A FORTHCOMING GLOBAL GEOLOGIC MAP OF PLUTO.
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Introduction: Following its flyby of the Pluto system in 2015, NASA's *New Horizons* spacecraft returned high quality images that reveal an unexpectedly diverse range of terrains on Pluto, implying a complex geological history [1,2]. Pluto's geological provinces are often highly distinct, and can exhibit disparate crater spatial densities [2-4]. Surface renewal is ongoing, as demonstrated most compellingly by the N_2 ice plains of Sputnik Planitia [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). Its complex nature is likely 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. Recent studies [7-12] have used climate modeling and theoretical considerations to formulate hypotheses regarding how volatile species are transported across Pluto on geological timescales in order to explain the appearance and distribution of certain features. Over the coming three years, we will be using established geologic mapping techniques to produce a global USGS Scientific Investigations Map (SIM) at 1:7M scale for the portion of Pluto that was imaged by *New Horizons*. Such a map will represent a critical tool for resolving differing hypotheses of Pluto's evolution. This abstract presents a summary of what mapping has been performed by the authors to date, as well as our mapping rationale for the global map.

Regional Geologic Mapping of Pluto to Date: Published mapping by PI White includes a very rough physiographic map that delineates different terrain types across Pluto's encounter hemisphere without regard to stratigraphy [2], as well as localized mapping for the "bladed" [13] and "washboard and fluted" [14] terrains. Co-I Singer has mapped the tentative cryovolcanic feature Wright Mons [15]. The most comprehensive mapping study to date, led by PI White, is the geological map of Sputnik Planitia and part of eastern Tombaugh Regio, produced at a 1:2M scale [16]. This study developed hypotheses concerning how climate-controlled volatile transfer, in combination with convection of the N_2 ice, have defined the observed variation in morphology and surface albedo across the plains. While the mapping has offered insight into how Sputnik Planitia is evolving, the scientific conclusions drawn from it nevertheless remain isolated to that feature. Crucially, the global and unequal cycling of volatiles on Pluto that is evident from climate modeling and a cursory examination of its surface means that the provenance of no single geological province can be considered in isolation, and a complete and fully integrated understanding of how Pluto's surface has evolved requires the production of a global geological map that identifies distinct geological units and assigns geological processes for their evolution, and also relative ages based on crater age dating and superposition relations.

Mapping Rationale: Our geologic mapping will follow the standard principles of the mapping of extraterrestrial bodies as outlined in the 2018 Planetary Geologic Mapping Protocols [17]. *New Horizons* imaged more than 75% of Pluto's surface, with the encounter hemisphere representing the ~50% of the surface that was imaged at pixel scales between 890 and 76 m/pixel during the hours before closest approach. The remaining >25% of the imaged surface is the anti-encounter hemisphere, imaged at pixel scales between 2.2 and 40.6 km/pixel. Our base map (projected at 300 m/pixel, Fig. 1a) excludes the highest resolution 117 m/pixel and 76 m/pixel strips that cross the encounter hemisphere, meaning that the total pixel scale range for the base map is 40.6 km/pixel to 234 m/pixel (Fig. 1b). Supplementing our monochrome base map is a global color mosaic (reaching 680 m/pixel) and a digital elevation model (DEM) of the encounter hemisphere (Fig. 1c), which can resolve topographic features as small as ~1.5 km across, and which has vertical precision ranging between 100 m and 800 m[18].

We will perform geological mapping of the encounter hemisphere at an equatorial scale of 1:7M, with a minimum feature diameter to be mapped of 7 km. The great contrast in pixel scale between the encounter and anti-encounter hemispheres, however, means that we will map the two hemispheres at different scales. This situation has been encountered in previous mapping projects for outer Solar System bodies. For instance, the global geologic map of Ganymede [19] utilized imaging that was better than 1 km/pixel for less than one-eighth of Ganymede's surface, meaning that the final map was considerably more detailed in some areas than others. For our map, we have defined a specific dichotomy between the low and high resolution mapping areas, with 1 km/pixel set as the bounding pixel scale. At the pixel scale of the anti-encounter hemisphere, only surface features on a scale of several to tens of kilometers can typically be discerned, and topographic relief and detailed textures of mapped units that are apparent within the encounter hemisphere will be invisible. The anti-encounter hemisphere mapping will therefore only occur upon completion of that for the encounter hemisphere, and will consist of a handful of undivided units that are defined based primarily on their albedo.

