REASSESSMENT OF INDIVIDUAL LUNAR WRINKLE RIDGE AGES IN MARE TRANQUILLITATIS.

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Introduction and Background: Lunar wrinkle ridges are common topographic landforms in the mare basins [1,2] which are linear, sinuous, or occur concentric to the basin center [1-3]. They may braid and rejoin along strike [2] and typically consist of a broad arch and a superimposed sharper, irregular ridge [1], but their asymmetric morphology is highly variable [1,4-7]. Usually, the side where the ridge is located is steeper [4]. The broad arches reach 20 km in width, 300 km in length, and 0.5 km in relief, while the ridges usually show a width of 400 m and height of 200 m [5].

The formation of wrinkle ridges has been highly debated, including volcanic and tectonic origins [1,2]. However, the current consensus is that they form via tectonic processes [2,5-9]. The morphological relationship between basalt flows and wrinkle ridges [10] indicate a formation shortly after the basin filling [9-11]. Ridges studied by Fagin et al. (1978)[12] indicate ages between 3.8 and 2.5 Ga. Ono et al. (2009)[9] showed that wrinkle ridges formed after 2.84 Ga due to global cooling. The existence of wrinkle ridges younger than 1 Ga was proposed by [11,13-15]. A global survey of lunar wrinkle ridge formation times resulted in ages consistent with loading by basalt fill [16]. However, the derived buffered crater count (BCC) age of wrinkle ridges in Mare Tranquillitatis ($2.41^{+0.73}_{-0.90}$ Ga) is younger than the trend and has large error bars [16].

Here, we make crater size-frequency-distribution (CSFD) measurements of individual wrinkle ridges located in Mare Tranquillitatis, in order to investigate possible origins for their young ages.

Methods: We used Lunar Reconnaissance Orbiter (LROC) Wide Angle (WAC; 100 m/pixel) data for mapping and CSFD measurements. LROC Narrow Angle Camera (NAC; ~0.9 m/pixel) and Kaguya (SELENE) Terrain Camera (TC; 7.5 m/pixel) data with incidence angles of 60° – 80° were also used for local CSFD measurements. The CSFDs were measured in ArcGIS with CraterTools [17]. Absolute model ages (AMAs) were derived with CraterStats using Poisson timing analysis [18] and cumulative, differential and relative (R) plots. Counting areas were generated both at the wrinkle ridge arch and if possible near the wrinkle ridge for representative counts [19]. We selected relatively flat surfaces within a single geomorphological unit.

Results: Six measurements on TC images were made at a wrinkle ridge located east of Arago E crater (***Fig. 1***). Three of these count areas were located on the ridge arch (WRA 1-3). We measured representative counts (WRR – wrinkle ridge representative count) at the foot of two of the ridges (WRR 1 and WRR 2). Another reference area, WRD 1, is located in a depression in front of the wrinkle ridge. All CSFD measurements show knees characteristic of resurfacing events [20] (e.g., ***Fig. 2***).

AMAs measured with craters larger than 100 – 200 m in diameter on TC data are >900 Ma and <2.6 Ga. However, the derived ages show large errors and the isochrons do not always fit through all the data points (***Fig. 2***). Young ages derived from smaller crater diameters range from 55 to 620 Ma.

Also, two measurements on NAC images at a southern located ridge were made. There, the oldest measured ages were between 1.4 and 3.2 Ga, with young ages from 130 to 360 Ma.

The counting areas are necessarily small (4.4 km² on average) due to variable geomorphology and steep slopes, which is one of the reasons for the large error bars on the derived ages [21].

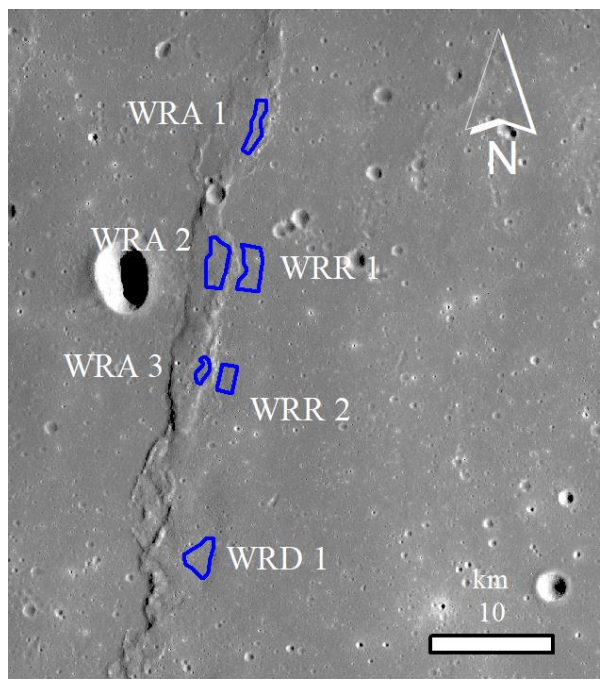

Figure 1. *CSFD measurement area locations on a wrinkle ridge in Mare Tranquillitatis near Arago E crater (22.7N, 8.5E) (TCO_MAPm04_N09E021N06E024SC).*

