

CHAOS TERRAINS ON PLUTO, EUROPA, AND MARS: INSIGHTS TO CRUSTAL LITHOLOGY AND STRUCTURE. H. L. Skjetne¹, K. N. Singer², B. M. Hynek³, P. M. Schenk⁴, C. B. Olkin², O. L. White⁵, T. Bertrand⁶, K. D. Runyon⁷, W. B. McKinnon⁸, J. M. Moore⁶, S. A. Stern², H. A. Weaver⁷, L. A. Young², K. Ennico⁷, The New Horizons Geology, Geophysics and Imaging Science Theme Team, ¹Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN, USA (hskjetne@vols.utk.edu), ²Southwest Research Inst., ³LASP, ⁴Lunar and Planetary Inst., ⁵SETI, ⁶NASA Ames, ⁷JHU Applied Physics Lab, ⁸Washington U. in St. Louis.

Overview: Chaos terrains are characterized by disruption of preexisting surfaces into irregularly arranged blocks with a “chaotic” appearance [1–6]. These distinctive areas of broken terrains can be observed across several solar system bodies, but are most notably found on Jupiter’s moon Europa, Mars, and Pluto. Although chaos terrains on these bodies share common characteristics, there are also distinct morphological differences between them (Fig. 1; [e.g., 1–3]). Fracturing (that can be induced through a variety of mechanisms) likely contributes to initial surface disruption, and subsequent processes may work to further destabilize the surface and contribute to certain morphological differences of chaoses observed across the solar system (Fig. 1 [e.g., 1–8]).

We present extensive mapping and morphological comparison of the individual blocks that make up chaos landscapes on Pluto, Europa, and Mars, using measurements of size (diameter) and height (the maximum elevation exposed above the mean basal elevation) of chaos terrain blocks. Knowing the physical characteristics of chaos terrains will help to constrain chaos formation models and the geologic evolution of each body [e.g., 2,6–8]. We demonstrate that measured physical characteristics of chaos terrain blocks can be used to infer information about the crustal lithology and structure of each body.

Image Datasets: Image and topography data were used to identify and map chaos across the three bodies.

Pluto. The *New Horizons* mission imaged a chain of six chaotic mountain ranges extending from the NW–SW extent of Sputnik Planitia (SP). The Ralph Multispectral Visual Imaging Camera (MVIC) imaged a $\sim 315 \text{ m px}^{-1}$ panchromatic mosaic and several better resolution image strips ($77\text{--}125 \text{ m px}^{-1}$). These datasets form the base mosaics. Stereo digital elevation model (DEM) at 240 m px^{-1} from combinations of MVIC and Long Range Reconnaissance Imager (LORRI) observations were used for topography.

Europa. East and west longitudinal strips at $210\text{--}220 \text{ m px}^{-1}$ from the *Galileo* mission’s regional mapping campaign and an albedo-controlled DEM with the same resolution were used to map two chaos regions (East and West RegMaps). For the third region studied covering Conamara Chaos we used a base mosaic and DEM at 180 m px^{-1} .

Mars. The *Mars Odyssey* Thermal Emission Imaging System (THEMIS) daytime infrared global mosaic at 100 m px^{-1} was used to map Martian chaos regions. Topography data from a 200 m px^{-1} product that combines data from NASA’s Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA) and the European Space Agency’s *Mars Express* High-Resolution Stereo Camera (HRSC).

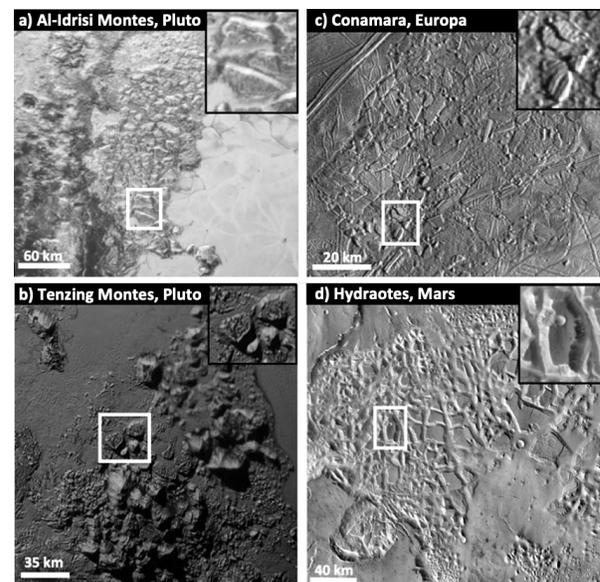


Figure 1. Chaotic terrains across the solar system. Subsequent processes after fracturing may influence the morphologies of chaos blocks: a) to c) If the blocks are completely destabilized and free from the surface below, they may rotate and translate. Block floatation may occur with sufficient density contrast and low viscosities and may reach an isostatic position [2,6]. d) Alternatively, the blocks may remain in place and the fractures may be deepened by erosion [5].

