CHAOS TERRAINS ON PLUTO, EUROPA, AND MARS – MORPHOLOGICAL COPARISON OF BLOCKS. H. L. Skjetne[1], K. N. Singer[1], B. M. Hynek[2], K. I. Knight[3], P. M. Schenk[4], C. B. Olkin[1], O. L. White[5], W. B. McKinnon[6], T. Bertrand[7], J. M. Moore[7], S. A. Stern[1], K. D. Runyon[9], H. A. Weaver[9], L. A. Young[1], The New Horizons Geology, Geophysics and Imaging Science Theme Team. [1]Southwest Research Inst., Boulder, CO (helle@boulder.swri.edu), [2]LASP, [3]Carson-Newman U., [4]Lunar and Planetary Inst., [5]SETI Inst., [6]Washington U. in St. Louis, [7]NASA Ames, [8]Lowell Observatory, [9]JHU Applied Physics Lab.

Introduction: Chaos terrain is formed by disruption of preexisting surfaces into irregularly shaped blocks with a "chaotic" appearance [e.g., 1-3]. This typically occurs through fracturing and can be induced by a variety of processes. The subsequent evolution of these blocks after fractures form can follow several paths. If the blocks are completely destabilized and free from the surface below they may rotate, translate, or potentially even float in a liquid or solid with sufficient density contrast [2,3]. Alternatively, the blocks may remain in place and the fractures around them may be deepened over time by erosion [4]. These distinctive areas of broken terrains are most notably found on Jupiter's moon Europa, Mars, and Pluto.

Several models for chaos formation have been proposed, and comparing across bodies may yield extra constraints on the formation and evolution of this enigmatic terrain type [e.g., 1,2,4,5]. This work focuses on providing a morphological comparison of the blocks that make up chaoses on Pluto, Europa, and Mars by measuring block diameters, heights, and axial ratios. In addition, we also provide a comparison between martian chaos blocks near Xanthe Terra and fretted terrain blocks in the Ismenius Lacus Quadrangle.

Mapping Method: Chaos terrain blocks were mapped on Pluto across mountain ranges extending from the NW to SW extent of the Sputnik Planitia (SP) using New Horizons ~315 m px^{-1} base mosaics and a 240 m px^{-1} stereo digital elevation model (DEM). Images from the Galileo mission's regional mapping campaign (East and West RegMaps) were used to map chaos blocks across regions on Europa, using 210-220 m px^{-1} base mosaics and DEMs [6], and 180 m px^{-1} base mosaics and DEM for Conamara. Base mosaics from the THEMIS (global daytime daytime IR) instrument on Mars Odyssey at 100 m px^{-1}, and a 200 m px^{-1} global DEM product from the MOLA instrument on Mars Global Surveyor were used to map blocks across all regions studied on Mars.

Chaos terrain blocks were mapped in ArcGIS using polygons to outline the perimeter of each block along their apparent base, using visual and topographic mapping. A general visual diameter cutoff was assigned to improve accuracy of measurements due to resolution constrains (see Figs. 2-4 for respective cutoffs). The apparent height of each block was determined by subtracting the average base elevation of the perimeter of the polygon from the highest elevation point within each polygon. To derive a measure of the mountain block size (diameter) we used the geodesic area of the feature to calculate an equivalent circular diameter. The axial ratio of each block was derived by creating a rectangle of the smallest area enclosing the block.

Results and Observations: The size vs. height distribution of blocks mapped across all regions of study are presented in Figs. 1,2,3,4.

