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Breaking up is hard to do: Global cartography and topography of Pluto's mid-sized icy Moon Charon from New Horizons

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ABSTRACT

The 2015 New Horizons flyby through the Pluto system produced the first high-resolution topographic maps of Pluto and Charon, the most distant objects so mapped. Global integrated mosaics of the illuminated surface of Pluto's large icy moon Charon have been produced using both framing camera and line scan camera data (including four-color images at up to 1.47 km pixel scales), showing the best resolution data at all areas of the surface. Digital elevation models (DEMs) with vertical precisions of up to ∼0.1 km were constructed for ∼40% of Charon using stereo imagery. Local radii estimates for the surface were also determined from the cartographic control network solution for the LORRI framing camera data, which validate the stereo solutions. Charon is moderately cratered, the largest of which is ∼250-km across and ∼6 km deep. Charon has a topographic range over the observed hemisphere from lowest to highest of ∼19 km, the largest topographic amplitude of any mid-sized icy body (including Ceres) other than Iapetus. Unlike Saturn's icy moons whose topographic signature is dominated by global relaxation of topography and subsequent impact cratering, large-scale tectonics and regional resurfacing dominate Charon's topography. Most of Charon's encounter hemisphere north of the equator (Oz Terra) is broken into large polygonal blocks by a network of wide troughs with typically 3–6 km relief; the deepest of these occur near the illuminated pole and are up to 13 km deep with respect to the global mean radius, the deepest known surfaces on Charon. The edge of this terrain is defined by large tilted blocks sloping ∼5° or so, the crests of which rise to 5 or 6 km above Charon mean, the highest known points on Charon. The southern resurfaced plains, Vulcan Planitia, consist of rolling plains, locally fractured and pitted, that are depressed ∼1 km below the mean elevation of the disrupted northern terrains of Oz Terra that comprise much of the northern hemisphere (but ∼2–2.5 km below the surfaces of the blocks themselves). These plains roll downward gently to the south with a topographic range of ∼5 km. The outer margins of Vulcan Planitia along the boundary with Oz Terra form a 2-3-km-deep trough, suggesting viscous flow along the outer margins. Isolated massifs 2–4 km high, also flanked by annular moats, lie within the planitia itself. The plains may be formed from volcanic resurfacing of cryogenic fluids, but the tilted blocks along the outer margins and the isolated and tilted massifs within Vulcan Planitia also suggest that much of Charon has been broken into large blocks, some of which have been rotated and some of which have foundered into Charon's upper “mantle”, now exposed as Vulcan Planitia, a history that may be most similar to the disrupted terrains of Ariel.

1. Introduction

The New Horizons spacecraft passed through the Pluto system on 14 July 2015, and executed a series of observations designed to map the composition, surface morphology, and topography of both Pluto and its largest moon, Charon (Stern et al., 2015; Moore et al., 2016), the topic of this report. Charon is comparable in size, density and bulk composition to the 11 classical mid-sized satellites of Saturn and Uranus, which are dominated by mixed ice and rock composition. These include Mimas, Enceladus, Dione, Tethys, Rhea, Iapetus, Miranda, Ariel, Umbriel, Titania and Oberon. These bodies exhibit a rich variety of geologic processes (e.g., Croft and Soderblom, 1991; Schenk et al., 2018a)

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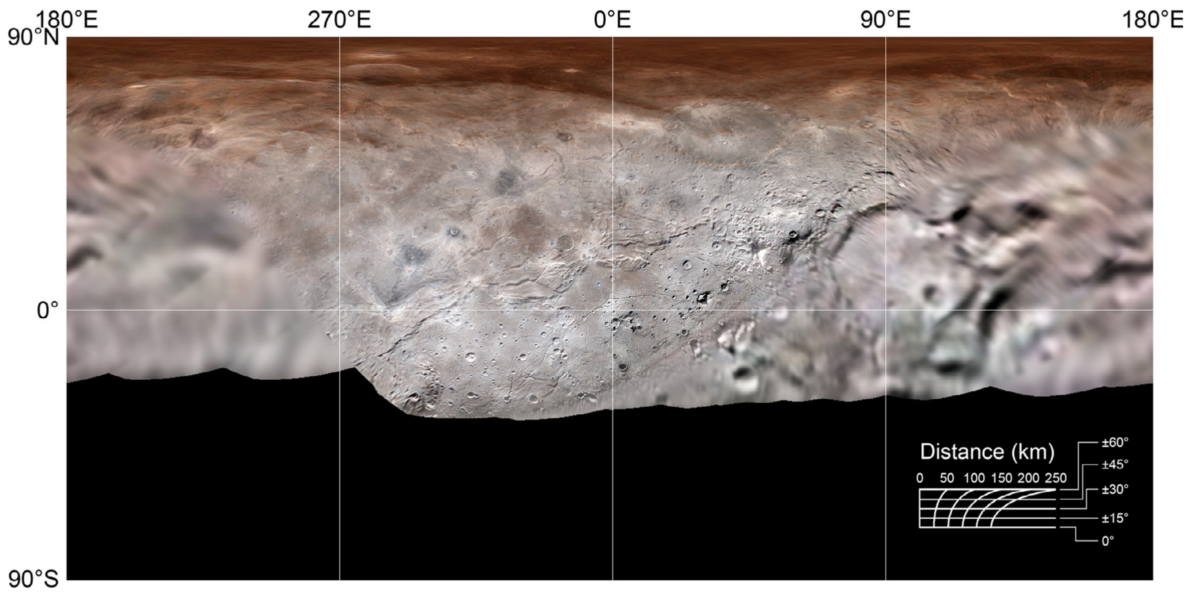

