A LANDSCAPE EVOLUTION PERSPECTIVE ON HOW YOUNG IS YOUNG ON THE LUNAR SURFACE.

C. I. Fassett[1] and B. J. Thomson[2], [1]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA (cfassett@mtholyoke.edu), [2]Center for Remote Sensing, Boston University, Boston MA (bjt@bu.edu).

Introduction: Recent high-resolution topography and image data have renewed interest in the possibility that localized volcanism and tectonism occurred on the Moon in the last tens-to-hundreds of million of years [e.g., 1-3].

Although evidence for localized youthful volcanism and tectonism is compelling, the predominant agent of landscape evolution on the Moon over the last ~3 Gyr is impact cratering. The Neukum model for the lunar crater flux [4] implies that craters with diameters of meters to tens of meters have affected the entire lunar surface over this period. The resulting sandblasting plays an important role in modifying the topography of much larger features, including larger impact craters [e.g., 5,6]. Older craters are have less distinct rims, less relief, and lower depth-diameter ratios, and are more topographically muted.

Given this progressive degradation of impact craters, we can estimate both the age of individual craters, and, combined with knowledge of the impact flux, estimate the rate of landscape evolution on the lunar surface more broadly. We have applied this approach in a recent study [7]. In this abstract, we consider the implications that this landscape evolution modeling perspective has for the age of young volcanic and tectonic features on the Moon.

Method: In our diffusion model, we assume (1) that lunar topography can be treated as a continuum problem, (2) that the net effect of the variety of ongoing geomorphic process is diffusional (consistent with observations), and (3) that the diffusivity of the topography of ~kilometer-scale craters is relevant to the rate that the surface as a whole evolves. A diffusional model implies that the surface topography h changes as:

$$\frac{dh}{dt} = \kappa \nabla^2 h$$

where κ is the diffusivity and the Laplacian of the topography gives its curvature. Data [8] suggest an average κ of ~5.5 m^2/Myr for the last 3 Gyr, although the effective diffusivity for the steepest / youngest slopes could be enhanced by a factor of ~3× (Fig. 11 in [7]).

Irregular Mare Patches: Some of the youngest suggested volcanic features on the Moon are irregular mare patches (IMPs), although their precise mode of origin is uncertain [see 3, 8-13].

Ina: The type example of an IMP is Ina caldera [3,8-11]. Youthful crater retention ages for Ina have been derived (~32 Myr [3] or <10 Myr [10]). Other important qualitative indicators of Ina's youthfulness highlighted by [10] are Ina's spectral immaturity, preservation of steep scarps, and small-scale relief.

Using a 2 m/px LROC NAC derived DTM [14], we extracted six topographic profiles that captured steep scarps in the northern part of Ina (Fig. 1). The first three profiles, Aa, Bb, Cc, are in areas of contiguous smooth material from the exterior of Ina to its interior. Profile Dd crosses a scarp in smooth material on the Ina interior, and Ee and Ff cross moats of rough terrain between two smooth plateau surfaces. We assume initially vertical scarps separating areas of flat topography. In reality, the initial topography was unlikely to be vertical, but this provides an upper limit for the amount of diffusion to reach the present state.

The resulting diffusion profiles fit to these scarps provide insight as to their age. The profiles from the exterior to the interior of the depression (Aa, Bb, Cc) are consistent with maximum ages of 50 to 400 Myr. The interior profiles (De, Ee, Ff) have maximum ages of 5 to 40 Myr. Younger ages are inferred at lower elevations and closer to the center of the depression.