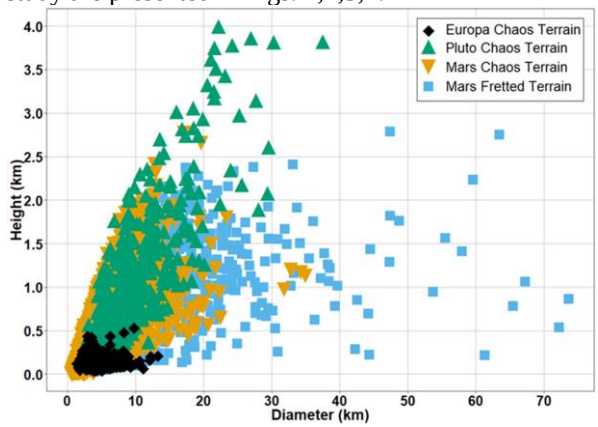

Figure 1. Size-height distribution of measured blocks across all regions studied. Pluto and Mars blocks exhibit a positive linear relationship, whereas blocks on Europa generally show a "flat" trend. Mars fretted blocks display a wider diameter range compared to chaos, and lower heights for larger blocks.

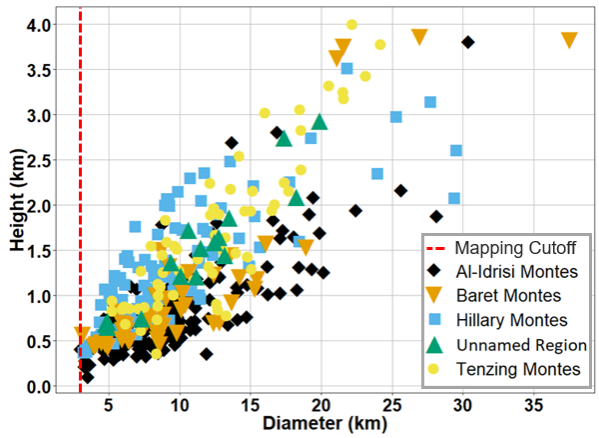

Figure 2. Pluto. Blocks in Tenzing Montes generally appear taller for the same effective diameter compared to other regions, which matches their "spikey" visual appearance. Some blocks in Tenzing Montes are tilted to varying degrees (~5-10°). Tilting alone may not be responsible for taller blocks, as tilted blocks are found throughout all regions.

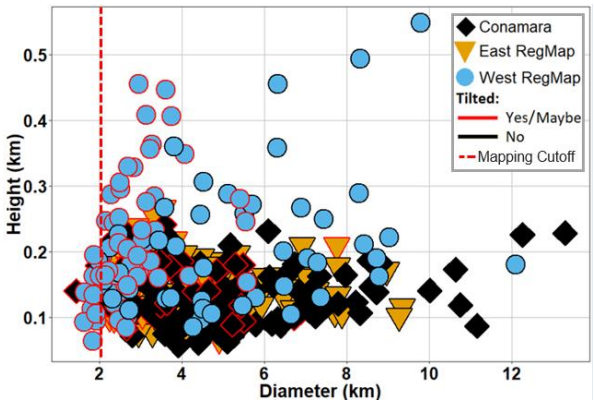

Figure 3. Europa. Block diameter and height appear to be independent variables. Although most blocks measure around 0.1-0.2 km in height for all diameters, untilted blocks in the West RegMap reach taller than blocks in other regions. Tilted blocks were individually labelled, as tilting could affect their apparent height.

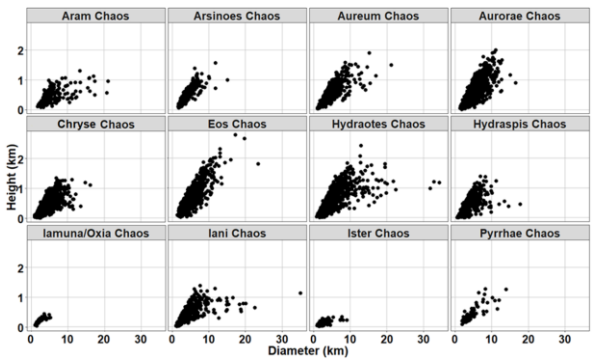

Figure 4. Mars. Some regional variation can be observed in the height of mountain blocks on Mars (mapped using a ~3 km diameter cutoff). Blocks in some regions generally do not exceed above 1-1.5 km in height, whereas blocks in other regions reach up to ~2 km.

