DISTRIBUTION AND CHARACTERISTICS OF BOULDER HALOS AT HIGH LATITUDES ON MARS: REWORKING OF SEDIMENT AND ICE INDICATES BOULDERS OUTLAST THE CRATERS THAT EXCAVATE THEM. Levy, J.S.[1,2], Fassett, C.I.[3], Rader, L.X.[4], King, I.R.[5], Chaffey, P.M.[4], Wagoner, C.M.[4], Hanlon, A.E.[4], Watters, J.L.[2], Kreslavsky, M.A.[6], Holt, J.W.[2], Russell, A.T.[2], and Dyar, M.D.[4]. [1]Dept. of Geology, Colgate University, 13 Oak Ave., Hamilton, NY 13346, USA, jlevy@colgate.edu, [2]Inst. for Geophysics, Jackson School of Geosciences, Univ. of Texas, Austin, TX 78758, [3]NASA Marshall Space Flight Center, Huntsville, AL 35805, [4]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075, [5]Dept. of Engineering, Harvey Mudd College, Claremont, CA 91711, [6]Earth and Planetary Sciences, Univ. of California, Santa Cruz, CA 95064.

Introduction: Boulder halos are a landform found at middle-to-high latitudes on Mars that consist of a concentric pattern of boulder-sized clasts on an otherwise flat-lying surface. They are also referred to as "palimpsest craters" [1], "type 2" craters [2,3], "circular structures of probably impact origin" [4], or boulder halo craters, though the connection to cratering is only inferred. The high martian latitudes where boulder halos have been reported coincide with latitudes where ground ice that lies within the upper ~1 m of the ground surface and is overlain by an ice-free regolith lag has been detected [5-7]. Concurrent observations of boulder halos in these latitude bands raise the possibility that the presence or attributes of boulder halos could be diagnostic of the distribution, thickness, depth, or other characteristics of ground ice, if the mechanisms involved in boulder halo formation and evolution can be determined.

Methods: We 1) surveyed 4,188 HiRISE images located between ~50-80° north and south latitude to determine whether boulder halos are present or absent; 2) determined the diameter of the smallest boulder halo present in each HiRISE image containing boulder halos; 3) extracted geological data for all HiRISE image centroids surveyed to evaluate whether systematic differences exist between sites with and without boulder halos; and 4) conducted detailed boulder halo size mapping on HiRISE images in the vicinity of the Phoenix lander in an effort to constrain the size-frequency-area distribution of boulder halos.

To determine boulder halo site densities, we calculated the percentage of HiRISE images with boulder halos present in them as a fraction of the total number of surveyed images in a moving 500 km window. For mapping (Fig. 1), this mitigates the apparent weight of closely-spaced (and potentially auto-correlated) HiRISE images that may be sampling a similar boulder-halo-generating unit. It does not, however, correct for any biases arising from image targeting.

Results: Significant differences are observed between these features in the northern and southern hemispheres. Boulder halos are much more common in the northern study area than in the southern one; they are present in 459 of 2447 (~19%) northern hemisphere images vs. 96 of 1741 (~6%) southern hemisphere images. Their minimum diameter is notably larger in the northern hemisphere than in the southern hemisphere, with median values of 260 m vs. 180 m, respectively (Fig. 3). But there are no clear spatial patterns of minimum diameter distributions with latitude or longitude.

Clear trends exist in neutron flux between boulder halo and non-halo sites. Thermal neutron flux is higher for non-halo sites than boulder halo sites. Epithermal neutron flux is greater for non-halo sites than boulder halo sites. Fast neutron flux is nearly identical and is statistically indistinguishable between non-halo and boulder halo sites. Surface thermal and radar properties are also different between boulder halo and non-halo sites. TES thermal inertia averages 190 TIU in non-halo sites and 226 TIU in boulder halo areas in the northern hemisphere. SHARAD reflectivity at 20 MHz averages -16.9 dB in non-halo areas and -20.2 dB at boulder halo sites in the northern hemisphere.

Boulder halos mapped at the *Phoenix* landing site that are larger than ~150 m and smaller than 2 km diameter generally follow power law size frequency distributions. However, below ~150 m, there is a marked reduction in the number of boulder halos that would be expected if the boulder halos were produced one-to-one with fresh impact craters (Fig. 2).

Discussion: Strongly peaked minimum boulder halo size distributions suggest a generally uniform thickness of LDM or overlying non-boulderiferous material, with no clearly thickened areas or drifts. Obviously, bigger impacts will give deeper apparent probe depths because the the population of initial impact sizes constrains the use of impacts as a probe of subsurface composition. The smallest boulder halos observed in this study have diameters of ~25-50 m, suggesting potential icy overlying layers thicknesses of ~5-10 m during boulder halo formation. This is consistent with minimum values for LDM thickness that are suggested by polygonally patterned ground spacing [8,9].

