SEISMIC RESETTING OF THE CRATER RECORD AROUND LUNAR LOBATE SCARPS. C. H. van der Bogert[1], J. D. Clark[1], H. Hiesinger[1], M. E. Banks[2,3,4], T. R. Watters[2], and M. S. Robinson[5], [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany (vanderbogert@uni-muenster.de); [2]National Air and Space Museum, Smithsonian Institution, Washington DC, USA; [3]Planetary Science Insitute, Tucson, AZ, USA; [4]NASA Goddard Space Flight Center, Greenbelt, MD, USA; [5]Arizona State University, Tempe, AZ, USA.

Introduction: The fresh appearance of lunar lobate scarps, including their sharp morphology, undegraded appearance, and the absence of large (>400 m) superposed craters, attest to their youth [1-6]. Using Apollo panoramic camera photographs, [3] derived age estimates for 21 scarps using crater degradation measurements for craters transected by or superposed on the scarps to bracket the timing of scarp activity. Their age estimates of 60±30 Ma to 680±250 Ma, with uncertainties of +2x to -4x, indicate that lunar scarps are Copernican in age [3]. Subsequent studies using both traditional and buffered crater counting (BCC) crater size-frequency distribution (CSFD) measurements [7-10], give absolute model ages (AMAs) for scarp formation from about 700 Ma to present, with a majority of activity in the last 200 Ma [11].

Using Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) and SELENE TC images, as well as NAC-derived/Lunar Orbiter Laser Altimeter-SELENE digital terrain models, we compared the application of both CSFD approaches for determination of scarp AMAs by re-examining five scarps previously dated by [3]: Henderson-2, Kondratyuk, Koval'skiy-3, Mandel'shtam-3, and Morozov.

Methods: We applied both a traditional CSFD [e.g., 12-15] and a BCC approach [16] for our measurements. The traditional method involves measuring all primary craters within a homogenous geomorphological unit, whereas the BCC method focuses exclusively on measuring craters that post-date a linear geologic feature. Count areas were selected adjacent to the studied scarps, and in the case of Mandel'shtam-3, at locations ~3 km distal to the scarp. The areas selected were unaffected by secondary craters and steep slopes. We fit the traditional CSFDs using both cumulative and Poisson age determinations [17-19] and the BCC data with cumulative fits, using the lunar cratering chronology of [13].

Results: The Copernican ages we derived are younger than the age determinations based on crater degradation measurements [3] (*Table 1*), and slightly older than ages estimated from the expected life-times of the scarps and their associated small graben [4-6]. In four cases, the traditional CSFDs produced ages within error of those via BCC measurements (*Table 1*). These results suggest that fault activity is directly related to surface renewal adjacent to and even kilometers away from the scarps.

We also observe that small craters (e.g., <20 m in diameter at Mandel'shtam-3) near the scarps exhibit

