EXAMINING THE EVOLUTION OF RECENT TROPICAL SUBSURFACE ICE ON MARS USING AGES OF SINGLE-LAYERED EJECTA CRATERS. M. R. Kirchoff and R. E. Grimm. Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder, CO 80302. Email: kirchoff@boulder.swri.edu.

Introduction: The evolution of subsurface tropical ice on Mars is vital to understanding the history of volatiles and implications for climate and geology. Ice is presently not stable below the mid-latitudes [e.g., 1], but the actual, time-integrated loss is uncertain [2, 3]. Layered-ejecta craters have long been thought to tap buried ice [e.g., 4]. They are present at all latitudes and sample to greater depths (kms) than possible with neutron spectroscopy or even surface-penetrating radar. With the advent of global 10-m imaging of Mars, individual craters can be dated from smaller craters superposed on their ejecta blankets [e.g., 5]. This approach promises a 4D reconstruction of buried ice on Mars.

We have begun estimating formation ages of single-layered ejecta (SLE) craters throughout Mars' tropical region. We focus on SLE craters because of their prevalence at these latitudes. We have selected 206 SLE craters from the Robbins [6] database, with diameter (D) ≥5 km to assure a large enough ejecta blanket for good crater count statistics. Once ages are estimated we compare the formation frequency with time of tropical SLE craters to that expected for all craters. If the SLE crater frequency falls on the expected trend, then this likely indicates equatorial subsurface ice has remained stable. Conversely, if the SLE crater frequency declines relative to the total frequency, then ice is implied to have been lost over time.

Methods: The keystone of this work is estimating formation ages of SLE craters in Mars' equatorial region (within ±30ºN). First, we measure small, superposed craters (SSCs) on the SLE crater ejecta blankets. Then, we fit the SSC cumulative size-frequency distributions (SFDs) with both Neukum [7] and Hartmann [8] isochrons. Once ages are estimated, we plot SLE crater formation frequency to compare to the expected frequency of all craters.

The most challenging aspect of this work is obtaining the best estimation of the SLE craters' formation ages. Several issues introduce error in the age calculations: removal of SSCs by erosion and/or dust deposition, inclusion of craters only partially buried by the ejecta blanket and are not superposed, inclusion of secondaries, and errors in the chronologies. While there is little we can do about the last issue, we have developed some strategies to mitigate the first three. Our first strategy is to measure craters of similar sizes to the SSCs within a reference area that is on the same terrain. We can then compare the crater SFDs for the two areas to determine if any diameter ranges have similar patterns and densities, which may indicate that partially buried craters are included in the SSC SFD, especially when densities at other diameters are not similar (e.g., Fig. 1a). Any diameters where similarity is found would not likely be used for computing ages. Differences between the SSC and reference SFDs can also help indicate diameter ranges to avoid because SSCs are possibly locally removed or contaminated with secondaries. Our second strategy is to ascertain which diameters of SSC SFDs are dominated by very degraded craters or obvious secondaries (those that form in chains and clusters) (e.g., Figs. 1a,b). Diameter ranges that are composed mostly of very degraded craters have also likely experienced crater erasure; thus we likely would not use these diameters for calculating ages. Meanwhile, diameter ranges that are composed mostly of obvious secondaries may also contain unrecognized secondaries, which would make that range unsuitable for computing ages. Finally, our third strategy is to analyze the chronology fits to the SSC SFDs (e.g., Fig. 1c). Diameter ranges that do not match would not result in reliable model ages for the SLE formation.

Results and Discussion: Fig. 1 shows an example of our analysis for one SLE crater (D=19 km, -9ºN, 312ºE). Comparison of SSC and reference area SFDs (Fig. 1a) indicate that SSC densities are lower for D< ~500 m (although the difference is small) and similar for D> ~500 m. The lower density for smaller SSCs could indicate that they experienced some erasure. On the other hand, the similar density for larger SSCs could indicate there may be some craters partially buried by the SLE's ejecta included, which are not superposed. Note, the very low density of obvious secondary craters on both areas imply these are not likely an issue. Examining the crater degradation classes for the SSCs provides another clue (Fig. 1b). Larger SSCs are mostly composed of very degraded craters (Class 4 craters have highest density), while smaller SSCs craters are mostly composed of less degraded craters (Class 3 craters have highest density). Therefore, it is probable that the similar density of SSCs to the reference SFD at larger diameters is indicating partially buried craters could be included, and subsequent crater erasure is not likely an issue. Hence, although both D=140-250 m and D=500-1400 m SSCs match the isochrons relatively well, we use the smaller diameters to estimate the formation age for this SLE crater (Fig. 1c; Neukum: 850-1500 Myr; Hartmann: 400-650 Myr).

Fig. 2 gives an example of another SLE crater (D=10 km, -24ºN, 243ºE), this one with a different issue indicated. In this case, the similar density of SSCs and reference area SFDs for D< ~100 m, plausibly indicates that this range has experienced erasure on both the ejecta and reference area (Fig. 2a). This is substantiated by deviation of the SSC SFD from all isochrons (Fig. 2c). Although, the SSCs in this diameter range appear to be composed of relatively fresh craters (Fig. 2b). This could, however be suggesting that the erasure was relatively complete and a new population of craters is forming. Nevertheless, this diameter range does not seem to be reliable for computing the formation age of this SLE. Therefore, we have used D=120-250 m SSCs to compute the age of this SLE crater (Neukum: 85-500 Myr, Hartmann: 40-200 Myr), which have a lower density than the reference area (Fig. 2a) and match the isochrons relatively well (Fig. 2c).

