PRELIMINARY EXAMINATION OF THE SPATIAL AND TEMPORAL DISTRIBUTION OF EQUATORIAL LAYERED AND RADIAL EJECTA CRATERS ON MARS. M. R. Kirchoff[1], R. E. Grimm[1], and J. D. Riggs[2]. [1]Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder, CO 80302. [2] Dept. of Applied Statistics and Research Methods, University of Northern Colorado. Email: kirchoff@boulder.swri.edu.

Introduction: We have begun an effort to compute the formation ages of adjacent layered and radial (lunar-like ballistic) ejecta craters to better understand the spatial and temporal evolution of martian subsurface equatorial ice – a key to constraining Mars' climate and geology. The assumptions are that layered ejecta craters tap buried ice [e.g., 1], while radial ejecta craters do not, at least in substantial quantities [e.g., 2]. Previously [3], we noted that layered and radial ejecta craters in a representative equatorial area (classified by [4]) appear spatially intimately mixed. The median intercrater distance considering both classes was found to be only 24 km and the correlation length (range of a spherical variogram fitted to binary class data; [5]) was just 7 km. This implies that encountering another crater of the same eject type has a higher probability than random sampling only within 7 km, and the subsurface ice spatial distribution could be very heterogeneous. Boyce and Mouginis-Mark [6] also suggested an intimate mixture of variable volatile concentrations, based upon finding that different classes of layered ejecta craters (single, double, multi), which plausibly require different concentrations of subsurface/surface volatiles to form [e.g., 7], are co-mingled.

However, these studies are missing temporal information. They implicitly assumed the subsurface volatile distribution does not change with time. In our previous study [3], we found that layered ejecta craters formed throughout the last ~3 Ga. Thus, the cratering response to temporal variations in buried ice could be disguised as spatial heterogeneity. The availability of near-global ~6-m/pixel imaging by the Context (CTX) Camera on the Mars Reconnaissance Orbiter allows us to estimate the model formation ages of individual larger craters from smaller craters superposed on their ejecta blankets [3]. The objective of our new study is to compute crater retention model formation ages of layered (any subclass) and radial ejecta craters with diameters (D) $\geq$3 km that are in close spatial proximity. Since the Mars' equatorial band is an important area for constraining the evolution of subsurface volatiles [e.g., 8], we chose a representative Noachian area there (Fig. 1). With these ages we can more robustly incorporate timing into the spatial analysis. Here we discuss some preliminary results for four of our groupings shown in Fig. 1.

Methods: We first identified groupings of radial and layered ejecta craters in proximity to each other spread over the study area (Fig. 1) using the classifications of Robbins and Hynek [4], and adjusted these classifications where necessary based upon our close inspection (see [9]). Then areas of the ejecta blankets suitable for measuring smaller, superposed craters and determining the formation age of the large craters are defined (e.g., Fig. 2). Criteria for this selection are: intact ejecta blanket, lack of obvious significant later modification, and coverage by CTX imaging (incidence angle of 40-80°). We also measure craters of a similar size to the superposed craters in nearby reference regions (Fig. 1, yellow squares) on the underlying terrain. We classify measured craters on a degradation scale from 1-4, with 1 being the freshest, and as potential secondary craters if observed in a cluster or chain (e.g., Fig. 2 and [3]). The reference regions allow us to assess if the superposed crater size-frequency distributions (SFDs) have been affected by processes (e.g., burial, erosion, or secondaries) not obvious in the visual inspection (see [3]). Finally, we compute the crater retention model ages of the larger craters using the Neukum chronology [10] fit to the superposed crater SFDs (see [3]).

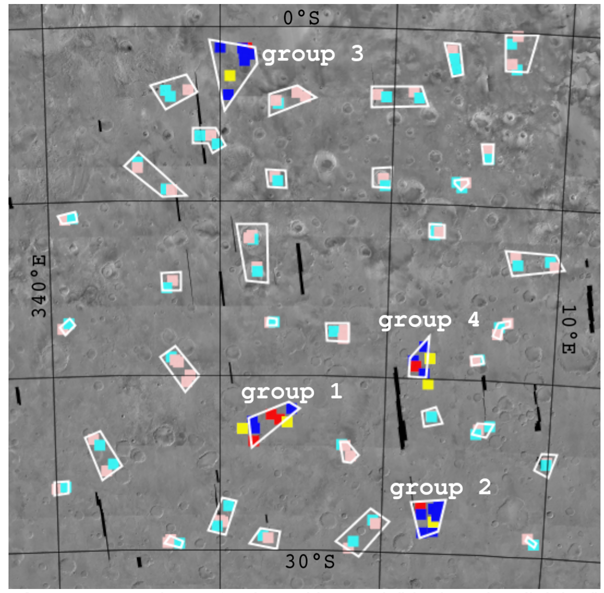

Figure 1. *Locations of selected layered (blue) and radial (red) ejecta craters. Dark shades indicate craters examined for this report, while light shades indicate craters yet to be dated. Yellow squares indicate locations of reference areas. Groupings are indicated by white outlines and labels. Diameters cover 3-70 km in a 30ºx30º area centered at 15ºS, 355ºE. Background is a CTX mosaic.*