Trends in Feature Topography with Diameter: Chaotic terrain blocks were mapped in ArcGIS using polygons to outline the basal perimeter of each block, using visual identification and topographic mapping for confirmation. Blocks below a given diameter ($\sim 3 \text{ km}$ on Pluto and Mars, and $\sim 2 \text{ km}$ on Europa) were excluded from our measurements due to resolution and terrain constraints, and to improve measurement accuracy and feature identification. To derive a measure of the mountain block size we used the surface area (A) of the block (measured geodetically on a sphere) and calculated an equivalent diameter (d) as

if the feature were a circle (i.e., $d = \sqrt{A/\pi}$). The apparent height of each block was determined by subtracting the average basal elevation from the highest elevation point within each chaos block polygon. Distributions of height vs. diameter of blocks across all studied bodies are presented in Fig. 2.

Implications for Crustal Lithology and Structure: If the height of chaos blocks reach a maximum and level out or are all the same (e.g., distribution of European blocks; Fig. 2), then this could yield information about the lithologic structure and layer thickness of a body (Fig. 3). Previous studies [e.g., 8] have used chaos block heights to estimate ice shell thickness using buoyancy models for iceberg-like blocks floating in isostasy (Fig. 3b).

Pluto. It is possible that chaos blocks at some point could have been partially or fully floating icebergs in the nitrogen (N_2) ice sheet of SP, which could assist with destabilization/tilting of blocks in Fig. 1 [1,9,10]. The calculations in [8] can be applied to calculate the root depth required for blocks to be floating in isostasy (Fig. 3a). However, the distribution in Fig. 2 does not match with what is expected of floating blocks as the blocks appear to be increasing in height with size. By using the same approach as [8], the required root depth for pure, solid water ice blocks to be floating in isostasy in the SP N_2 ice sheet would be 40–50 km for the tallest blocks in Fig. 2 (~4 km) that may be approaching a maximum height [1]. SP is estimated to be ~7–9 km deep near the center [11,12] and is likely shallower near the edges where the blocks are located. This implies that at least at the present moment most of the blocks are likely not floating in isostasy.

Europa. Chaos blocks on Europa provides the best example of a plateauing height distribution (Fig. 2). The same analysis as in [8] using typical untilted block heights of ~0.1–0.3 km (and less extreme density contrast compositions; [7,8]) leads to ice shell thickness predictions of ~1–4 km. For the taller untilted blocks around 0.5 km in the West RegMap region (see [1]) the same analysis yields a slightly thicker lithospheric estimate of ~5 to at least 9 km.

Mars. The maximum height of blocks in a region could be used to infer a relative lithologic layer thickness if erosional processes excavated a distance (h) from the cap rock down to a more erosion/fracture resistant layer (Fig. 3c). The “surface tops” of Martian blocks commonly matches the elevation as the surrounding plateau [3]. In certain regions blocks generally do not exceed a height of 1–1.5 km, whereas blocks in other regions measure up to 2–2.8 km [1].

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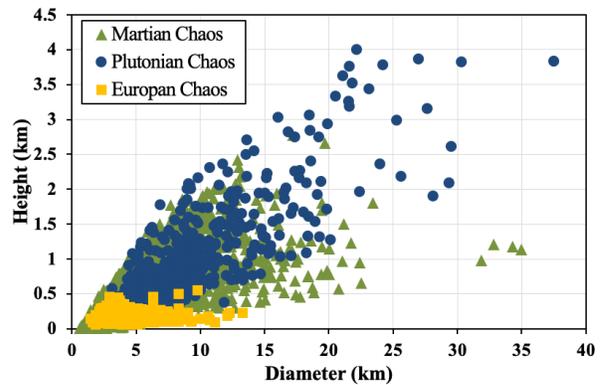


Figure 2. Trends in topography with diameter across the three studied bodies. Chaos blocks on Pluto and Mars show a positive linear relationship, whereas blocks in chaos on Europa display a “flat” height and diameter trend. Peak height distributions for chaos blocks across the regions studied are ~2.5–4 km for Pluto, ~0.5 km for Europa, and ~2–2.8 km for Mars. Refer to [1] for individual trends in chaos regions across each studied body.

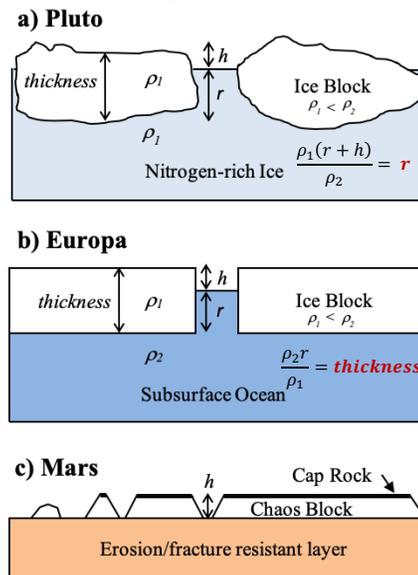


Figure 3. Cartoons of chaotic mountain block profiles. a) Parameters for estimation of block root depths (r) from isostasy are shown for Pluto. b) Parameters for estimating ice shell thickness from isostasy are shown for Europa. c) Possible lithospheric structure on Mars that could explain why chaotic maximum block-top elevations are sometimes similar on a regional scale [3]. The competence of lithologic layers could influence the maximum h of blocks, as some lithologic layers could be more resistant to erosional or deformational processes.

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