MARTIAN SUBSURFACE PROPERTIES AND CRATER FORMATION PROCESSES INFERRED FROM FRESH IMPACT CRATER GEOMETRIES. S. T. Stewart and G. J. Valiant, Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138 (sstewart@eps.harvard.edu).

Introduction: The geometries of simple impact craters reflect the properties of the target materials, and the diverse range of fluidized morphologies observed in Martian ejecta blankets are controlled by the near surface composition and the climate at the time of impact. Using the Mars Orbiter Laser Altimeter data set, quantitative information about the strength of the upper crust and the dynamics of Martian ejecta blankets may be derived from crater geometry measurements. The final forms of larger craters are controlled by gravitational collapse of the shock-weakened rock [1], and the transition between the strength regime and gravity regime is proportional to the effective strength of the surface [2]. Photogrammetry studies of Martian craters determined that the transition between crater formation regimes occurs at smaller crater diameters than expected from comparisons to the Earth, moon, and Mercury [3, 4]. The smaller transition diameter and shallower crater depths have been interpreted as evidence for the presence of weak, layered, or volatile-rich materials on Mars [3, 5]. Observed regional variations in a wide range of crater morphologies suggest that Martian crater forms reflect subsurface heterogeneities [6].

This study focuses on deriving quantitative information about the strength of the Martian crust, including regional variability, and the formation of fluidized ejecta morphologies through analyses of fresh impact crater geometries. We measure several geometrical properties of impact craters using the MOLA altimetry profile data set and a new crater measurement interactive toolkit [7-9]. In this work, we focus on fresh craters on highland and lowland plains, where crater geometry measurements are most accurate. We describe large, resolved differences in fresh crater geometries between lowland plains regions (Utopia basin, Isidis basin and Acidalia Pl.) and highland plateau regions (Lunae Pl., Solis Pl.). Using crater size scaling relationships, we infer the differences in material strength in the studied highland and lowland terrains. Finally we compare the measured crater cavity and ejecta volumes to the Maxwell Z-model [10-12].

Crater Measurement Methods and Tests: We have developed a cross-platform interactive crater measurement toolkit, called *HMars*, that uses the MOLA PEDR altimetry profiles and on-the-fly, profile-derived digital elevation maps [7-9]. We tested our toolkit for systematic errors, resolution limits, and reproducibility. We conducted measurements of simulated craters on different background terrains and verified that no systematic offsets were present in the crater measurements. The resolution limits and standard deviation for each measurement were derived by varying the altimetry track density on simulated craters on different terrains. The reproducibility was tested by comparison to published crater geometry measurements and comparing measurements by different users.

Study regions: We present the results from a survey of the freshest craters in Utopia Planitia-Elysium Mons region, Isidis Planitia, Acidalia Planitia, Lunae Planum, and Solis Planum. Fresh craters were identified quantitatively by deep crater cavities and high rims, and qualitatively by imagery of the crater and ejecta blanket. We focused on craters with $4 < D_{Rim} < 50$ km; however, in a few cases, smaller craters were well-resolved and those were included in our analyses. A total of 501 potentially fresh craters were measured in these regions, and 188 craters satisfied all conditions to be included in the freshest subset of craters in each region.

Results: We find large, resolved differences between the geometrical properties of the freshest highland and lowland craters. Simple lowland craters are 1.5-2.0 times deeper ($\geq 5\sigma$ difference) with >50% larger cavities ($\geq 2\sigma$) compared to highland craters of the same diameter. Rim heights and the volume of material above the pre-impact surface are slightly larger in the lowlands over most of the size range studied.

Subsurface strength and crater collapse. The different shapes of simple highland and lowland craters indicate that the upper ~6.5 km of the lowland study regions are significantly stronger than the upper crust of the highland plateaus. Lowland craters collapse to final volumes of 40-70% of their transient cavity volumes, while highland craters preserve only 20-50%. Based on the break in crater depth to diameter trends, the effective yield strength of the upper crust in the lowland regions falls in the range of competent rock, approximately 9 to 12 MPa, and the highland plateaus may be weaker by a factor of 2 or more, consistent with heavily fractured Noachian layered deposits.

Crater and ejecta formation processes. The measured volumes of continuous ejecta blankets and uplifted surface materials exceed the predictions from standard crater scaling relationships and Maxwell's Z model of crater excavation by a factor of 3. The excess volume of fluidized ejecta blankets on Mars cannot be explained by concentration of ejecta through non-ballistic emplacement processes and/or bulking. The observations require a modification of the scaling laws and are well fit using a scaling factor of ~1.4 between the transient crater surface diameter to the final crater rim diameter and excavation flow originating from one projectile diameter depth with $Z = 2.7$.

Discussion: This work presents the first quantitative analyses of crater geometries to infer regional differences in subsurface properties. Using crater scaling laws for the volume of the transient crater cavity, we demonstrate the freshest lowland craters in this study preserve a larger volume fraction of the transient cavity compared to highland craters. Therefore, the effective strength of the upper crust in the studied areas in the lowland plains is stronger than in the highland plains, a conclusion also reached by independent workers [13]. The presence of large simple craters up to 10.5 km rim diameter in Utopia indicate that the effective yield strength of the upper several km is similar to competent rock (approximately 9 to 12 MPa). In Isidis and Acidalia, similar effective strength is inferred from similar depth to diameter ratios and cavity volumes. Unlike lowland craters, the geometries of fresh highland simple craters grade smoothly to large, gravity dominated crater sizes. The transition from strength to gravity dominated craters may be as small as about 3 to 5.5 km, implying effective strengths of 3.5 to 6 MPa, in between the range of values for soils and competent rock [14]. The presence of large (7-10 km rim diameter) simple craters in Utopia reflect the strength of the Noachian infill in the Utopia basin. The weaker highland materials are consistent with weak, highly fractured, layered and possibly volatile rich Noachian deposits.

The observed crater cavity volumes and ejecta volumes can be fit by a crater size scaling factor of 1.4 between the transient crater surface diameter and final crater rim diameter. The refined model represents the first observationally constrained set of scaling laws for Martian impact craters. The model provides a reliable set of initial parameters for studies of the dynamics of the ejecta blanket emplacement processes and the origin of fluidized ejecta morphologies on Mars.

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