Detailed halo size-frequency distributions in the vicinity of the *Phoenix* landing site (Fig. 3) help distinguish two competing interpretations of boulder halos: punch-through and excavation vs. surface reworking. These counts clearly demonstrate that even exceptionally dense and well-formed populations of boulder halos are not "fresh" in the sense that they post-date the emplacement of the surface. Naïve best-fits are young (5-20 Ma), but in the most robust parts of the curves, such as they are, would be consistent with a crater populations with retention ages of 10s to 100s of Ma are observed. This is significantly older than the most recent "ice age" refresh of high latitude regions on Mars by LDM processes [10-12], which may be as recent as 0.1 Ma [13]. This mismatch between the characteristic age of the boulder halo population in the martian northern plains (10s to 100s of Ma) and the inferred recent deposition of ice in the region (~0.3 to 0.5 Ma) suggests that boulder halos may persist through numerous ice emplacement or enrichment events [e.g., 14]. Interplay between inflation and deflation processes may thus have a strong role in the formation or preservation of boulder halos. More broadly, survival time of boulder halo ring arrangements and their constituent boulders may be much longer than lifetimes of crater topography, consistent with estimates of boulder abraision and destruction timescales [15].

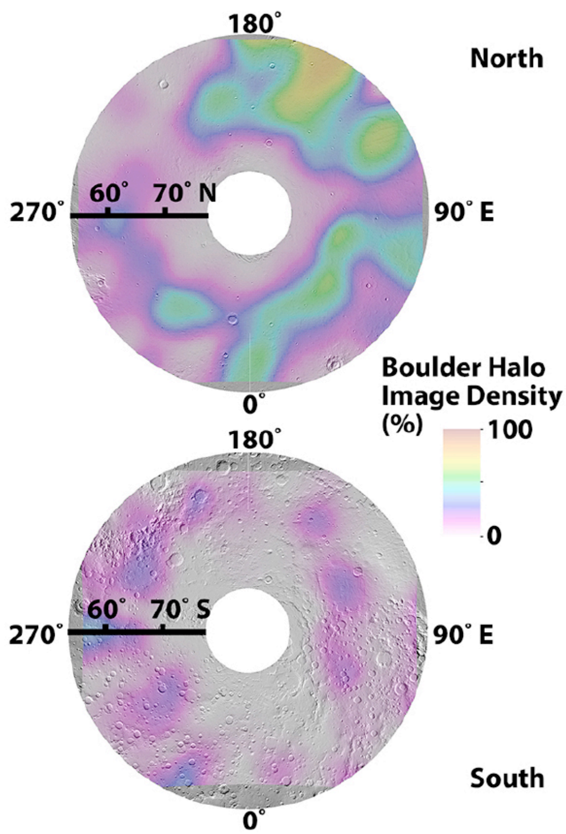

Fig. 1. Spatial distribution of HiRISE images with boulder halos present in them.

Fig. 3. (Right) . Histogram showing the smallest boulder halo diameter present in each HiRISE image containing boulder halos. Logarithmic diameter bins (square root of two step) are used. Populations are grouped by northern and southern hemisphere

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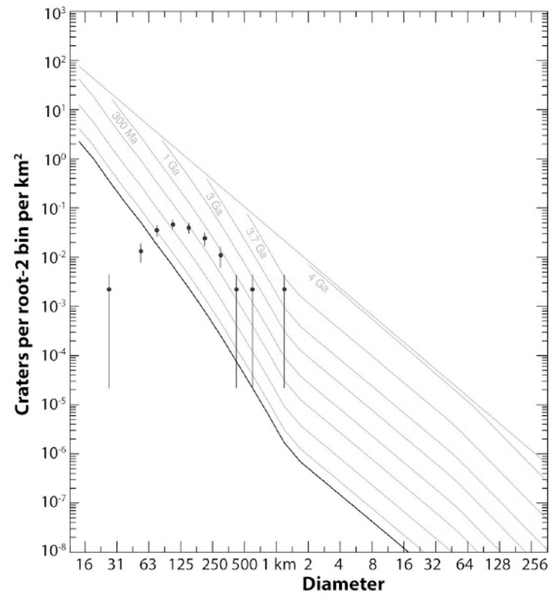

Fig. 2. Boulder halo size-frequency distribution in the vicinity of the Phoenix landing site. Error bars are the square root of the bin count.