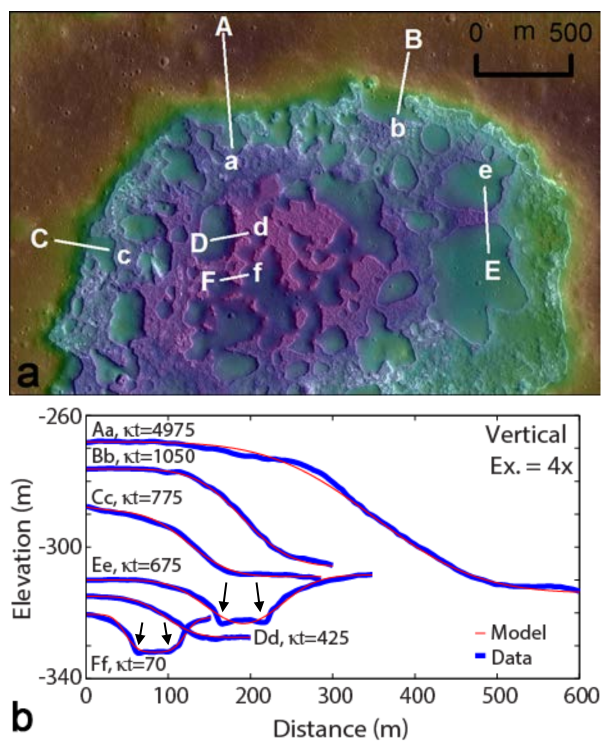


Fig. 1. (a) LROC-derived profiles of Ina. (b) Profiles and scarp diffusion fits. To convert κt to an estimate of the (maximum) age (in Myr), divide by κ ~5.5 to 16.5, or use eq. 6 from [7]. (The ages quoted here are using eq. 6).

However, profiles Ee and Ff suggest much more stringent limits on the age of most recent activity. Both have ~15-100 cm deep troughs at the base of scarps (black arrows, Fig. 1) where the local topographic curvature is 0.1-0.2 m^{-1} (on a 2m-baseline). At these curvatures, the gradation rate is ~0.5-3 m/Myr (eq. 1). These troughs should thus infill in <1-2 Myr, yet they remain topographic lows. This implies they formed at the base of these scarps recently, or are forming currently (in a geologic sense), consistent with [10].

Small Scarps and Graben: A variety of small-scale tectonic landforms on the Moon have been interpreted as young (Copernican; perhaps <50 Myr) on the basis of their fresh-appearing morphology, fine-scale relief, and relationship with small craters [1-2,12].

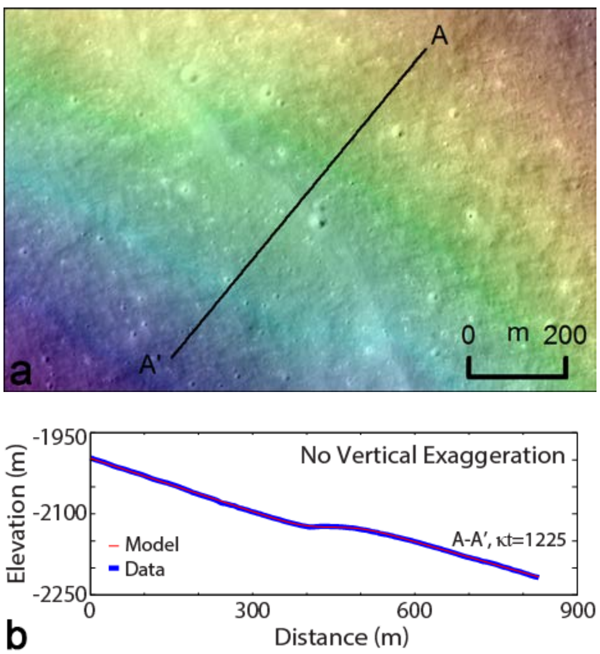
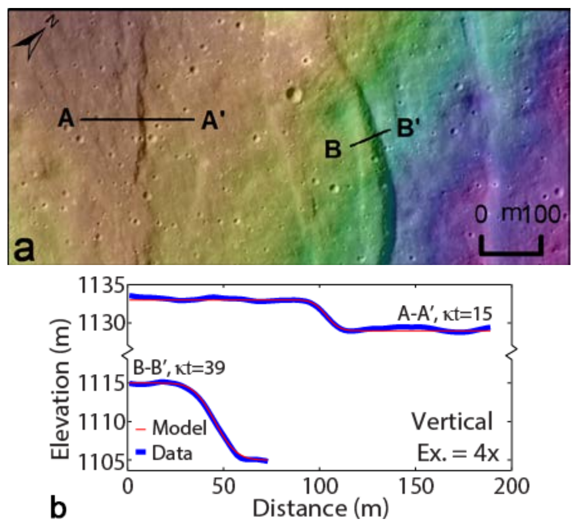


