THE GEOLOGY OF PLUTO. K. N. Singer[1], O. L. White[2,3], J. M. Moore[3], A. D. Howard[4], P. M. Schenk[5], D. A. Williams[6], R. M. C. Lopes[7], S. A. Stern[1], K. Ennico[3], C. B. Olkin[1], H. A. Weaver[8], L. A. Young[1], and the *New Horizons* Geology, Geophysics and Imaging Theme Team. [1]Southwest Research Institute, Boulder, CO, 80302, [2]SETI Institute, Mountain View, CA, 94043, [3]NASA Ames Research Center, Moffett Field, CA, 94035, [4]Planetary Science Institute, Tucson, AZ, 85719, [5]Lunar and Planetary Institute, Houston, TX, 77058, [6]Arizona State University, Tempe, AZ, 85281, [7]NASA Jet Propulsion Laboratory, Caltech, Pasadena, CA, 91109, [8]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, 20723.

Introduction: The flyby of NASA's *New Horizons* spacecraft [1] past Pluto on 14 July 2015 yielded robust data sets that permitted geological analysis for more than 50% of its surface. The encounter hemisphere of Pluto was imaged at a pixel scale equal to or better than 890 m/pixel, revealing an unexpectedly diverse range of terrains and implying a complex geological history [2,3]. A digital elevation model constructed for the encounter hemisphere [4] is an essential dataset for assessing the relief and relative elevations of Pluto's various terrains. The remaining >25% of the imaged surface is the anti-encounter hemisphere, imaged at pixel scales coarser than 2.2 km/pixel, typically allowing only surface features on a scale of tens of kilometers to be discerned for this hemisphere. This presentation reviews the primary processes that are thought to drive Pluto's geology, and constructs a narrative of its geological history.

The Source of Pluto's Geological Diversity: Pluto's geological provinces are often highly distinct, and can exhibit disparate crater spatial densities [3,5,6]. Pluto's geology displays evidence for having been affected by both endogenic and exogenic energy sources (including internal heating and insolation/climatic effects). The geology's complex nature is caused by combinations of these influences governing the distribution and behavior of different surface compositional suites to strongly varying degrees across even small lateral distances. Most surprisingly, large-scale surface renewal in response to internal heating is ongoing through the present day, as demonstrated compellingly by the sprawling, convecting N_2 ice plains of Sputnik Planitia [7-11]. This landform, which dominates the encounter hemisphere, has likely been one of the most influenential features on Pluto's geological and atmospheric evolution for much of its history. Sputnik Planitia has been the subject of investigation on its role in Pluto's tectonism and polar orientation [12-15]. At both global and local scales, mobilization and transport of volatiles across Pluto on geological timescales appear to have played a prominent role in determining the appearance and distribution of Pluto's highly varied landscapes, as shown by climate modeling [16-24]. Mapping and landform evolution modeling studies have sought to decipher the nature and origins of individual terrain types on Pluto, which frequently reveal the importance of N_2 ice glaciation and surface-atmosphere interactions throughout Pluto's history [3,4,25-33]. Aside from features influenced by the atmosphere, Wright and Piccard Montes may represent cryovolcanic edifices and if so they may yield information about Pluto's thermal history [3,34].

