TRITON, EUROPA, ENCELADUS & PLUTO, OH MY!: TOPOGRAPHY OF ACTIVE ICY OCEAN WORLDS. J. Kay, P. Schenk, L. Prockter, Lunar and Planetary Institute/USRA, Houston, TX, USA (schenk@lpi.usra.edu),

INTRODUCTION: With the recent discoveries at the ocean worlds Enceladus and Pluto, and the publication of the Roadmaps to Ocean Worlds study [1], interest has been renewed in the active icy moon Triton [2] and its place as a potentially currently active ocean world. A Discovery-class mission to Triton is actually possible and will be proposed in the next Discovery call [3]. Although subject of Earth-based observations of its global spectral properties, only one spacecraft (Voyager 2) has visited this moon and returned resolved data (using 1970s era instrumentation). Here we examine Triton from a topographic perspective in comparison to similar data for other ocean, or active worlds, namely Pluto, Europa, and Enceladus.

TRITON: Resolved Triton imaging included the illuminated portion of the encounter (Neptune-facing) hemisphere in 1989 at pixel scales ranging from ~1.6 to ~0.35 km. While much of this imaging included stereo parallax, Triton topography proved to have very low amplitudes [4] and the parallax was insufficient to resolve geologic features in most cases. There are two important exceptions: Voyager imaging parallax was more than sufficient to detect several atmospheric plumes originating as narrow columns that fan out at ~8 km altitude due to upper level winds [5]. Our examination of these images suggests that there may be additional lower level plumes that do not reach the 8 km shearing altitude.

The second exception is the stereo combination between the global mapping mosaics at 1.6 to 1.0 km pixel scales and the (sometimes smeared) high-resolution mosaic near closest approach at 350 m pixel scales. This mosaic includes samples of eroded plains, volcanic plains and structures (e.g., Leviathan Patera and Kraken Catena), and cantaloupe terrain of Bubembe Regio [ref?]. These stereo data allow construction of DEMs with best nominal vertical precisions of ~200 m. Despite this, the only geologic features that are explicitly resolved are the depressed interiors of many of the cantaloupe cells (typically 20-40 km across and attributed to diapirism [5]).

Use of these stereo data for regional-scale topographic study is hampered by the compression used to return the data. The compression used for global mosaic images resulted in a pattern of alternating line dropouts along the left and right sides of the images, erasing half of the reseaux patterns in those portions of the images (reseaux are fiducial markings on the Voyager chip used to remove the camera distortions). The removal of half a reseau leads to unknowable errors in its position and distortions in the resulting projection and stereogrammetry of these images. Despite this, the apparent regional topographic amplitude in these DEMs is only $\pm$0.5 km, comparable to that observed in the limb profiles [4]. This indicates that the amplitudes of geologic features and the known geologic provinces on Triton is <1 km. Whether true globally will have to be determined by future missions, and no topography exists for southern terrains, where the plumes are.

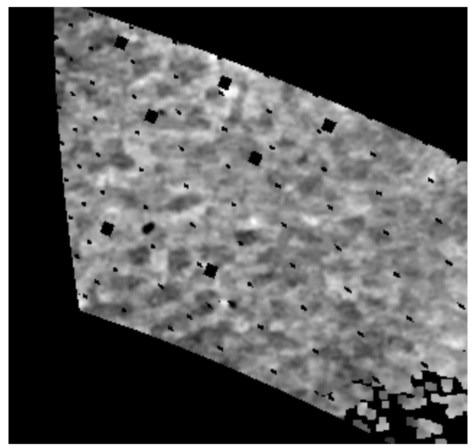

Figure 1. Stereogrammetric DEM for cantaloupe terrain on Triton. Bright is high, dark is low. The depressed centers of numerous closed cells are visible in this DEM. Total amplitude shown is 1 km. Scene width is 400 km, north is to right.

The heights of individual geologic features on Triton must be determined using photoclinometry (Fig. 2). These data have large long-wavelength uncertainties but in general are reliable to within ~10% for small-scale features (as confirmed by shadow measurements). These data cover the terminator region to within ~20° of the sunset line and confirm the visual impression that geologic features are no more than 750 m in height. Even Leviathan Patera, perhaps the most "volcano-like" feature on an icy body in the Outer Solar System, has an elevation range of <1 km.

EUROPA, PLUTO & ENCELADUS: The topography of these bodies has been reported elsewhere [6-8]. Here we are concerned mainly with the regional topographic properties of these geologically complex ice-rich moons. Cassini achieved global mapping of Enceladus down to ~100 m on average (and higher locally), with global topographic coverage from stereogrammetry. While 100-km-scale dimples 1-1.5 km deep occur [9], the amplitude of Enceladus topography globally is the lowest of any icy body for which we have a minimum 40% global coverage [8].

