MEGAFLOOD ORIGINS FOR PLUTO'S WASHBOARD AND FLUTED TERRAINS. J. W. Miller (juliawmiller@g.ucla.edu) and A. Yin, Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, Los Angeles, CA, USA, 90095.

Introduction: The New Horizons flyby of Pluto revealed a frozen surface likely shaped by both past and present glacial activity. Howard et al. (2017) described active nitrogen glaciers flowing into the northeastern edge of Sputnik Planitia and proposed that the the dendritic valley networks to the northeast of Sputnik Planitia were incised by glaciers[1]. Glacial origins have also been hypothesized for the washboard and fluted terrains[2] and sinuous flat-floored troughs northeast of Sputnik Planitia[1], but we find that this interpretation is less consistent with detailed observations of the region's surface morphology.

The washboard and fluted terrain, consisting of parallel ridges with km-scale spacing and relief[3] was interpreted to have formed by buoyant water-ice fragments rising to the surface of N2 ice glaciers and collecting in elongated sublimation pits[2]. However, this model requires the N2 ice sheet to have stayed motionless over a sufficiently long time to allow sublimation pits to form as clearly defined features with a consistent orientation, which seems unlikely given the evidence of modern glacial flows on surfaces with similar topographic gradients[1]. Meanwhile, the lack of clear flow directions and absence of glacial scouring and debris in the flat-floored troughs calls the hypothesis of glacial incision into question.

It is important to note that the region northeast of Sputnik also contains landforms that have not been explained despite the fact that they are spatially intermingled with the valley networks and the washboard-fluted terrain. These include steps along steep-walled flat-floored valleys, plunge-pool-like depressions at the bases of the valley steps, badlands bounded by the valley networks, and pothole-like depressions without raised rims. When considering these landforms and the earlier documented valley networks and the washboard-fluted terrain as a whole, we suggest that they might all be explained by a single geologic process: N2-fluid megaflooding sourced from the glaciated northern highland region.

Data and Methods: We used ArcGIS to combine the highest-resolution images taken from the New Horizons LORRI instrument and correlated them with the relevant elevation data. This allows us to observe the extent, shape, and orientation of landforms in the washboard terrain and its bounding regions.

Results: The northern valley terrain (in the top half of Figure 1A) contains flat-floored and steep-walled troughs terminating within deep-cut valleys. The valley floors locally display streamlined ridges indicating a southward flow direction. Farther to the south is a complex assemblage of terrains consisting of steps and troughs, hosting washboard ridges in low-lying areas (green arrow in Figure 1C) and fluted ridges carved into the sides of craters and troughs (blue arrows in Figure 1B). Individual washboard ridges consistently display convex southward geometry pointing to the local downhill direction. The washboard terrain is underlain by layered deposits exposed at crater and trough walls. The area is locally dotted with steep-walled circular depressions without raised rims (orange arrows in Figure 1C).

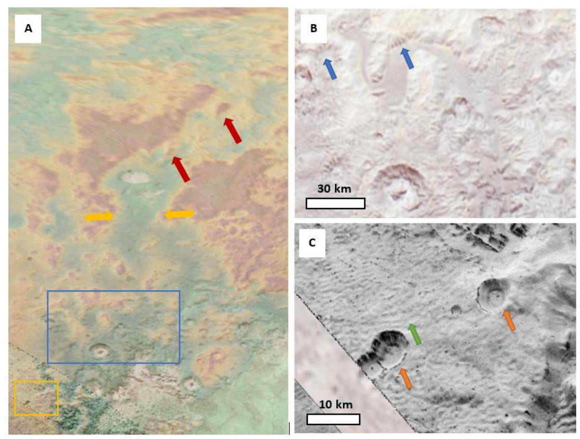

Figure 1: A) The primary region of interest for the study, to the northwest of Sputnik Planitia from 42°-78° N. The northern portion of this area contains wide, steep-sided valleys with streamlined features. B) Immediately adjacent to Sputnik Planitia, the region indicated in the blue rectangle in (a) has a channeled-scabland-like appearance, with broad, sinuous and flat low-lying regions and both isolated and interconnected regions of higher elevation. Blue arrows point to rip walls. C) The orange rectangle in (a), showing high-resolution images of washboard terrain. The green arrow points to concave ripple-like features and the orange arrows point to several steep-sided kolk-like features.

Interpretation: Global climate models suggest that liquid nitrogen at Pluto's surface is unlikely in the past tens of millions of years[4,5]. However, the climate may have been milder earlier in the body's history, during the hypothesized formation of the washboard and fluted terrain (~4.0 Ga[2]). Differentiation and radiogenic heating, for example, would likely have had a significant and sustained effect on surface temperatures[6,7]. In addition, slow rates of atmospheric escape[8] imply that Pluto would have retained large quantities of nitrogen over longer timescales than previously expected and estimates of nitrogen reservoirs for early Pluto are substantially greater than those determined at the present day[9]. In light of these possibilities, we propose that the landform assemblage as a whole in the region of northeast of Sputnik may have been created by repeated mega-flood events: the N2 liquid was released from the northern highland valley region where glacial landforms indicate the former presence of an ice sheet.