Pluto's Geological History: The N_2 ice of Sputnik Planitia is mostly contained within an elongate depression measuring 1200 by 2000 km wide [4], interpreted to be an impact basin that likely dates to >4 Ga [3]. This basin represents a powerful cold trap for volatiles [15], and modeling of volatile behavior in response to topography has shown that infilling of the basin with all available surface N_2 ice would be complete by tens of millions of years after its formation [23], meaning that Sputnik Planitia has existed on Pluto's surface for the majority of its history, and has undergone continual resurfacing via convection, glacial flow, and sublimation/recondensation since its formation. Uplands to the north and west of Sputnik Planitia have been erosionally sculpted into a variety of dissected terrains with dendritic valley networks, interpreted to have been carved by the flow of glacial N_2 ice [30], and the infilling of Sputnik Planitia would have been accompanied by recession of N_2 ice glaciation from these areas, with profound geological consequences. The washboard and fluted terrain on the northwestern rim of Sputnik Planitia is interpreted to be refractory debris entrained in the glacial N_2 ice that was deposited on the landscape after its recession [25]. The northwestern rim of Sputnik Planitia appears to be a convergence zone of two large-scale fracture systems, including a complex, eroded, north-south-oriented ridge-trough system ~300-400 km wide and extending >3200 km long (and which may pre-date the Sputnik basin) [4], and the younger, more sharply-defined, segmented grabens informally named Inanna, Dumuzi, and Virgil Fossae. The blocky mountain ranges that line Sputnik Planitia's western edge are interpreted to have formed via glacial N_2 ice receding from the uplands intruding this tectonically fractured and brecciated H_2O ice crust, with crustal fragments breaking form tilted blocks that are now grounded in the denser N_2 ice of Sputnik Planitia [30].

Beyond Sputnik Planitia, the primary influence on Pluto's geology appears to be atmosphere-surface volatile transport, which is strongly controlled by Pluto's eccentric seasons and climate zones [18-20], a consequence of its high obliquity that varies between 103° and 127° on a 2.76 million year cycle [35]. The sequence of dark maculae that extend along Pluto's equatorial regions exist within Pluto's permanent diurnal zone, and experience the "mildest" climate of any region on Pluto. The low albedo is interpreted to be caused by atmospheric deposition of complex molecules called tholins upon the landscape [22]. The maculae have not been affected by geological processes, in particular seasonal mobilization of volatile ices [20], that would disrupt the continuous mantle of tholins since their deposition, and therefore are likely amongst the oldest landscapes on Pluto. The informally named Cthulhu Macula, the largest of the maculae, includes regions that display very high densities of large and relatively unmodified craters [3,5,6], another testament to the great age of these landscapes. The tholin mantle becomes discontinuous and then dissipates completely north of 37°N, the northern boundary of the diurnal zone oscillation range. This north polar zone always experiences arctic seasons, with up to century-long summers and winters during each orbit, and so should experience pronounced volatile cycling in response to the extreme temperature variations across a Plutonian year, yielding younger surface ages than for the non-Sputnik permanent diurnal zone. Evidence for volatile mobilization outside the permanent diurnal zone includes the informally named Piri Rupes, interpreted to be a recessional scarp where a volatile surface layer has sublimated above a refractory substrate [3], and the mantled uplands northeast of Sputnik Planitia, which appear to be covered by smooth-surfaced deposits that may be derived from slow atmospheric vapor condensation, and some of which have been modified by sublimation pitting [31].

The bladed terrain of Tartarus Dorsa east of Sputnik Planitia is amongst the highest elevation terrain on Pluto and consists of rounded, elongate swells reaching hundreds of kilometers long, the surfaces of which show a rippled texture of narrow, aligned, linear ridges separated by a few kilometers and reaching hundreds of meters high. The terrain is interpreted to be a massive deposit of CH_4 ice that preferentially precipitated at low latitude and high elevation early in Pluto's history, with subsequent excursions in Pluto's climate partially eroding the deposits via sublimation into the present blades [28]. No unambiguously recognizable craters appear on the bladed terrain, indicating that the processes creating the blades must be ongoing into the relatively recent past. The western portions of the bladed terrain transition to the bright, pitted uplands of east Tombaugh Regio, which are presently experiencing deposition of N_2 ice fed by sublimation from Sputnik Planitia [30], with the N_2 ice subsequently re-entering Sputnik Planitia via glacial flow. These uplands may therefore represent a glacially modified portion of the bladed terrain [28].

South of Sputnik Planitia, the twin edifices of Wright and Piccard Montes reach >150 km in diameter and >4 km high, with large central depressions reaching tens of km across, and which are deeper than the edifices are high. Tentatively interpreted as cryovolcanic in origin [3,34], these structures exhibit very few superposed craters, and so potentially represent evidence for endogenic heating having been sufficient to facilitate the eruption of cryolavas onto Pluto's surface relatively late in its history (possibly ~1 Ga or later).

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