GEOLOGY OF CHARON Ross A. Beyer[1,2], J. Spencer[3], S. Robbins[3], K. Singer[3], C. Beddingfield[1,2], W. M. Grundy[4], K. Ennico[2], J. T. Keane[5], W. B. McKinnon[6], J. M. Moore[2], F. Nimmo[7], C. Olkin[3], K. Runyon[8] P. Schenk[9], A. Stern[3], H. Weaver[8], L. A. Young[3], and the New Horizons Science Team. [1]Carl Sagan Center at the SETI Institute, [2]NASA Ames Research Center, Moffett Field, CA, USA (Ross.A.Beyer@nasa.gov), [3]SwRI, [4]Lowell Observatory, [5]Caltech, [6]WUStL, [7]UCSC, [8]JHU APL, [9]LPI

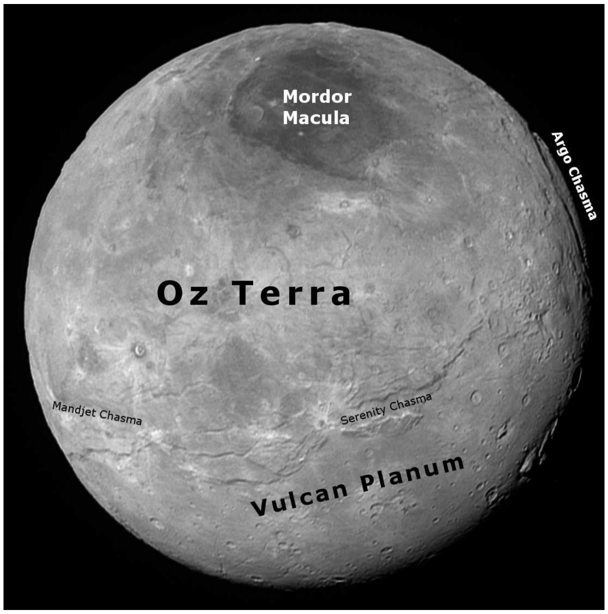

Figure 1: The C_LORRI_FULLFRAME_1 observation (LOR_029914776, ~2.4 km/pixel) showing the New Horizons encounter hemisphere of Charon.

The New Horizons flyby of the Pluto system [1] transformed our understanding of Charon from an astronomical object [2] to a geological one [3]. And while Pluto was certainly the prime focus of the encounter, Charon proved to be a geologically complex world in its own right, different in character from Pluto. Charon shows signs of tectonic disruption in the northern Oz Terra region, and evidence for large-scale resurfacing in the equatorial Vulcan Planitia. [1]

Geological Speculations Before the New Horizons flyby, we could only speculate on what the surface of Charon might look like [5] based on our understanding of icy satellites and their evolution.

It was expected that Charon would have undergone a differentiation process with radiogenic heating that might have led to a subsurface ocean, but due to its size, that heat (and any ocean) would be gone today. The tectonically fractured surface of Ariel was a possible analog. Given the telescopic spectroscopic identification of ammonia-hydrates [6], it was also hypothesized that cryovolcanic features [7] might be observed.

[1]Some names on Charon are now formalized and others are still informal, and follow the informal names in Moore et al. [3] and Beyer et al. [4].

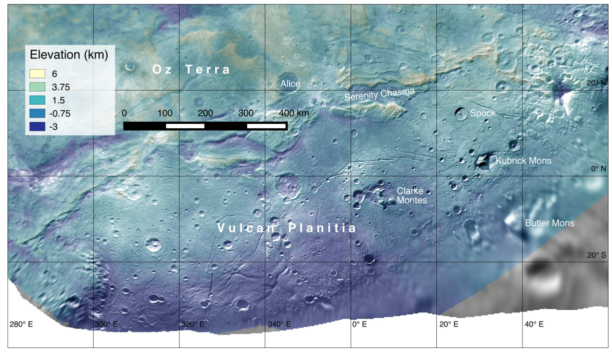

Figure 2: Terrain model in simple cylindrical projection.

New Horizons Imaging of Charon There is whole disk coverage of Charon starting one rotation from closest approach at 17 km/pixel, and then approximately every 15 degrees of rotation, all the way to the best full-disk mosaic at 0.89 km/pixel. The highest resolution observation consisting of a strip of images was at 0.16 km/pixel.

The best mapping and stereo imaging [8] were from the illuminated Pluto-facing hemisphere of Charon captured near closest approach.

Cratering and Ages Cratering on Charon is detailed in Robbins et al. [9] and Singer et al. [10]. The cratering statistics tell the story of a globally old surface, even across the varying terrains described below. This is consistent with most of the interesting geological activity happening very early in Charon's history.

Geological Mapping of Charon Robbins et al. [11] identified ten primary geomorphologic unit categories covering 35% of Charon's surface and used lower resolution data to speculate about less-resolved areas of Charon. Over a thousand linear features were mapped, 90% of them being tectonic in nature. A chronostratigraphy was constructed from examination of cross-cutting and embayment relations that supports the evolutionary story of Charon's disrupted crustal blocks and vast smooth plains.

