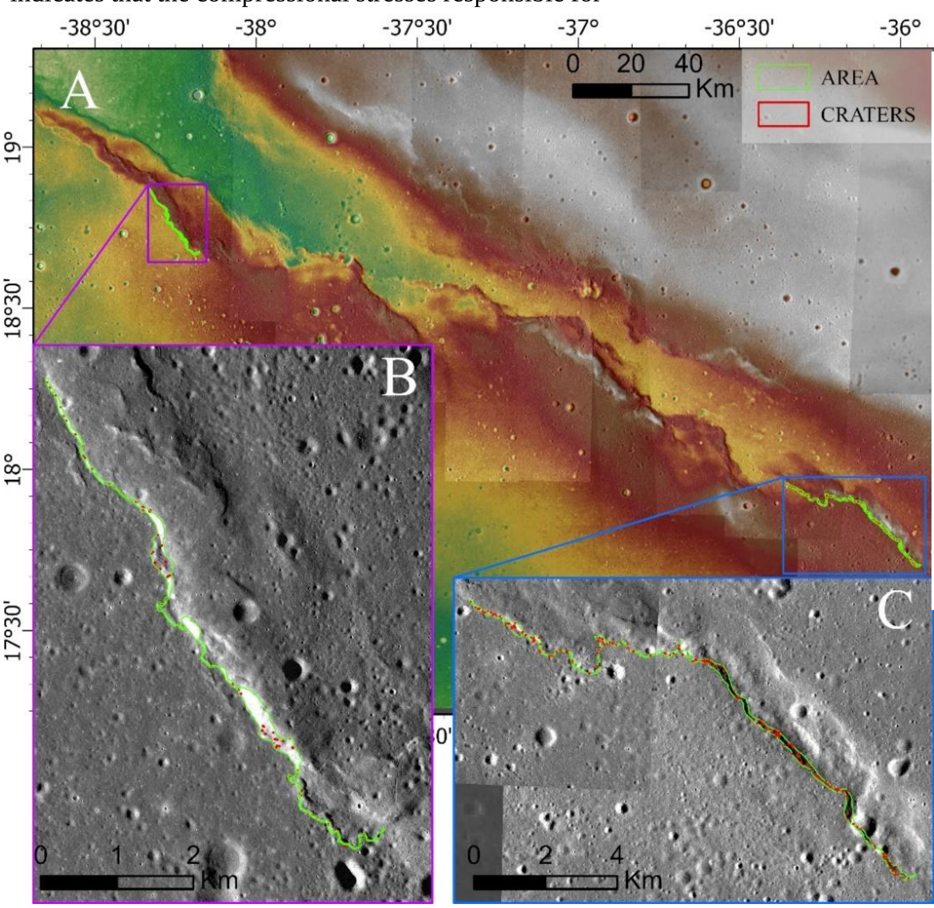

Figure 2: (**A**) LROC NAC mosaic of the wrinkle ridge first identified in [8] and analyzed here overlain by LOLA SLEDM elevation data green-yellow tones indicate lower elevation and red-white tones indicate higher elevation. (**B**) NW and (**C**) SE buffered crater count area and crater polygons overlain onto the LROC NAC mosaic created for this work.

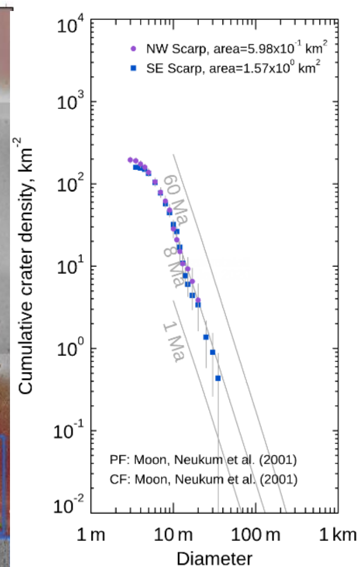

Figure 1: Cumulative SFD plot of the NW (purple circles) and SE (blue squares) scarp buffered crater counts. 60 Ma, 8 Ma, and 1 Ma isochrons plotted for reference.