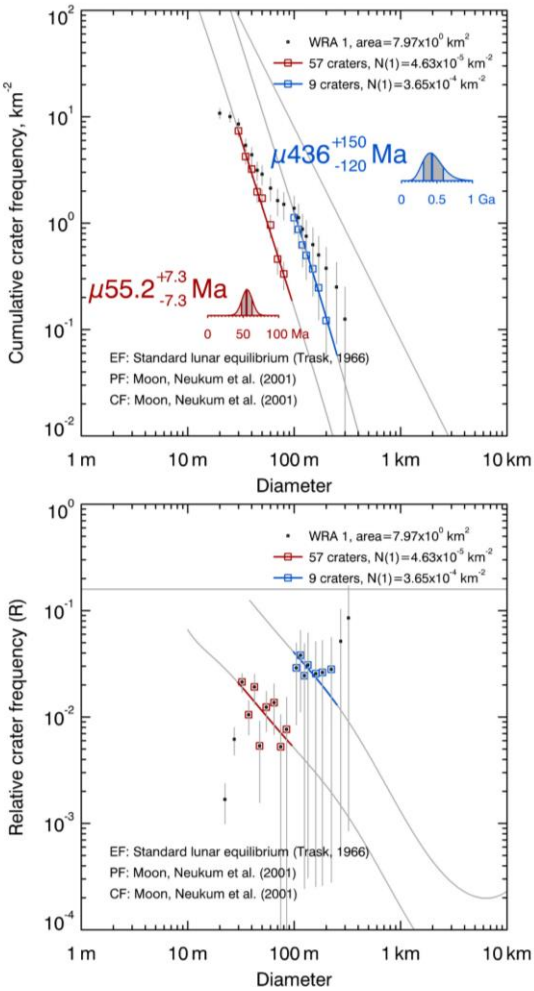

Figure 2. *CSFD measurement at the top of a flat arch section of a wrinkle ridge, WRA 1, in Mare Tranquillitatis (TCO_MAPm04_N09E021N06E024SC) plotted in cumulative and relative form with two possible resurfacing events and AMAs (red and blue).*

Discussion: New studies indicate young compressional tectonic activity on the Moon [14,15,16,19,22] and block fields along wrinkle ridges may result from recent seismic shaking due to wrinkle ridge activity [14,23,24]. Hence, absolute model ages derived from crater size-frequency-distributions measurements with smaller diameters, if correct, could be attributed to young tectonic activity. The variation of ages <620 Ma could result from unevenly spread activity. However, our data do not yet support this and further CSFD measurements have to be carried out. We focus on using NAC images because of the irregular arch morphologies and the resulting difficulty to identify craters.

The small quantity of superimposed craters and the need to distinguish between predating and postdating craters impede the BCC method (e.g., [19]). Therefore we used traditional CSFD measurements. Due to the need to include craters measured along the length of a wrinkle ridge, BCC measurements cannot be expected to give the exact age of an individual wrinkle ridge, rather an average age that reflects the average activity along the entire length of the ridge. Traditional CSFD measurements along a wrinkle ridge could provide individual ages of different wrinkle ridge segments, and information about the growth direction with time. However, our data do not yet provide the needed detail.

Summary and Conclusions: Yue et al. (2017)[16] derived young ages with large error bars for wrinkle ridges in Mare Tranquillitatis. The young ages could result from (1) a methodological BCC problem, (2) subsequent resurfacing of the crater population causing younger ages, or (3) a different stress mechanism in that region [16]. Our data do not yet provide an answer. Our CSFD measurements also show ages inconsistent with wrinkle ridge formation directly after the basalt fill was emplaced, as well as large error bars. It is not yet possible to assign the ages to a different stress mechanism or a different subsequent resurfacing of the crater population. Although, the presence of young basaltic volcanism in Mare Tranquillitatis [25] could imply a different stress mechanism. Thus, we are performing ongoing work on more NAC-scale CSFD measurements of wrinkle ridges in Mare Tranquillitatis.

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