# REMOTE SENSING CONSTRAINTS ON LUNAR CHRONOLOGY.

R. R. Ghent[1, 2], S. Mazrouei[1], J. L. Bandfield[3], L. M. Carter[4], J.-P. Williams[5] and D. A. Paige[5], [1]Dept of Earth Sciences, University of Toronto, Canada; ghentr@es.utoronto.ca, [2]PSI, Tucson, AZ; rghent@psi.edu; [3]Space Science Institute, Boulder CO; [4]NASA Goddard Space Flight Center, Laurel, MD; [5]Earth, Planetary, and Space Sciences, UCLA, Los Angeles, CA.

**Introduction:** A critical and underconstrained element of the effort to understand fundamental physical processes operating on the Moon is the rate at which these processes occur. Establishing rates, or absolute ages planetary features or terrains is difficult. For example, absolute ages on the Moon are generally determined by analyzing the statistical distribution of small craters superimposed on the feature or terrain of interest, and relating the relative ages thus derived to the absolute timescale via returned samples [e.g., 1]. This methodology requires significant labor resources and uncertainty over identification of secondary craters and the effects of variations in physical properties of the target material [2] further complicate crater counting.

Here, we present an alternative method for the derivation of surface ages using observations of impact craters and two datasets: 1) thermal infrared data from the LRO Diviner thermal radiometer and 2) Earth-based S- and P-band radar. We show that remote sensing observations can shed light on the rates of geological processes, and on the fundamental underpinnings of lunar chronology.

**Data:** Rock abundance (the fraction of each pixel covered by exposed rocks larger than the diurnal thermal skin depth, or ~0.5 m) is derived from Diviner nighttime thermal infrared temperatures [3]. Lunar regolith fines are highly insulating; therefore, rocks covered by even a small thickness of regolith are not detectable in this dataset. Thus, the rock abundance dataset provides a reliable inventory of surface rocks. Radar data, by contrast, senses rocks anywhere within the sensing depth, or up to ~10 wavelengths. Comparison of Diviner rock abundance with radar data of multiple wavelengths allows us to estimate the relative abundance of surface vs. subsurface rocks.

**Surface rock breakdown and survival time:** Using Diviner rock abundance data for the ejecta blankets of 9 large craters with published model ages derived from ejecta blanket crater counts, we have previously established a relationship between crater age and ejecta rock content [4]. To characterize the rock distribution, we measured the 95th percentile values of rock abundance for each crater's ejecta. We found that as craters age, this value decreases from >10% toward the background value of ~0.5% as a power-law function of time. Craters older than ~1.5 Gyr show surface rock populations indistinguishable from the background. We conclude that the survival time for rocks larger than ~0.5 m is on the order of 1.5 billion years. This places a new observational constraint on the rate of rock breakdown.; if micrometeorite bombardment is the dominant process, this rate should match that predicted by the microbolide flux. Alternatively, if thermally induced stresses are sufficiently high to break down rocks [e.g., 5-7], our result should constrain the relative importance of this process.

**Subsurface rock survival time:** Earth-based radar observations at 70 and 12.6 cm wavelengths show that craters older than 1.5 Gyr, whose ejecta are free of surface rocks, maintain their rocky ejecta signatures [8]. In fact, most nearside impact craters show rocky ejecta in radar images. We interpret this as evidence that the majority of surviving impact ejecta on the Moon reside in the shallow subsurface: too deeply buried by fine regolith to be visible to Diviner, but within the radar penetration depth of 1-10 meters (depending on wavelength). We observe no correlation between degree of subsurface rockiness, measured using radar circular polarization ratio, and crater age. This ultimately places a constraint on the rate of regolith overturn by bolides large enough to penetrate the regolith to meter scales to break down buried rocks.

**Variations in impact flux:** Using the results of [4], we have calculated absolute ages for ~500 craters with diameter >5 km between 80S and 80N [9]. We find evidence for a factor of 2-3 increase in impactor flux at all sizes (that is, impactors that create craters ≥5 km in diameter) at ~388 Ma. This finding supports other lines of evidence for an increase, e.g., from the occurrence of lunar impact spherules [10]. This result has profound implications for work that depends on the recent flux for age dating.

**References:**[1] Hiesinger, H., et al. (2012), *JGR 117*, E00H10, doi:10.1029/2011JE003935. [2] van der Bogert, C. H., et al. (2016), Origin of discrepancies between crater size-frequency distributions…. *Manuscript. Icarus-14423.* [3] Bandfield et al. (2011), *JGR 116*, E00H02, doi:10.1029/2011JE003866. [4] Ghent R. R., et al. (2014), *Geology*, *42* (12), 1059-1062. [5] Molaro, J., and S. Byrne (2012), *JGR 117*, E10011, doi:10.1029/2012JE004138. [6] Delbo et al., (2014), *Nature 508* (7495), 233-236. [7] Molaro, J. L., et al. (2015), *JGR120*, 255-277. [8] Ghent, R. R., et al. (2016), Icarus, doi: 10.1016/j.icarus.2015.12.014. [9] Mazrouei, S. et al. (2015), *LPSC XLVI*, Abstract #2331; [10] Zellner, N. E. B. & Delano, J. W. (2015). *Geochim. et Cosmochim. 161*, 203–218.