A METHODOLOGY FOR DETERMINING ABSOLUTE MODEL AGES FOR RECENTLY ACTIVE LUNAR WRINKLE RIDGES. J. D. Clark1, C. A. Nypaver2, D. J. Sparks3, C. H. van der Bogert4, T. Frueh4; T.R. Watters2, H. Bernhardt1, M. E. Banks3, 1Department of Geology, University of Maryland, College Park, MD, USA (jdclark@umd.edu), 2Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC, USA, 3Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN, USA, 4Institut für Planetologie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany, 5NASA Goddard Space Flight Center, Greenbelt, MD, USA

Introduction: The onset of wrinkle ridge formation within the lunar maria is estimated to have begun shortly after and/or concurrent with basalt emplacement [e.g., 1–3]. The kinematics and timing of early lunar wrinkle ridge formation are well constrained [e.g., 2–4], but recently formed tectonic structures (< 1.5 Ga) on the maria are less well understood. Recent work has identified numerous wrinkle ridges on the nearside maria inferred to be recently active based on their cross-cutting relationships with decameter-scale impact craters and undegraded morphologies, and association with small meter-scaled graben [5–7]. However, unlike larger ridges or young lobate scarps in the lunar highlands [e.g., 8–9], robust and consistent methods for absolute model age (AMA) determination have yet to be established for these more recently active ridges.

In the work presented here, we build on prior age determination studies for young tectonic structures on the Moon [8–10] by conducting traditional crater counts over a recently active wrinkle ridge in eastern Mare Procellarum (18.80°N, 38.19°W). The goal of this work is to test and refine age dating methods for tectonic structures for the maria. Specifically, we apply age-determination methods used for lobate scarps in the lunar highlands for use with small, recently active wrinkle ridges. By doing so, our work strives to provide a baseline methodology for deriving AMAs for young wrinkle ridges.

Methods: Our initial study focuses on a 35 km long wrinkle ridge segment in eastern Mare Procellarum that hosts several tertiary ridges splitting away from or superposed on the primary ridge structure. We use high-resolution (2.0–5.0 m/pixel) images from the Lunar Reconnaissance Orbiter Camera (LROC) with high solar incidence angles (55–80°) for our crater size-frequency distribution (CSFD) measurements. Individual NAC images were calibrated and georeferenced in the Integrated System for Imagers and Spectrometers: Version 3 (ISIS3) and mosaiced in ArcGIS Pro. The CSFD measurements were done in ArcMap 10.6 using CraterTools [11] and/or QGIS using OpenCraterTool [12], and then exported to Craterstats for plotting and fitting [13]. Using the techniques outlined by [14], the derived AMAs are based on the production and chronology functions of [15] valid for lunar craters >10 m and <100 km in diameter.

Similar to [8–10], we implemented multiple techniques to determine ages for recent coseismic slip events at the wrinkle ridge in Mare Procellarum. Count areas were defined on relatively flat (<10°) portions of the broad wrinkle ridge arch. We also defined areas on the mare floor along strike from the wrinkle ridge for comparison. Clementine Color-Ratio images were used to locate and omit Aristarchus Color-Ratio impact secondary craters from our count areas [16].

Results and Discussion: Traditional CSFD measurements on the broad 5 km wide arch of the wrinkle ridge gives an age of ~1.4 Ga (Fig. 1). The adjacent mare units range in age from 1.2 Ga, 1.8 Ga, 2.1 Ga, and 3.5 Ga, based on the investigation by [17] and therefore, it is likely that this age reflects the age of the mare basalt unit that the ridge crosses.

![Figure 1: Overview of the NW-SE striking wrinkle ridge analyzed in this work. The yellow polygon is the count area used to derive an AMA of ~1.4 Ga (LROC NAC M127800942LE, M1295650427LE).](image)

Past work used the Buffered Crater Counting (BCC) [18] method on the crisp southwestern wrinkle ridge segment (see also Fig. 2) to derive an AMA of ~8 Ma [10]. Unfortunately, this can only be considered as a minimum age, because of significant slopes along parts of the measurement trace. However, other approaches for age determination can give clues about the reliability of the derived AMA. The southwestern ridge crosscuts several small, decameter-scale craters, for example, a ~15-m diameter crater at 38.25°W 18.74°N (Fig. 2c). Prior models of lunar impact crater lifetimes indicate that a 15-m impact crater on the lunar surface has a maximum lifetime of ~37.5 Ma [19], although non-tectonic, gravity-driven mass wasting might have...
contributed to the ridge’s progression and partial burying of craters. Furthermore, 1–10 m-wide graben are present at numerous locations along the topographic crest of the wrinkle ridge in question (Fig. 2B). Meter-scale topographic features, such as those graben observed here, are also short-lived (~<500 Ma) on the lunar surface due to regolith turnover and infilling from micrometeoroid bombardment, and distal ejecta deposition [20–21]. Based on our derived AMAs and the small-scale topographic features observed in association with the ridge in question, we interpret this ridge to have undergone reactivation as recently as ~8–105 Ma.

The AMAs derived for the broad arch of the wrinkle ridge are consistent with the previously derived ages of the surrounding mare units - potentially indicating that this ridge has not undergone seismic resetting to the same degree as some lobate scarps in the lunar highlands [e.g., 8–9]. However, small crosscut craters and meter-scale graben associated with the ridge may indicate reactivation of some portion of the ridge-forming fault as recently as ~8.0–37.5 Ma. One possible explanation for this age discrepancy is decreased seismic energy release associated with the reactivation of an older wrinkle ridge in the lunar maria relative to the formation of a new lobate scarp in the lunar Highlands. As a result of the decreased energy release, the distance to which the peak ground acceleration and associated shaking resets the surrounding impact crater SFD may be confined to a region that is closer to the reactivated ridge fault. Alternatively, the differences in regolith properties between highlands and mare materials allow for differences in the transmission of seismic energy, and therefore the regolith mobility and seismic resetting during a fault slip event.

**Conclusions:** In this work, we investigate age constraints for a recently reactivated wrinkle ridge in eastern Mare Procellarum. Traditional CSFD methods over the broad arch of this wrinkle ridge give an AMA of ~1.4 Ga, but an analysis of small-scale surface features on and around this ridge may indicate that some portion of the ridge fault was reactivated as recently as ~8.0–37.5 Ma. These results support the notion that the CSFD spatially associated with this ridge has not been reset due to seismic-induced ground motion for craters >10 m in diameter. Such an observation indicates that either 1) wrinkle ridge reactivation events produce less seismic energy than lobate scarp fault slip events, or 2) the highlands regolith in which lobate scarps form has significantly different material properties compared to mare regolith. Future work will involve deriving AMAs using BCC methods at various regions along this and other apparently young lunar wrinkle ridges. A comparison of small, recently formed wrinkle ridges and larger reactivated ridges will also provide insights into the relative ground acceleration and seismic resetting associated with such events.

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**References:**