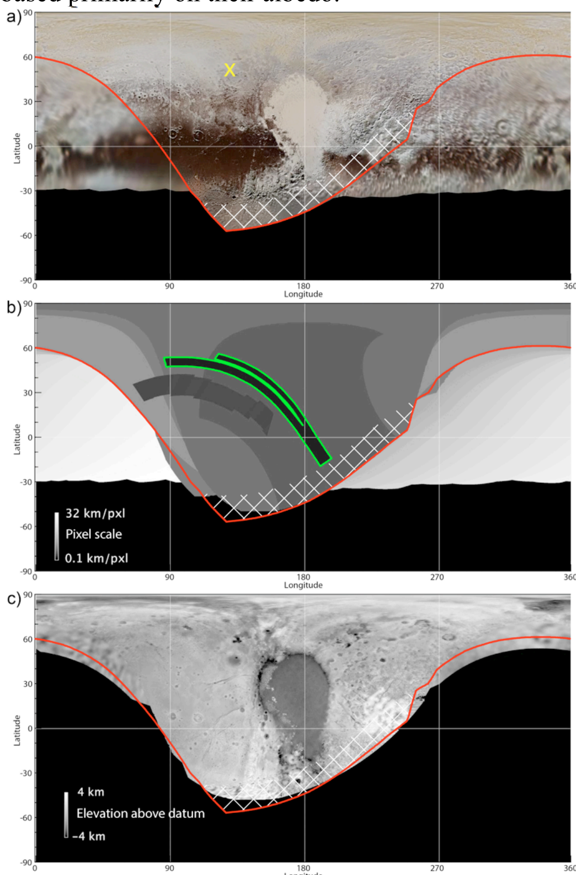

Figure 1. (a) Global mosaic of Pluto projected at 300 m/pixel, which will be used as the base map for our global geologic map. *New Horizons* did not image black areas. An enhanced color mosaic has been overlain on the base map. The red line marks the boundary between the encounter and anti-encounter hemispheres for mapping purposes. The crosshatched zone indicates the region of twilit haze imaging. The yellow cross marks the sub-solar point at the time of closest approach. (b) Map of variation in pixel scale across the base map in (a). The 117 m/pixel and 76 m/pixel strips (outlined in green) are not included in the base map. (c) Stereo digital elevation model of the encounter hemisphere, projected at 300 m/pixel.

A consequence of the flyby nature of the *New Horizons* mission is that, for the encounter hemisphere, each point on the surface was only imaged at a single solar incidence and emission angle. The sub-solar point is at 130.5°E, 51.5°N, with the solar incidence angle increasing to 90° at the edge of the encounter hemisphere, while the anti-encounter hemisphere imaging was mostly obtained at incidence angles >75°. The variation in emission angle follows a similar pattern. We will therefore have to account for such variance in order to ensure consistency in unit definition across the map. Much of the base map is illuminated and viewed at an oblique angle such that the relief of the terrain is emphasized. But for the high-Sun and near-nadir viewing angles in the central portion of the encounter hemisphere, we can ameliorate the situation by using the global DEM to assess surface relief, rather than relying on shading in the base map images to convey such relief.

The combination of superposition relations and crater age dating will aid understanding of ongoing activity on Pluto and the relative timing of different events as determined by our unit interpretation. Crater density across Pluto's surface is highly variable, and in the case of a craterless landscape such as Sputnik Planitia, stratigraphic correlation of units within it is restricted entirely to superposition and crosscutting relations [14]. For elsewhere across Pluto, previous crater analyses [2-4] have focused on measuring crater statistics for the entire encounter hemisphere or for broad physiographic provinces. We will build on previous work by integrating the locations of craters that have already been identified [3,4] into the proposed map, including craters with diameters ≥7 km. These crater densities will be utilized to infer relative terrain ages for the specific units mapped in this proposal, allowing us to define a geologic timescale for Pluto.

References: [1] Stern S. A. et al. (2015) *Science*, *350*, aad1815. [2] Moore J. M. et al. (2016) *Science*, *351*, aad7055. [3] Robbins S. J. et al. (2017) *Icarus*, *287*, 187-206. [4] Singer K. N. et al. (2019) *Science*, *363*, 955-959. [5] Trowbridge A. J. et al. (2016) *Nature*, *534*, 79-81. [6] McKinnon W. B. et al. (2016) *Nature*, *534*, 82-85. [7] Bertrand T. and Forget F. (2016) *Nature*, *540*, 86-89. [8] Binzel R. P. et al. (2017) *Icarus*, *287*, 30-36. [9] Earle A. M. et al. (2017) *Icarus*, *287*, 37-46. [10] Stern S. A. et al. (2017) *Icarus*, *287*, 47-53. [11] Forget F. et al. (2017) *Icarus*, *287*, 54-71. [12] Bertrand T. et al. (2018) *Icarus*, *309*, 277-296. [13] Moore J. M. et al. (2018) *Icarus*, *300*, 129-144. [14] White O. L. et al. (2019) *Nature Astronomy*, *3*, 62-68. [15] Singer K. N. (2016) *LPS XLVII,* Abstract #2276. [16] White O. L. et al. (2017) *Icarus*, *287*, 261-286. [17] Skinner J. A. et al. (2018) *Planetary Geologic Mapping Protocol-2018.* USGS, Flagstaff, AZ. [18] Schenk P. M. et al. (2018) *Icarus*, *314*, 400-433. [19] Collins G. C. et al. (2013) *USGS Scientific Investigations Map 3237.*