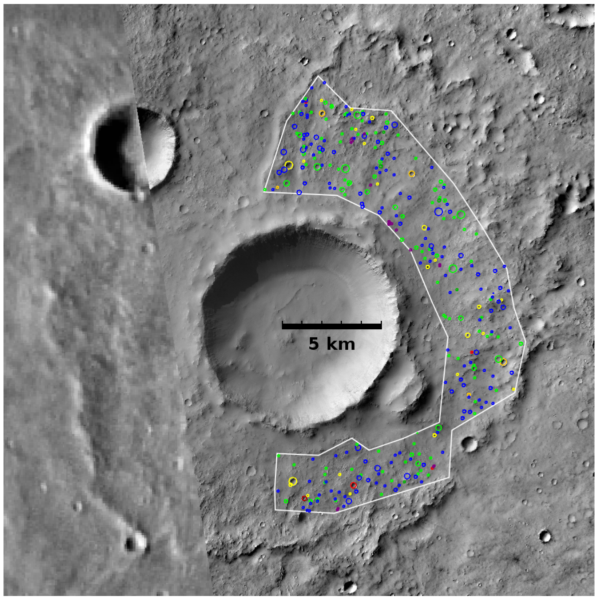

Figure 2. *Circles indicate superposed crater measurements on a (single) layered ejecta crater, with color indicating classification: red for class 1, yellow for 2, green for 3, blue for 4, and purple for secondaries. White polygon outlines the designated count area. Crater is located at -18.2ºN, 2.2ºE in Group 4. CTX image on THEMIS mosaic.*

The ages are then combined with the spatial distribution of ejecta type and sizes to infer very preliminary constraints on their spatial and temporal evolution. To statistically explore the data, we use three, two-way contingency tables [11]. The tables give frequency distributions of crater age bins (categorized as 1.2-2.3, 2.3-3.4, and >3.4 Ga) by ejecta type (layered and radial), crater age bins by group assignation, and ejecta type by group assignation. These tables identify if independence between variable pairs exists. For example, Group 2 crater ages are classified exclusively in the >3.4 Ga bin.

Results and Discussion: Fig. 3 is a plot of crater diameter vs. model formation age (with uncertainties) by location group and ejecta type for craters examined. There are no trends to be seen as yet; and the statistics indicate that ejecta layer types are not significantly associated with a specific age category or size. We did find that Group 2 is statistically different from the other groups. This appears to be because all craters in that group are >3.4 Ga, showing no younger craters (examined, that is). The reason for this is currently being explored. The void in the lower right of the plot is a combination of cratering statistics – younger craters tend to be smaller – and sampling so far. The data set does contain some larger craters, which may yet be young.

Future work: Much work remains to get the complete picture of how tropical martian surface and subsurface ice has evolved. Crater retention model ages will continue to be computed for the remaining craters. We are developing a spatial/temporal statistical model [12] to predict ejecta type from age, diameter, and spatial correlation structure. The model has the general form of a kriging, linear regression model with parameters to account for the spatial and temporal dependencies of crater location and age. Finally, we hope to understand the erosion rate of radial vs. layered ejecta. The data so far show fewer radial ejecta craters remaining than layered, and the radial ejecta craters are, on average, smaller and younger. This implies that radial ejecta may erode faster than layered, if they form at roughly similar rates, which is indicated by the global average of each type of crater [e.g., 7]. Our data set is designed to constrain if larger, older radial ejecta craters exist in same ratio as smaller, younger ones.

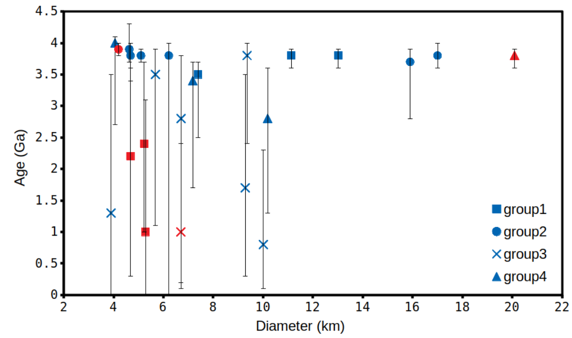

Figure 3. *Plot of craters examined. Blue indicates layered ejecta and red for radial ejecta craters. Symbol shape indicates location group. Ages are shown with uncertainties.*

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References: [1] L. Li et al., MAPS 50, 508–522, 2015. [2] P.J. Mouginis-Mark, MAPS 50, 51–62, 2015. [3] M.R. Kirchoff & R.E. Grimm, JGRP 123, 131–144, 2018. [4] S.J. Robbins & B.M. Hynek, JGR 117, E05004, doi: 10.1029/2011JE003966, 2012. [5] C.V. Deutsch & A.G. Journel, GSLIB: Geostatistical Software Library and Users Guide, Oxford U. Press, 1997. [6] J.M. Boyce & P.J. Mouginis-Mark, JGRP 111, E10005, doi: 10.1029/ 2005JE002638, 2006. [7] N.G. Barlow, in Large Meteorite Impacts III, Geol. Soc. of Am., pp. 433–442, 2005. [8] R.E. Grimm et al., JGRP 122, 94–109, 2017. [9] M.R. Kirchoff et al. 11th PCC, Abst. #2058, 2020. [10] G. Neukum, et al., SSR 96, 55–86, 2001. [11] A. Agresti, An introduction to categorical data analysis, Wiley-Interscience, 2019. [12] N.A.C. Cressie, Statistics for Spatial Data, Wiley & Sons, 1993.