The presence of streamed landforms on the interpreted glacial valley floors suggests southward glacial flows, whereas variously shaped closed depressions may represent subglacial cavities and ice-margin lakes. The valley narrows (proposed to be the region between the two arrows in Fig. 1A) may have jammed episodically by advancing mountain glaciers. The washboard terrain was originally occupied by a proglacial plain before its formation. The plain was underlain by layered deposits that may have filled up the Burney crater. Outbursts of glacier lakes into the proglacial created linear ridges (i.e., the fluted terrain) due to mega-flood streamlining, complex ridges from turbulent flows with complex routings, and steps from turbulent channel flows. A possible Earth analogue for the landscape formation of the region northeast of Sputnik as a whole is the channeled scablands of eastern Washington. This terrain (Fig. 2) was formed through repeated outbursts of Lake Missoula episodically dammed by the advancing Cordilleran ice sheet at ~15[10,11,12]. Using this analogue as a guide, we suggest that the complex-ridged terrain resembles the scabland terrain, the steps resemble cataracts, highly dissected steep trough walls resemble flood-induced rip walls/coulees, circular depressions resemble vortex kolk pits, and convex-southward washboard ridges resemble giant ripples[13] of Pardee (1942).

Conclusions and Future Work: The curvilinear nature of the ridges and the resemblance of the wider area to the scablands associated with terrestrial megafloods provide support for the idea of liquid nitrogen floods in Pluto's ancient past.

To test our hypothesis, we plan to conduct a field study in the scablands of Eastern Washington to more carefully examine the variation in wavelength and amplitude of the Giant Current Ripples with distance from the location of outflow.

We additionally intend to look more closely at the range of climate conditions possible for early Pluto to develop a better understanding of what processes might have been possible on its surface.

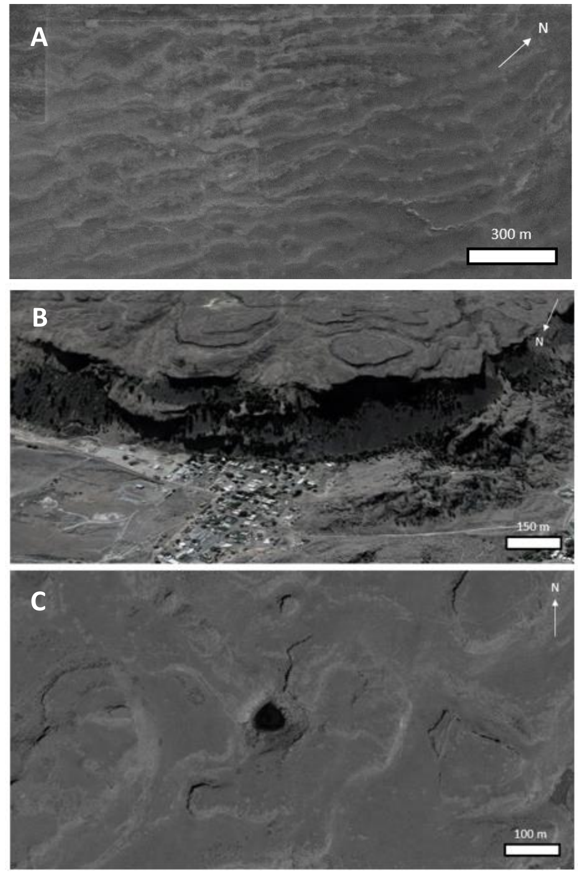

Figure 2: A) Giant current ripples near Marlin, Washington (47°25′48″ N 118°59′04″ W). B) Coulee near Coulee Dam in eastern Washington (47°55′44″ N 119°02′31″ W). C) Channeled scablands with a central kolk pit in eastern Washington (46°54′21″N 119°16′47″W). All images are from Google Earth.

This might include numerical modelling of potential orbital parameters of the Pluto-Charon system, and in particular, investigating the effects on climate of high eccentricity and obliquity coupled with high levels of radiogenic heating.

References: [1] Howard et al. (2017) *Icarus* **287**, 287–300. [2] White et al. (2019), *Nature Astron.* **3**, 62-68. [3] Moore et al. (2016), *Science* **351**, 1284-1293.[4] Earle et al. (2017), *Icarus* **287**, 37–46. [5] Bertrand et al. (2018), *Icarus* **309**, 277–296. [6] Robuchon and Nimmo (2011), *Icarus* **216**, 426-439. [7] McKinnon et al. (2021), *The Pluto System After New Horizons*, 507-544. [8] Gladstone et al. (2016), *Science* **351**, 1280-1286. [9] Glein and Waite (2018), *Icarus* **313**, 79-92. [10] Bretz (1923), *J. Geol.* **31**, 617–649. [11] Bretz (1969), *J. Geol.* **77**, 505-543. [12] O'Connor et al. (2020), *Earth Sci. Rev.* **208**, 103-181. [13] Pardee (1942), *GSAB* **53**, 1569-1600.