Disrupted Crustal Blocks Across Charon's northern region are a variety of terrains that display extensional tectonic features with kilometers of relief. Oz Terra comprises the area on the encounter hemisphere north of Vul-

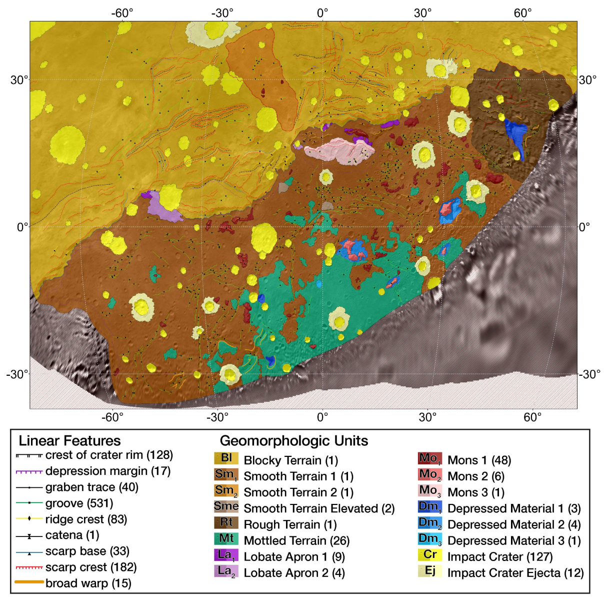

Figure 3: Geomorphologic map of Charon features overlain on a mosaic of LORRI images [11].

can Planitia, and has three latitudinal zones: (1) low-latitude chasmata, (2) mid-latitude crustal blocks, and (3) high-latitude depressions and ridges [4].

The low-latitude scarps and chasmata are roughly aligned with the border of Vulcan Planitia, indicating a stress-relationship with Vulcan or more precisely the events that led to the resurfacing in that area. The chasmata appear to be graben, and the numerous scarps appear to be the traces of normal faulting.

The mid-northern latitudes are characterized by large areas bounded by scarps. These appear to be large crustal blocks several hundred kilometers across separated by troughs. There is no major alignment in this zone, indicating that there was no preferred direction of stress.

The highest latitudes display an irregular landscape. Views of the limb show large relief here, and stereo topography reveals a depression 8 km deep.

There is no evidence for compressional or strike-slip faulting. Based on the crater counts, all of this extension was ancient. This implies global expansion of the surface on the order of 1%, and the likely mechanism for driving such an expansion is the freezing of a subsurface ocean early in Charon's history [4].

Smooth Plains The smooth plains of Vulcan Planitia that occupy the equatorial area of Charon are likely the result of global expansion driven by the freezing subsurface ocean which yielded a large cryoflow that completely resurfaced at least 400,000 km^2 [12]. The textures on Vulcan are very different from those in Oz Terra and the topographic relief much less. The boundary consists of southward facing scarps from Oz Terra overlooking Vulcan Planitia.

Vulcan Planitia consists of smooth material and mottled material and is criss-crossed with a pattern of rilles (small graben) that are primarily aligned with the border scarps of Oz Terra. In addition to the 'normal' terrain of Vulcan, there are also some curious, isolated mountains that stand a few kilometers above the plains, surrounded by depressions that are either the downward flexure of plains material or incomplete embayment of pre-existing mountains [3]. The embayment hypothesis is also supported by depressions along the border scarps.

The most reasonable explanation for Vulcan Planitia is that it is the result of a large cryoflow of ammonia-rich material that erupted during the period of global expansion and sub-surface ocean freezing. This was not a flow from a single effusive center, but likely erupted from many locations across the region flooding the area in a manner similar to lunar maria emplacement [12].

Summary Many icy worlds in the solar system show signs of having subsurface oceans today or in the past, indicating that they are a normal part of icy world evolution, and Charon seems to be no different. The advantage of Charon is that its small size allowed the dynamic of an early ocean, freezing, global expansion, and resurfacing to play out, and then stop without overprinting by other processes; leaving us a clear record of those geologic events.

References: **[1]** Stern et al. In: *Science* 350.6258 (2015). DOI: 10.1126/science.aad1815. **[2]** Christy and Harrington. In: *Icarus* 44 (1980), pp. 38–40. DOI: 10.1016/0019-1035(80)90051-2. **[3]** Moore et al. In: *Science* 351 (2016), pp. 1284–1293. DOI: 10.1126/science.aad7055. **[4]** Beyer et al. In: *Icarus* 287 (2017), pp. 161–174. DOI: 10.1016/j.icarus.2016.12.018. **[5]** Moore et al. In: *Icarus* 246 (2015), pp. 65–81. DOI: 10.1016/j.icarus.2014.04.028. **[6]** Cook et al. In: *Astrophys. J.* 663 (2007), pp. 1406–1419. DOI: 10.1086/518222. **[7]** Kargel. In: *Icarus* 100 (1992), pp. 556–574. DOI: 10.1016/0019-1035(92)90118-Q. **[8]** Schenk et al. In: *Icarus* 314 (2018), pp. 400–433. DOI: 10.1016/j.icarus.2018.06.008. **[9]** Robbins et al. In: *Icarus* 287 (2017), pp. 187–206. DOI: 10.1016/j.icarus.2016.09.027. **[10]** Singer et al. In: *Science* 363.6430 (Mar. 2019), pp. 955–959. DOI: 10.1126/science.aap8628. **[11]** Robbins et al. In: *Journal of Geophysical Research: Planets* 124.1 (2019), pp. 155–174. DOI: 10.1029/2018JE005684. **[12]** Beyer et al. In: *Icarus* 323 (2019), pp. 16–32. DOI: https://doi.org/10.1016/j.icarus.2018.12.036.