Our results are too preliminary for firm conclusions, but already point to two endmembers. If larger SSCs indicate SLE crater ages, then the SLE population could be indistinguishable from the total crater population. If, however, SLE ages are indicated from smaller SSCs, then SLE formation within the last several hundred Ma indicates that deep, tropical ground ice has been preserved throughout Mars' history.

References: [1] M. T. Mellon, et al., *JGR* 102, 19357–69, 1997. [2] S. M. Clifford & D. Hillel, *JGR.* 88, 2456–74, 1983. [3] R. E. Grimm & S. L. Painter, *GRL* 36, L24803, doi: 10.1029/2009gl041018, 2009. [4] M. H. Carr, et al., *JGR* 82, 4055–65, 1977. [5] D. Reiss, et al., *MAPS* 41, 1437–52, 2006. [6] S. J. Robbins & B. M. Hynek, *JGR* 117, E05004, doi: 10.1029/2011JE003966, May 2012. [7] G. Neukum, et al., *SSR* 96, 55–86, 2001. [8] W. K. Hartmann, *Icarus* 174, 294–320, 2005. [9] M. R. Kirchoff, et al., *Icarus* 225, 325–41, 2013.

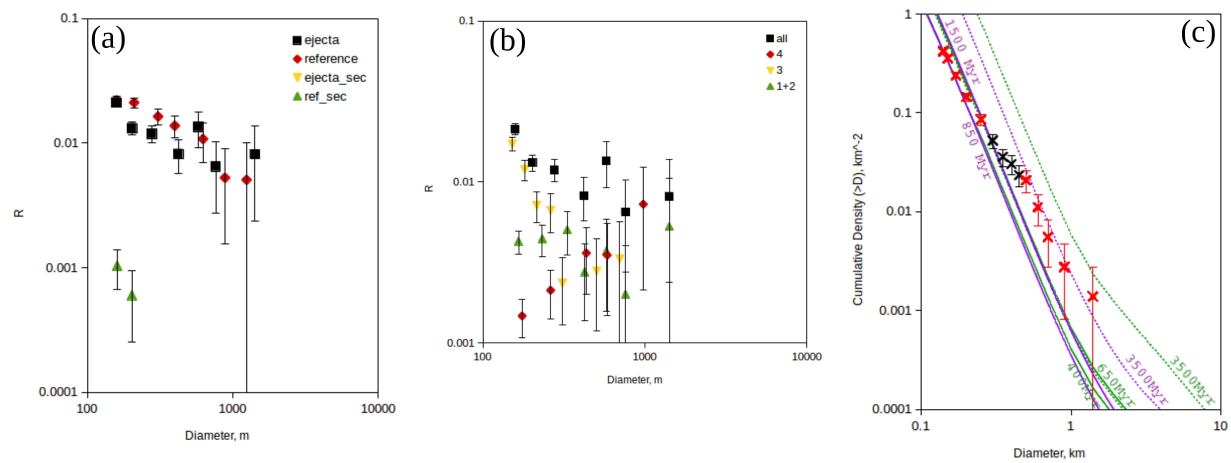

Figure 1. Analysis of SSCs from the D=19 km SLE crater located at -9°N, 312°E and its associated reference area. (a) R-plot comparison of SSC SFD, reference SFD, and obvious secondaries. (b) R-plot comparison of crater degradation classes and all classes combined for SSCs. Degradation classes range from Class 1, which is least degraded, to Class 4, which is most degraded (see [9]). (c) Computation of SLE crater age. x's represent SSC SFD. Red x's indicate portions of the SFD that match isochrons. Neukum isochrons indicated by purple lines and Hartmann indicated by green lines. Fits used to compute reported ages indicated by solid lines and fits that are considered less likely to represent the formation age indicated by dashed lines.

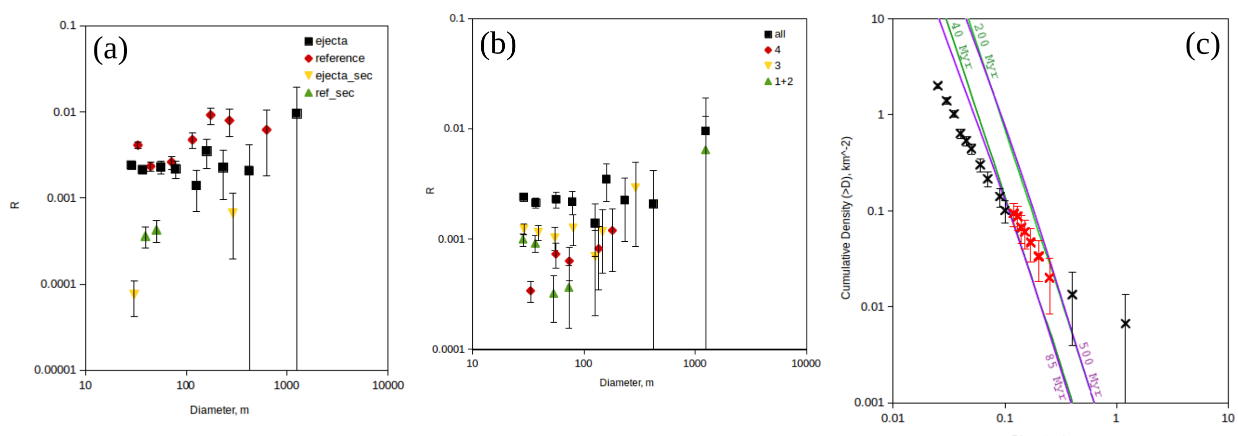

Figure 2. Analysis of SSCs from the D=10 km SLE crater located at -24°N, 243°E and its associated reference area. Plots as described in Fig. 1.