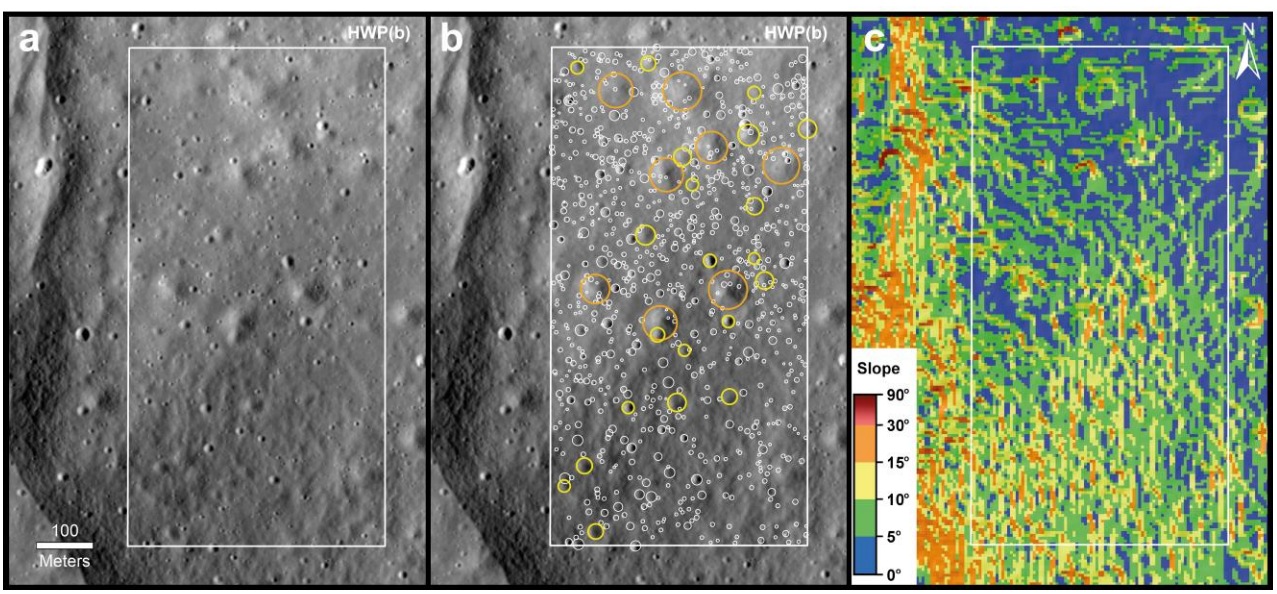

Figure 1. *(a) A count area on the hanging wall at Mandel'shtam-3 scarp (left)(NAC M191909925). (b) Craters >50 m in diameter exhibit highly degraded rims and flat v-shaped floors (orange), while many craters with diameters of ~20-50 m show these morphologies (yellow). (c) NAC DTM-derived slope map.*

Table 1. *Scarp ages of Binder and Gunga (1985)[3] compared with AMAs from BCC (cumulative fits) and traditional (Poisson fits) CSFD measurements.*

Scarp	Crater Degradation Age (Ma)	BCC AMAs (Ma)	Traditional AMAs (Ma)
Henderson-2	210 ± 60	75 ± 20	77 ± 9
Kondratyuk	680 ± 250	61 ± 20	79 ± 5
Koval'skiy-3	240 ± 60	120 ± 50	160 ± 30
Mandel'shtam-3	180 ± 50	56 ± 8*	98 ± 8
Morozov-1	140 ± 50	91 ± 30	84 ± 10

**May indicate continued activity on the scarp.*

fresh morphologies, whereas larger craters (typically >50 m in diameter at Mandel'shtam-3) exhibit highly degraded rims, hummocky textures, and are frequently shallow with v-shaped floors (*Figure 1*). Such features have been attributed to seismic shaking effects [7,20,21]. The diameter ranges of the small fresh craters correspond to the fit ranges for young AMAs that define a resurfacing event caused by the scarp formation. A study of multiple count areas around Mandel'shtam-3 indicates that the largest diameter craters affected by the resurfacing event varies with distance from the scarp.

Discussion: ***Seimic Resetting of the Cratering Chronology.*** The similarity between BCC and traditional CSFD measurements at and around many of the lunar scarps we studied indicates that scarp-related seismicity reset the crater chronometer not only at, but also in the terrain surrounding lobate scarps. The diameter-dependent morphological characteristics of small craters in the count areas are consistent with seismic shaking. The occurrence of ground motion associated with scarp activity is also supported by boulder movement: [8] inferred low to moderate scarp-related ground motion based on the low runout efficiency of fallen boulders in Schrödinger basin.

BCC vs. Traditional CSFD Measurements. The advantage of BCC is that it allows the dating of linear geological features. However, it requires deciding which craters post-date the feature. Identifying the relative ages of the craters, their ejecta, and the scarps can be quite difficult, especially when measuring scarps near the limits allowed by the image resolution [e.g., 8]. Missing craters that post-date a scarp would give an age that is too young, whereas including craters that pre-date a scarp would generate an erroneously old age. BCC measurements typically encompass one entire scarp or scarp complex (due to the need to measure as many craters as possible), and the resulting age represents the end of the formation of the scarp or the last measureable evidence for movement on that fault [e.g., 16]. However, the steep slopes on and surrounding the scarps may be affected by ongoing gravity-driven mass-wasting, potentially erasing and covering small impact craters that postdate the last fault movement, which would result in underestimated ages [22,23]. Some of these caveats may help explain why one of the BCC AMAs we derived is younger than that determined using the traditional approach.

However, because our study shows that the age determinations using both BCC measurements and traditional count areas are similar in most cases, we can now use traditional CSFD measurements to investigate scarp ages in more detail [24]. Indeed, several of the challenges associated with BCC measurements are eliminated: (1) all the craters within the traditional count area are measured, without the need to determine whether they pre- or post-date scarp formation; (2) larger count areas can be defined, which allow collection of better statistics (e.g., smaller error bars); and (3) traditional CSFDs provide additional information about the pre-existing crater populations – for example when the larger crater diameter ranges can be fit with older ages.

Conclusions: The late-Copernican ages we derived continue to support the occurrence of geologically recent tectonic activity on the Moon. The similarity between BCC and traditional CSFD measurements at and around the lunar scarps we studied, as well as morphological evidence for seismic modification of the craters, point to scarp-related seismicity as a process for resetting the crater chronometer in the terrain surrounding lobate scarps. Indeed, shallow moonquakes may be associated with tectonic activity at lunar scarps [8,25], which is also revealed in the crater record. Further CSFD studies will explore the magnitudes and extents of shaking around scarps and evaluate how this may relate to scarp morphology and topology.

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