Fig. 1. Global image mosaic of Charon, produced at 300 m/pixel. Dark areas were unilluminated during the 2015 encounter. The encounter hemisphere is in map center, with approach imaging to the left starting at ~60 km/pixel resolution and increasing in quality to the west (left). Global cylindrical map from −180° to +180°E is centered on 0° longitude. The color version of this mosaic uses MVIC 875, 625, and 475 nanometers filter images. Global 4-color mosaic of Charon at 300 m/pixel. MVIC filters used here are centered on 875, 625, and 475 nanometers, displayed in the red, green, and blue color channels, respectively. Dark areas were unilluminated during the 2015 encounter. The encounter hemisphere is in map center, with approach imaging to the left starting at ~60 km/pixel resolution and increasing in quality to the west (left). Global cylindrical map from −180° to +180°E is centered on 0° longitude. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

from tectonic fracturing to volcanic resurfacing by several possible ice phases as well as a variety of exogenic alteration processes. These icy bodies formed and evolved in close proximity to large planetary bodies, which have influenced their geology through tidal heating and deformation (Collins et al., 2010). Hence there was considerable interest in how Charon evolved being a satellite of a much smaller planetary body, namely Pluto.

Charon is also very similar in size and density to the ice-rich solar-orbiting dwarf planet Ceres (e.g., Buczkowski et al., 2016), and both bodies appear to have ammonia-enriched surface (and likely internal) compositions (e.g., Grundy et al., 2016a; Dalle Ore et al., 2018; Cook et al., 2018; De Sanctis et al., 2016). While Ceres (like Charon) has likely been in solar orbit for some time, its unusual surface composition has led to speculation that Ceres is a possible escapee of the Kuiper Belt (McKinnon, 2012) [or the Jupiter-Saturn region (J. Castillo-Rogez, pers. comm.)] and a possible cousin to Pluto or Charon.

As a class, impact and other geologic processes on the icy mid-sized bodies also occur under lower surface gravity and (usually) lower heat budgets than typically observed on the larger icy moons such as Ganymede, Europa, and Triton, or on Pluto, and as such Pluto is discussed in a separate report (Schenk et al., 2018b). Happily, Charon proved to be a geologically complex world disrupted by tectonism and volcanism (Moore et al., 2016; Beyer et al., 2017; Robbins et al., 2017). Here, using cartographic and topographic mapping products from New Horizons we document and describe the regional and global topographic characteristics of Charon, and compare them with other similar-sized icy bodies.

2. Cartographic mapping

2.1. Global mapping coverage and base map production

The New Horizons mapping strategies for Charon were essentially the same in character as those for Pluto (Schenk et al., 2018b), leading to the production of similar mapping data sets for the two bodies. Here we summarize those mapping strategies and data sets for Charon but refer the reader to the Pluto report for technical details. The cartographic and stereo imaging campaign was conducted by the Long-Range Reconnaissance Imager (LORRI, Cheng et al., 2008) and the Multi-spectral Visible Imaging Camera (MVIC) on the Ralph instrument (Reuter et al., 2008), supplemented by LEISA multispectral mapping (e.g., Grundy et al., 2016a; Dalle Ore et al., 2018), with the best mapping and stereo imaging on the illuminated Pluto-facing hemisphere of Charon (Figs. 1–4).

We define longitude and latitude on Charon according to the right hand rule and follow the recommendations of Zangari (2015). Charon's positive pole is defined by Archinal et al. (2011a, b) and points in the direction of the angular momentum vector. Charon's prime or 0° meridian is the sub-Pluto longitude. Consequently, an observer at infinity who sees Pluto at a sub-observer longitude of 180°, will see a sub-observer longitude of 0° on Charon (and thus New Horizons imaged the anti-Charon hemisphere of Pluto and the sub-Pluto hemisphere of Charon). Informally, we refer to the positive pole direction as "North," and to the direction of increasing longitude as "East".

During approach, LORRI imaging of Charon (and Pluto) was acquired approximately every 15° of longitude during the last Pluto/Charon day (6.4 Earth days) before encounter, thereby providing continuous longitudinal mapping (Fig. 1). Pixel scales improved toward the west from ~35 to 0.15 km/pixel as Charon rotated under the approaching spacecraft (Fig. 2a). Terrains south of −38° were in darkness due to polar obliquity at the time of encounter. In order to produce a global map of Charon with minimal viewing angle distortions and best resolution at each point on the surface, all imaging data at emission angles > 75° (and >70° for low resolution images) and all data at incidence angles > 88° (and >85° for low resolution images) were removed (Fig. 2c, d). The resulting global map product shows the illuminated surface of Charon North of −35° latitude. The global Charon base map (Fig. 1) and topographic DEM (Fig. 3) were constructed in the same manner and using the same parameters as for Pluto (Schenk et al., 2018b) except that the encounter hemisphere mapping area data are approximately a factor of two lower in resolution due to the greater distance of Charon at closest approach. The best hemispheric MVIC scan was at ~0.6 km/pixel, and the highest resolution LORRI 5 × 1 mosaic along the center of the hemisphere was at ~0.15 km/pixel