MORPHOLOGY AND SEDIMENT DYNAMICS OF ELONGATING LINEAR DUNES AT HELLESPONTUS MONTES, MARS

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1. INTRODUCTION

Bedforms on planetary surfaces, such as dunes and ripples, act as a record for wind regime, past and current climate, erosion rates, and availability of sediment [1-3]. Linear dunes are present across multiple planetary surfaces, including Earth, Mars, and Titan [4-7], yet their sediment dynamics are poorly understood. Linear or longitudinal dunes are characterised by elongated sand ridges, whose crests are orientated < 15° from the resultant sand flux (Figure 1).

Linear dunes typically develop in multidirectional wind regimes and may simultaneously migrate laterally (i.e., normal to crest; e.g. [8]) and by elongation (i.e., parallel to crest; e.g. [9-10]). Recent laboratory and numerical experiments, as well as remote sensing and field observations, have shown that in areas with multidirectional wind regimes and low sediment supply (i.e., non-erodible bedrock), linear dunes will form and grow by elongation (the "fingering mode"; [9-12]). Testing these predictions and comparing the morphology and development of terrestrial linear dunes to those on other planetary surface is critical for understanding dune dynamics.

In contrast to the surfaces of Earth and Titan where linear dunes are abundant and can form extensive sand seas, linear dunes on Mars in non-polar regions are rare, compared to other types of dune. However, the abundance of high-resolution, multi-temporal martian orbital remote sensing data means that the surface of Mars is still an important planetary laboratory for understanding linear dunes on planetary surfaces. Here we report on the morphology, development, and sediment dynamics of linear dunes in the Hellespontus Montes region of Mars.

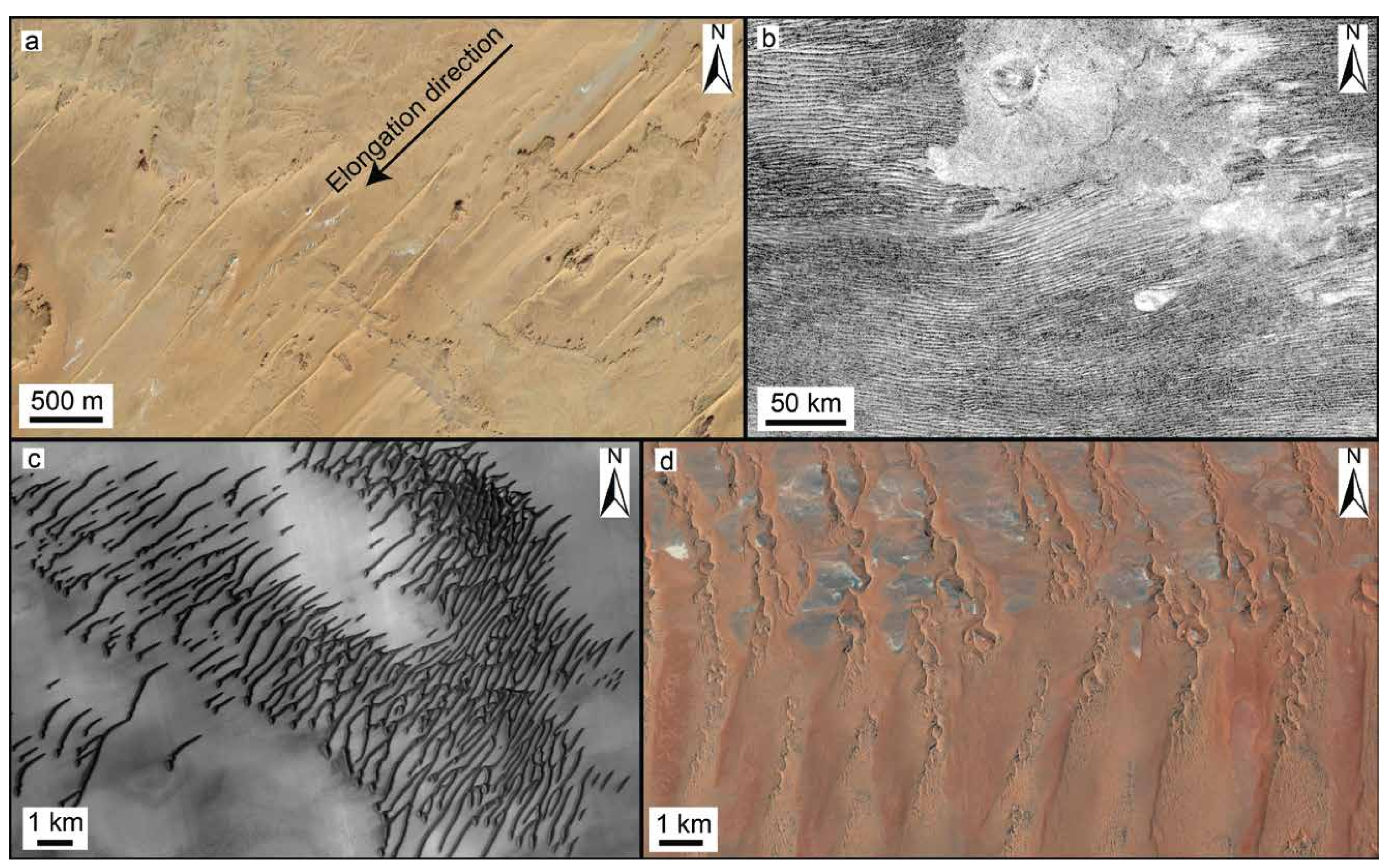

Figure 1. Examples of linear dunes on planetary surfaces. (a) Linear dunes elongating from behind topographic mesas near the Bodele Depression, Chad; (b) Linear dunes in the equatorial regions of Titan; (c) Linear dunes in the north polar regions of Mars; (d) Sinuous linear dunes in the Namibian desert.