Fig. 2. (a) LROC-derived profiles of Lee-Lincoln scarp on the steep highland slopes near the Apollo 17 landing site. (b) Profile and best fit diffusion model given an initial geometry with two sloping surfaces separated by an initially vertical scarp.

Lee-Lincoln Scarp: Fig. 2 gives a model fit to a portion of Lee-Lincoln scarp, which along with crossing Taurus-Littrow valley, has a pronounced extension on the surrounding North Massif hillside [1]. Because this slope is steep (15-18°), preserving the scarp is difficult unless it is young. Our best fit maximum κt is 1225, equivalent to ~75 Myr. Doubling the diffusion time, or even increasing it by 50%, efficiently removes the terrace that defines the scarp's location. The age we derive is again a maximum, since the initial geometry assumed is steeper than realistic.

Virtanen Graben: Fig. 3 shows model fits to profiles of graben-bounding scarps northeast of Virtanen crater, interpreted as younger than 50 Myr [2]. Fits to the scarps bounding these graben give best-fit κt values <40, consistent with ages of 1-2 Myr and very unlikely to be older than 10 Myr.

Conclusions: Degradation on the lunar surface can be modeled as a diffusive process; the most likely diffusive agents are ubiquitous small-scale meteoritic impacts. The effect of diffusion is scale-dependent, destroying small features more quickly than large features. As a result, small-scale relief has a limited lifetime on the lunar surface. Our recent study provides a means to calibrate this degradation process and allow us to assign dates to youthful geologic features. Model results indicate that (1) Ina experienced resurfacing within the past 5 to 40 Ma, and the persistence of submeter troughs indicates very recent or ongoing activity, (2) Lee-Lincoln scarp is likely to be <75 Myr old, and (3) graben near Virtanen crater are also very young (best fit, 1-2 Myr; very unlikely to be >10 Myr).



(a) LROC-derived profiles of graben NE of Virtanen on the farside highlands [2]. (b) Profiles and best fits, given initially vertical scarps.

References: [1] Watters, T.R. et al. (2010) *Science*, *329*, 936-940. [2] Watters, T.R. et al. (2012) *Nature Geo.*, *5*, 181-185. [3] Braden, S.E. et al. (2014) *Nature Geo.*, *7*, 787-791. [4] Neukum, G. et al. (2001) *Sp. Sci. Rev.*, *96*, 55-86. [5] Gault, D.E. (1970) *Radio Sci.*, *5*, 273-291. [6] Soderblom, L.A. (1970) *JGR*, *75*, 2655-2661. [7] Fassett, C.I. and Thomson, B.J. (2014) *JGR*, *119*, 2255–2271. [8] Whitaker, E.A. (1972) *NASA SP-289*, 84-85. [9] Strain, P.L. and El Baz, F. (1980) *Proc. LPSC 11*, 2437-2446. [10] Schultz, P.H. et al. (2006) *Nature*, 444, 184-186. [11] Garry, W.L. et al. (2012) *JGR*, *117*, E00H31. [12] Schultz, P.H. (1976) *Moon Morphology*. [13] Stooke, P.J. (2012), *LPSC 43*, 1011. [14] Tran, T. et al. (2010), *ASPRS/CaGIS 2010*.