Implications for Crustal Lithology: The size and height distributions of chaotic mountain blocks could provide information about the lithologic structure of the crust. If the blocks are all the same height or reach a maximum height and level out (i.e., cease to increase in height with increasing diameter), then this could yield information about the layer thickness of the fractured unit. The blocks on Europa are an example of this kind of distribution (Fig. 3). The block heights in Conamara have been previously used by [7] to estimate a 0.2-3 km thickness of the icy lithosphere assuming the blocks were floating and reached an isostatic level. The same analysis as [7] using our typical untilted block heights on Europa (Fig. 3) of ~0.1-to-0.2 km and less extreme compositions [6] leads to ice shell thickness predictions of ~1-to-4 km, and up to ~5-to-9 km for the taller blocks (~0.5 km) in the West RegMap.

On Pluto, it is possible the chaotic blocks could have been partially or fully floating icebergs in the nitrogen ice sheet of SP, which would assist with destabilization or breakup/tilting [8-9]. Pure water ice and nitrogen ice may have a density contrast of >5% at Pluto's surface temperatures, however other components are likely present as well (e.g., CH_4, CO, tholins; [e.g., 10-13]). However, the distribution in Fig. 2 does not match what is expected of floating blocks. It is possible that the very largest blocks on Pluto may be reaching a maximum height of ~4 km, but there are insufficient data points to infer if this could be indicative of layer thickness. Additionally, using the same calculations as [7] to calculate the minimum root depth required for SP blocks to be floating in isostacy yields a minimum root depth of >50 km. Unless the blocks are much less dense than H_2O ice it is unlikely that the blocks are floating at the present time, as SP is estimated to be ~7-9 km deep [14,15] and is likely more shallow near the edges (assuming an impact origin of SP).

For Mars a different process could lead to an estimate of layer thickness. The competence of lithologic layers could influence the maximum height of blocks, as different layers are more resistant to erosional or deformational processes such as erosional downcutting, faulting and fracturing. The "surface tops" of martian blocks commonly matches the same high elevation as the surrounding plateau [2], and the maximum height of blocks in a region could be used to infer the relative layer thickness of a lithologic layer because erosional processes could have carved the weaker surface layers down to a more resistant layer. In certain regions blocks generally do not exceed above 1-1.5 km in height, compared to blocks in other regions reaching up to ~2 km in height (Fig. 4). Regional variation in the maximum height of blocks could be the result of e.g., subsidence [2], spatial variability in the competence of lithologic layers and/or differential exposure to erosional processes over time.

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References: [1] Collins G. M. and Nimmo F.N. (2009) U. Arizona Press, 259-281. [2] Meresse S. et al. (2008) Icarus 194, 487-500. [3] White et al. (2017) Icarus 287, 261-286. [4] J. A. P. Rodriguez et al. (2005) Icarus 175, 36-57. [5] Schmidt B. E. et al. (2011) Nature 479, 502-505. [6] Singer et al. (2019) Icarus, under review. [7] Williams, K. K. and Greeley, R., (1998) Geophys. Res. Lett. 25, 4273-4276. [8] White O. L. et al. (2017) Icarus 287, 261-286. [9] Howard et al. (2017) Icarus 287, 287-300. [10] Moore, J. M. et al. (2016) Science 351, 1284-1293. [11] Grundy, W.M., et al. (2016) Science 351. [12] Protopapa, S. et al. (2017) Icarus 287, 218-228. [13] Schmitt, B. et al. (2017) Icarus 287, 229-260. [14] Nimmo F. N. et al. (2016) *Nature 540*, 94-96. [15] McKinnon W. B. et al. (2017) *LPSC XLVIII Abstract*, 2854.