EVIDENCE FOR RECENT TROPICAL SUBSURFACE ICE ON MARS FROM 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 near-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. Ages of these craters can provide new constraints on when subsurface ice existed for locations where it is presently unstable at the surface.

Methods: Fundamental to this work is estimating the formation ages of SLE craters in Mars' tropical latitudes (within ±30ºN). We use small, superposed craters (SSCs) measured on the SLE crater ejecta blankets and both Neukum [7] and Hartmann [8] chronologies to compute ages. However, 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 that 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.

The first strategy is measuring craters of similar sizes to the SSCs within a nearby reference area that is on the same geological unit. Comparison of crater size-frequency distributions (SFDs) for the two areas may then reveal if any of these issues need to be addressed. For example, similarities in density and shape of the crater SFDs at larger diameters when densities at other diameters are not similar may indicate that partially buried craters are included in the SSC SFD. Therefore, we avoid using this portion of SSC SFD to determine the SLE crater formation age. Furthermore, differences in the SFDs can also help indicate diameter ranges to avoid, in this case due to crater removal or secondary crater contamination. For instance, if the SSC SFD slope is shallower than the reference area, this may suggest SSCs on the SLE crater ejecta have experienced local removal or that the reference area is contaminated by secondaries. We use the other strategies discussed next to ascertain which cause is the most plausible, and thus, which diameter ranges are unsuitable for computing ages.

Our second strategy is to compare the SSC and reference area SFDs to a subset of the SSC SFDs only including degraded craters and SFDs of obvious secondaries (those that form in chains and clusters). If the density and shape of the degraded subset SFD is similar to the total SSC SFDs, then this might imply that those diameter ranges have experienced more crater erasure. Likewise, correlation between the obvious secondary SFD and SSC and/or reference area SFDs may suggest that these distributions contain a significant number of unrecognized secondaries for some diameters. In either case, we do not use data to compute ages for which these issues are indicated.

Finally, the third strategy is to analyze isochron fits to the SSC SFDs. Diameter ranges that do not match are not used to estimate model SLE formation ages.

Results and Discussion: Table 1 shows the calculated model formation ages of our first set of SLE craters. These craters are mostly chosen from low dust regions (as indicated by Thermal Emission Spectrometer [9]) to minimize effects on the crater SFDs due to dust deposition. Otherwise no (conscious) preference was given for location or preservation state of the SLE during selection.

The chief result from the ages of these first 20 craters is that SLE craters appear to have formed throughout the Amazonian. Moreover, we have potentially found SLE craters that have formed within the last 500 Myr. These results imply that tropical subsurface ice is preserved well into the very recent geological history of Mars.

The existence of young SLE craters implies that ice-depth estimates can be interpreted as contemporary values, and thus places limits on Mars total H_2O loss since the cryosphere stabilized. The median diameter of the youngest 5 craters examined to date is ~10 km, which implies an excavation depth [10] to ice of ~600 m. If young SLE craters exist down to the previously mapped ~5 km onset diameter [11], the depth to ice could be as little as ~300 m today. The ice table depth decreases smoothly with increasing latitude to near zero at 50º latitude and higher [12]; summing this volume for representative porosity structures yields H_2O sublimation loss of 10-20 m Global Equivalent Layer (GEL), in agreement with recent multireservoir D/H models [13]. Grimm et al. [12] discuss the physical controls on Mars' remarkable ability to retain subsurface H_2O over eons.

Future Work: The ultimate goal of this work is to determine the temporal evolution of equatorial subsurface ice throughout the Amazonian. If SLE craters form by tapping subsurface H_2O, our preliminary results have already shown that tropical buried ice is still present into the recent history of Mars. However, we do not yet know how common young SLE craters are. If our first set presented here is biased and young SLE craters are rare, then that would imply the amount of subsurface volatiles has receded to some degree and may only be currently present in small pockets. In contrast, if our preliminary set is representative of the whole and young SLE craters are frequent, then the buried ice could exist in large amounts and occur throughout the equatorial region. In order to constrain which of these scenarios is correct, once we have a large enough sample of estimated SLE crater formation ages, we will compare the formation frequency with time of tropical SLE craters to that expected for all craters. We will also analyze trends of crater depths, ejecta mobility, and location with respect to age to determine how the ice depth and concentration has changed with time and place [e.g., 14].

This work was supported by NASA grant NNX14AM28G (MRK).

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, 2012. [7] G. Neukum, et al., *SSR* 96, 55–86, 2001. [8] W. K. Hartmann, *Icarus* 174, 294–320, 2005. [9] S. W. Ruff & P. R. Christensen, *JGR* 107, 5119, doi:10.1029/2001JE001580, 2002. [10] H. J. Melosh, *Impact Cratering: A Geologic Process,* 1989. [11] S. W. Squyres, et al., in *Mars*, pp. 523–554, 1992. [12] R. E. Grimm et al., *47th LPSC.*, this volume, 2016. [13] H. Kurokawa, et al., *Geochem. J.*, in press, arxiv.org/abs/1511.03065, 2015. [14] R. O. Kuzmin, et al., *SSR* 22, 195–202, 1988.

Table 1. Estimated Formation Ages of SLE Craters in Ga.

Latitude	Longitude	Diameter (km)	SSC range (m)*	Neukum Age	Hartmann Age
24.4ºS	243.6ºE	10.0	120-250	0.08-0.50	0.04-0.20
7.8ºS	86.0ºE	8.9	70-170	0.20-0.40	0.07-0.15
25.4ºN	321.0ºE	11.7	100-300	0.30-0.60	0.15-0.30
29.8ºS	174.0ºE	9.8	90-150	0.30-0.75	0.15-0.35
28.4ºS	272.0ºE	8.9	110-500	0.50-0.80	0.25-0.35
3.4ºN	194.2ºE	9.5	200-450	0.55-2.50	0.25-1.00
14.7ºN	71.2ºE	10.1	110-200	0.6-1.50	0.25-0.75
6.0ºS	10.9ºE	7.5	110-450	0.75-1.50	0.35-0.60
9.1ºS	312.3ºE	19.0	140-250	0.85-1.50	0.40-0.65
26.0ºS	105.0ºE	10.3	120-170	1.00-2.00	0.50-0.95
27.4ºS	148.5ºE	7.9	100-170	1.00-2.00	0.50-1.00
17.1ºN	128.3ºE	9.4	120-350	1.50-3.50	0.60-3.00
27.5ºS	293.3ºE	9.5	250-500	1.50-3.50	0.65-2.00
26.6ºS	295.6ºE	9.0	130-500	2.00-3.50	0.70-1.50
25.7ºS	295.0ºE	11.9	350-600	2.50-3.50	1.00-2.50
15.0ºS	103.4ºE	8.3	150-300	2.50-3.50	1.00-3.00
27.7ºS	272.3ºE	11.1	350-700	2.50-3.50	1.00-3.00
14.7ºS	31.7ºE	5.7	200-600	2.50-3.50	1.50-3.00
28.7ºN	325.0ºE	10.8	350-800	3.00-4.00	1.50-3.50
21.9ºS	354.4ºE	13.0	350-1200	3.50-4.00	2.50-3.50

*Range of SSC diameters over which the chronologies were fit to compute ages.