LOBATE DEBRIS APRONS OBSERVED ON PLUTO FROM NEW HORIZONS.

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Introduction: Lobate Debris Aprons (LDAs) are broad and thick ice-rich slumping material that are commonly found at the base of topographically prominent features, mainly glaciers and massifs [1,2]. These features have been observed at the mid-latitudes on Mars and mainly used for research in recent climate changes. On Pluto, similar features, both in appearance and topographic profiles, are observed on the western mid-latitude rim of Sputnik Planitia, mostly on the bases of the chaotic blocky mountains or the glacier fragments further south of the impact basin (Figure 1). These features on Pluto may also provide insight into recent climatic changes in regards to surficial interactions and viscous flowing on Sputnik Planitia during the Plutonian summer season (the time at which New Horizons arrived at Pluto in 2015). These Plutonian LDAs have been found to be divided by different climate zones.

Pluto's climate zones are defined by latitude ranges [3,4]. In the current period on Pluto, the Arctic Climate Zone (30°N – 90°N) experiences periods of constant sunlight in summer and darkness in winter lasting more than one full rotation. The Tropical Arctic Zone (30°N – 60°N) experiences both overhead sun and arctic seasons. The region below 30°N currently experiences the Diurnal Climate Zone, with day/night cycles throughout an orbital year.

We present an analysis of the timing emplacement of 7 LDAs along the western lobe of Sputnik Planitia. Our objective is to define the geomorphology of these LDAs with implications from Pluto's specific climate zones.

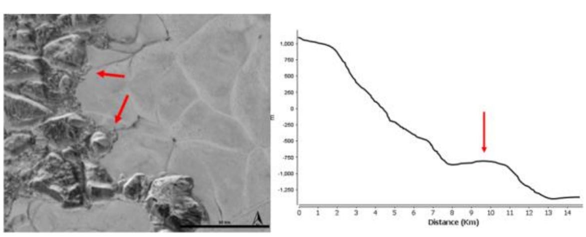

Figure 1: Left: LORRI image of an LDA site on the shores of Sputnik Planitia. Scale bar at 50 km. Arrow points north. Right: Example of an LDA DEM profile (x-axis distance in km; y-axis elevation in m).

Methodology: The primary datasets used to evaluate the geologic observations surrounding Sputnik Planitia were from the Long Range Reconnaissance Imager (LORRI): a visible camera instrument onboard the New Horizons probe (~300 m/pixel). Additional data products used for the manipulation of the images and measurements was JMARS. 300-m resolution New Horizons Digital Elevation Models (DEMs) [5] were also in the updated JMARS package (v 3.8.2).

This study utilized the DEMs of 7 chosen areas of prominent LDAs on the western rim of Sputnik Planitia (Figure 1; Table 1). From the DEMs, we measured the diameter of the lobe, slope, and apron height. We used certain approximate values from [1,6] (Table 2).

Table 1: Locations of the LDAs on Pluto in this study and respective climate zones.

Site	Latitude	Longitude	Current Climate Zone
A	39.98	161.81	Tropical Arctic
B	36.75	159.11	Tropical Arctic
C	32.92	158.75	Tropical Arctic
D	28.33	157.5	Diurnal
E	25.13	153.44	Diurnal
F	25.05	159.78	Diurnal
G	12.91	162.16	Diurnal

Table 2: Definitions and theoretical values for parameters used in the numerical approximations.

Description	Symbol	Value
Water ice density	ρI	920 kg m^{-3}
Density difference between water ice and solid nitrogen	Δρ	60 kg m^{-3}
Gravity	g	0.617 m s^{-2}
Viscosity (water ice)	η	1x10^{14} Pa s
Slope	θ	From DEM
Apron Height	H	From DEM
Apron Toe Height	T	From DEM
Radius	R	From DEM

These values are then used to calculate the approximate downhill velocity *v* of the LDA material:

$$v = \frac{(\rho_I H - \Delta\rho T)gR}{6\eta} * (sin\theta - \mu cos\theta)$$

The velocity is then used in a distance-rate-time equation to estimate the time emplacement of the current LDA morphology.

Results: The slopes of the LDA sites above the proposed arctic circle latitude on Pluto (A-C) are relatively shallower than the southern LDA sites (D-G). These slopes are considered when measuring the emplacement time of the aprons. Figure 2 shows the relative time emplacement of these LDA sites on Pluto using the variables from Table 2. An initial timing limit was placed as Sputnik Planitia is a young geological feature (< 10 million years old) [7]. The LDA sites (A-C) show a relatively higher time of emplacement compared to those found below this latitude. It should be noted that these ages estimate the emplacement of the lobate debris apron in its entirety, not the glacier itself.

