VULCAN PLANITIA, TYPE EXAMPLE OF OUTER SOLAR SYSTEM AMMONIA-WATER CRYOVOLCANISM. William B. McKinnon[1], R.A. Beyer[2,3], P.M. Schenk[4], S.J. Robbins[5], J.M. Moore[2], K.N. Singer[5], O.L. White[2], J.R. Spencer[5], J.C. Cook[5], W.M. Grundy[6], D.P Cruikshank[2], H.A. Weaver[7], L.A. Young[2], C.B. Olkin[2], S.A. Stern[2], New Horizons Geology, Geophysics & Imaging Theme Team, New Horizons Composition Theme Team. [1]Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University in St. Louis, Saint Louis, MO 63130 (mckinnon@wustl.edu), [2]NASA Ames Research Center, Mountain View CA, [3]SETI Institute, Mountain View CA, [4]Lunar and Planetary Institute, Houston TX, [5]Southwest Research Institute, Boulder CO, [6]Lowell Observatory, Flagstaff AZ, [7]Johns Hopkins Univ. Applied Physics Laboratory, Laurel MD.

Introduction: On Charon, Vulcan Planitia (VP) forms a broad contiguous undulating plain south of the more rugged and tectonically disrupted Oz Terra (both of these names being informal). Whereas the southern margin of this plain extends to the terminator, the northern margin is well observed. Though scarred by pitting and curvilinear ridges, troughs and fractures, VP is relatively contiguous and devoid of major tectonic disruptions, at least compared with Oz Terra [1-4]. Convex marginal scarps 1-3 km high form a nearly contiguous "moat" or trough along the outer margin of VP; with the side along the northern terrains being higher in elevation by a kilometer or so. Similar moats surround the isolated mountains that rise 3-6 km high in scattered locations of eastern VP. This marginal relief suggests that the materials that resurfaced the plains were relatively viscous and resisted outward flow, forming an outer rampart [1]. Liquid-solid NH_3/H_2O mixtures have substantially higher viscosities than water or ammonia-water alone and could satisfy these constraints. Moreover, ground-based and New Horizons identification of NH_3 in Charon's optical surface [5,6] indicate that VP is the long-sought (and best) evidence for ammonia-water cryovolcanism in the outer solar system.

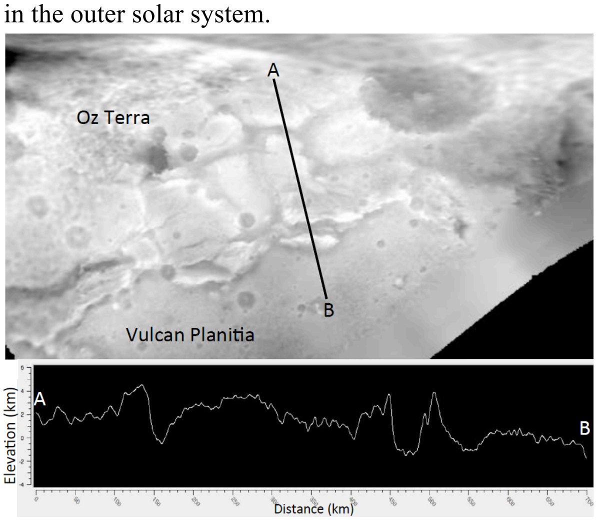

Fig. 1. Stereo Topography of Charon, from [3]. A typical profile is shown across Oz Terra and the boundary with Vulcan Planitia (lower-lying and thus not a planum) to the south. Cryovolcanic fill is apparently ~2-km thick, unless moats at northern and western margins are flexural.

Cryovolcanic Eruption Model: In [3,4] we argue that VP could be explained by stoping, in which lithospheric blocks, disrupted by strong extensional stress, might sink into a less dense (NH_3-rich), residual internal ocean. Given numerous mechanical and other obstacles, here we address the alternative: traditional cryovolcanic eruption, into a broad (impact?) basin. The absence of a clear vent or feeder dike system is not a major issue, as the same can be said of the Moon, where it took very-high-resolution gravity to reveal the volcanic plumbing of the maria [7]; however, the surface swells that form convex sinuous depressions ~100 -km long, in southwest VP, could mark an eruptive center, if late-stage cryomagmas were withdrawn [8].

Voluminous (i.e., flood) eruptions of cryomagmas are to be expected on midsize ice satellites, when they do occur, due to the low driving stresses due to buoyancy (low gravity) [9]. Charon may or may not have undergone extensive, giant-impact induced melting of its ices, but an ocean earlier in geologic time is plausible [10], and is a natural location for NH_3 to be sequestered. Even if non-buoyant compared with the porous icy lithosphere above, internal pressurization [11] may have led to the eruption of VP cryomagmas.

We estimate that Charon should have accreted sufficient nitrogen to explain such an extensive cryovolcanic unit as VP. E.g., a 400,000 km^2 plains unit 2-km thick and of ~dihydrate composition would require a bulk NH_3 abundance of $\sim 2 \times 10^{-4}$, ~20 times less than Charon's likely accreted NH_3-ice [12,13]. Sequesteration in a global residual ocean of dihydrate composition (32 wt% NH_3) would only yield an ~15-km thick basal layer, however, unless there is another source of NH_3 (i.e., core organics) or other substances (salts, methanol) are involved [13].

References: [1] Moore J.M. et al. (2016) *Science 351*, 1284–1293. [2] Beyer R.A. et al. (2017) *Icarus 87*, 161–174. [3] Schenk P.M. et al. (2018) *Icarus*, in press. [4] Beyer R.A. et al. (2018) *Icarus*, submitted. [5] Grundy W.M. et al. (2016) *Science 351*, 10.1126/science.aad9189. [6] Dalle Ore et al. (2018), *Icarus 300*, 21–32. [7] Andrews-Hanna J.C. et al. (2014) *Nature 514*, 68–71. [8] Robbins S.J. et al. (2018) *JGR Planets*, submitted. [9] Stevenson D.J. (1982) *Nature 298*, 22–24. [10] Bierson C.J. et al. (2018) *Icarus 309*, 207–219. [11] Manga M. & Wang C.Y. (2007) *GRL 34*, L07202. [12] McKinnon W.B. et al. (2017) *Icarus 287*, 2–11. [13] McKinnon W.B. et al. (2008) in *TSSBN*, Univ. Ariz. Press, 213-241.