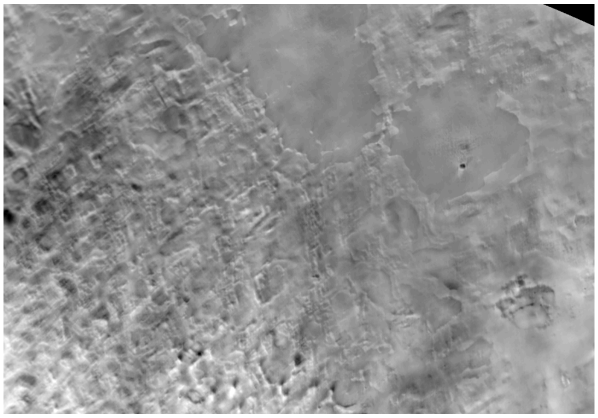

Figure 2. Portion of a topographic map for equatorial Triton based on photoclinometry. Area shown is 800-km wide and total amplitude of 1 km is shown. Large flat areas to top are walled plains. Leviathan Patera is the small 80-km-wide circular depression at lower right; cantaloupe terrain is to the left.

For Europa, a known ocean world with provisional indications of activity, we have <10% coverage by resolvable stereo, but if we sum these DEM data (assuming they are representative samples) we obtain a provisional hypsogram even narrower than Enceladus (Fig. 3), with full-width at half-maximum (FWHM) of ~1 km for Enceladus and provisionally ~0.3 km for Europa (even though local extremes of 1 km relief occur. Available topography for Triton suggests a FWHM of <0.5 km. While this implies that Europa is globally flatter than Enceladus, a known active ocean world, we must await the return to Europa for a better topographic map. The difference may also be due in part to the likely greater preservation of older ice shell on small Enceladus. The resurfaced south polar terrains on Enceladus have much lower topographic amplitude than older terrains to the north and may be more similar to Europa.

For Pluto, the topographic range is much greater (>6 km) [8]. Much of this is related to the large Sputnik Planitia (SP) basin, constructional volcanism (Wright and Piccard Mons) and the variety of terrain types. However, the older lightly cratered plains flanking SP are relatively flat and undisturbed with FWHM of ~2 km. These terrains could reflect a period when Pluto was warmer and perhaps an ocean world.

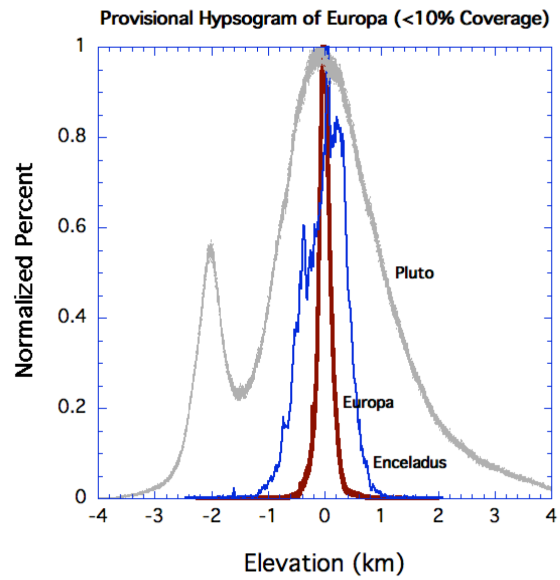

Figure 3. Hypsogram of Europa, Enceladus & Pluto compared. See text for discussion of issues related to the Europa data set.

OBSERVATIONS: Global topographic properties clearly reflect the geologic history of icy bodies. Ocean worlds have low topographic amplitudes due to the erasure of older cratered terrains and the lack of preserved deviation-inducing large impacts. Ongoing activity such as at southern Enceladus or (likely) Triton and Europa produce very low topographic signatures. Whether these data can be used to infer the level of activity or depths to oceans requires further analysis.

References: [1] Hendrix, A. R. et al. (2019) *Astrobiology* 19(1), doi:10.1089/ast.2018.1955. [2] Croft, S. et al. (1995) *Neptune and Triton,* Univ. Arizona Press, pp. xxx. [3] Prockter, L. et al., this meeting; Mitchell K. et al., this meeting [4] Thomas, P. et al., [5] Schenk, P., and M. Jackson, Geology. [6] Schenk, P., submitted, 2019. [7] Schenk, P. et al., Icarus, 2018a. [8] Schenk, P. et al., in Enceladus and the Icy Moons of Saturn, 2018b. [9] Schenk, P., and W. McKinnon, Geo. Res. Lett., 2006.