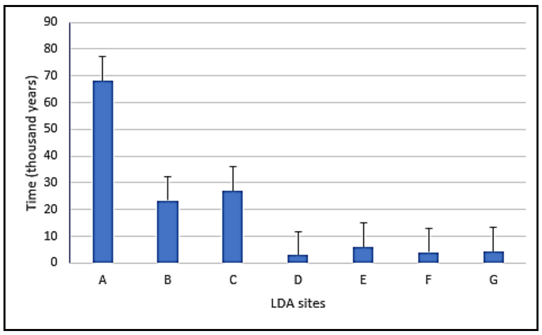

Figure 2: Estimated emplacement ages of the LDA sites as defined by Table 1. Error bars show upper-limit standard deviation.

While Sites A-C appear "older" in their time emplacement, we propose that this timing is rather a clue to the cyclic nature of localized insolation and the material slumping process progresses relatively faster in the more northern latitude LDA sites than the southern sites.

Discussion: Figure 3 shows the maximum diurnal insolation reached at each latitude over a single Pluto year during three epochs [4] with the LDA latitude locations (red box indicating LDA Sites A-C; purple box indicating LDA Sites D-G). Note how the LDA sites at the Tropical Arctic Zone (A-C) experience a higher insolation at the current orbit than the Diurnal Climate Zone sites (D-G). Pluto's average insolation varies dramatically with latitude over short timescales (within a few decades) [4]. Over a single Pluto orbit (248 Earth years) leading up to the New Horizons fly-by, Pluto's poles have averaged 0.25 J/m^2. LDA sites at the Tropical Arctic Climate Zone experienced these more intense summers, relating to more slumping of material than the more southern latitude LDA sites.

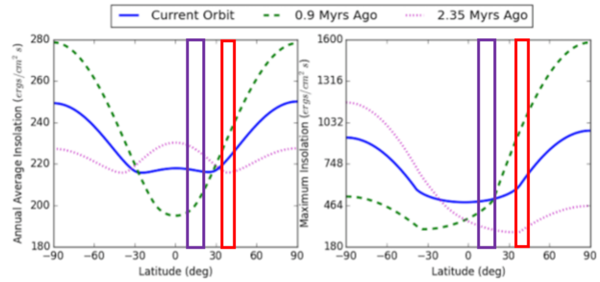

Figure 3: (Left) Annual average insolation vs latitude for a single Pluto year. (Right) Maximum diurnal insolation vs latitude. Dark blue line is current orbit. Boxes represent latitudes of LDA sites. Adapted from [4].

Since climate zones and insolation are both dependent on obliquity, the ranges of Pluto's climate zones fluctuate with its changing insolation patterns. When Pluto's arctic and tropical arctic zones are at their maximum range, Pluto's poles receive the maximum annual average insolation, and the equator with about 30% less average annual insolation [4].

Conclusions: We conclude that Pluto's LDAs can be mobilized in a slumping formation down a slope onto the surface of Sputnik Planitia. Their present locations and morphologies can be adequately explained by a direct influence of insolation changes, mainly at the current arctic circle at ~30° N. Once slumping occurs above this latitude, the LDA would "grow" with each summer cycle. This, in turn, defines the LDAs to be of relatively older ages (> 20,000 years) due to a more continuous cycling of slumping from more accumulation of sunlight/insolation. Below this latitude, the LDA experiences a shorter burst of activity in sunlight accumulation, making these features appear relatively young within ages of < 15,000 years. These LDA features allow us to observe a geologically young feature upon Sputnik Planitia, and the cyclic nature of mass wasting influenced by climate zones. The dramatically different insolation patterns experienced over time have the potential to not only effect volatile transport but also have a lingering effect on the surface geology and composition of Pluto.

References: [1] Parsons, R. et al. (2010) 41st LPSC, Abstract 1463. [2] Joseph, E. et al. (2016) 47th LSPC, Abstract 2962. [3] Binzel, R. et al. (2017) Icarus, 287, 30-36. [4] Earle, A. (2018) Doctoral Dissertation, MIT. [5] Schenk, P. et al. (2018) Icarus, 314, 400-433. [6] O'Hara, S., Dombard, A. (2018) 49th LPSC, Abstract 1360. [7] Buhler, P., Ingersoll, A. (2018) Icarus, 300, 327-340.