2. Study Site

Our study site is an 8 by 10 km kilometre dune field on the western margins of Hellespontus Montes (41.5°S, 44.5°E), comprising both linear and barchan dunes. The Hellespontus Montes dune field contains some of the best developed linear dunes on Mars outside of the polar regions and has extensive repeat High Resolution Imaging Science Experiment (HiRISE; 0.25 m/pixel; [13]) coverage, spanning 8 Earth years. High regional sediment fluxes (~ 0.9 m/EY; 14 $m^3\ m^{-1}\ EY^{-1}$) are associated with the Hellas basin slope winds, mid-latitude westerlies, and locally rugged terrain [14].

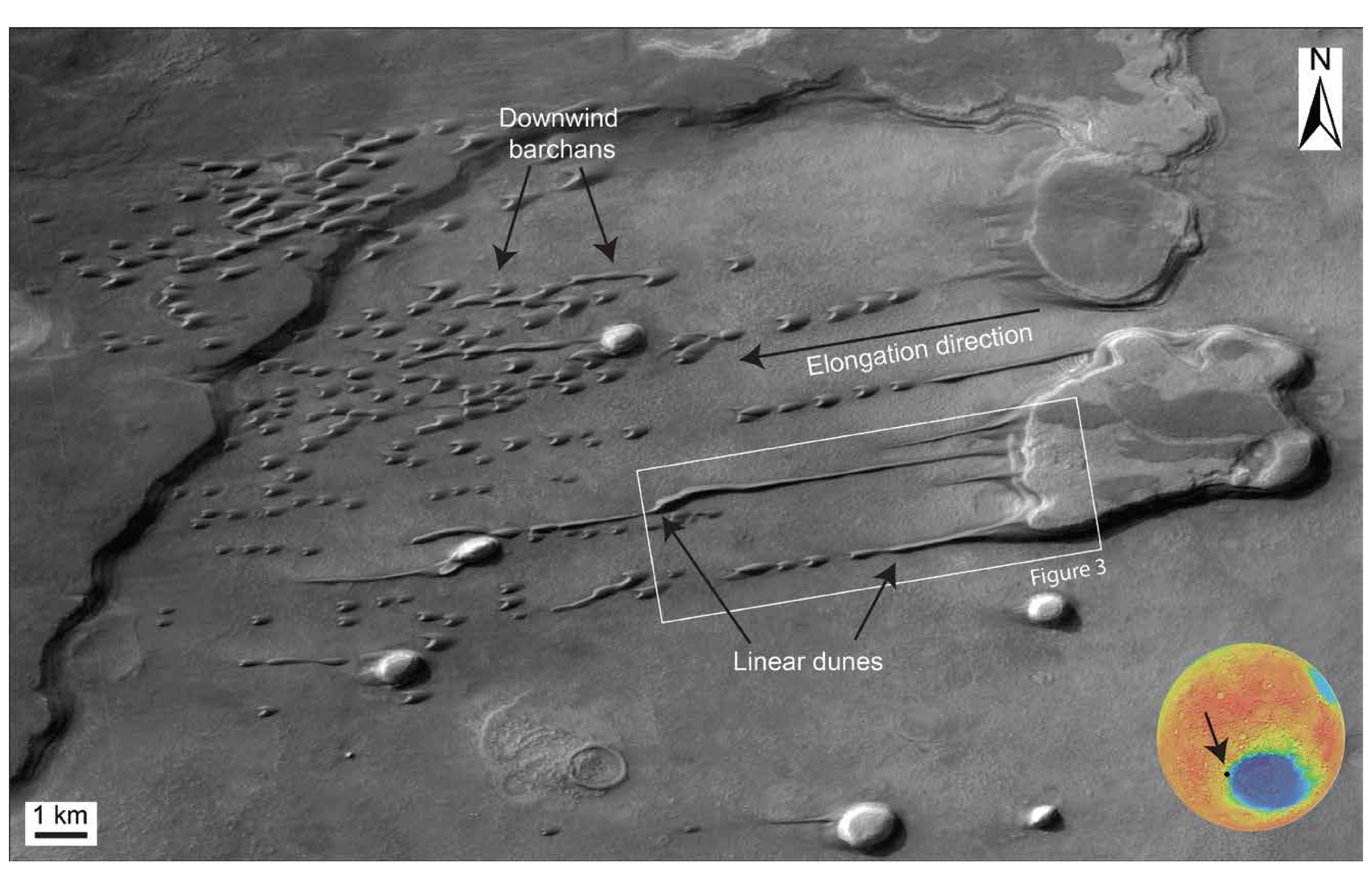

Figure 2. CTX image showing the Hellespontus Montes dune field. Linear dunes elongate in a westward direction from mesas, before breaking down into barchan dunes at the downwind end of the dune field. Very little intra-dune sand is observed throughout the dune field.

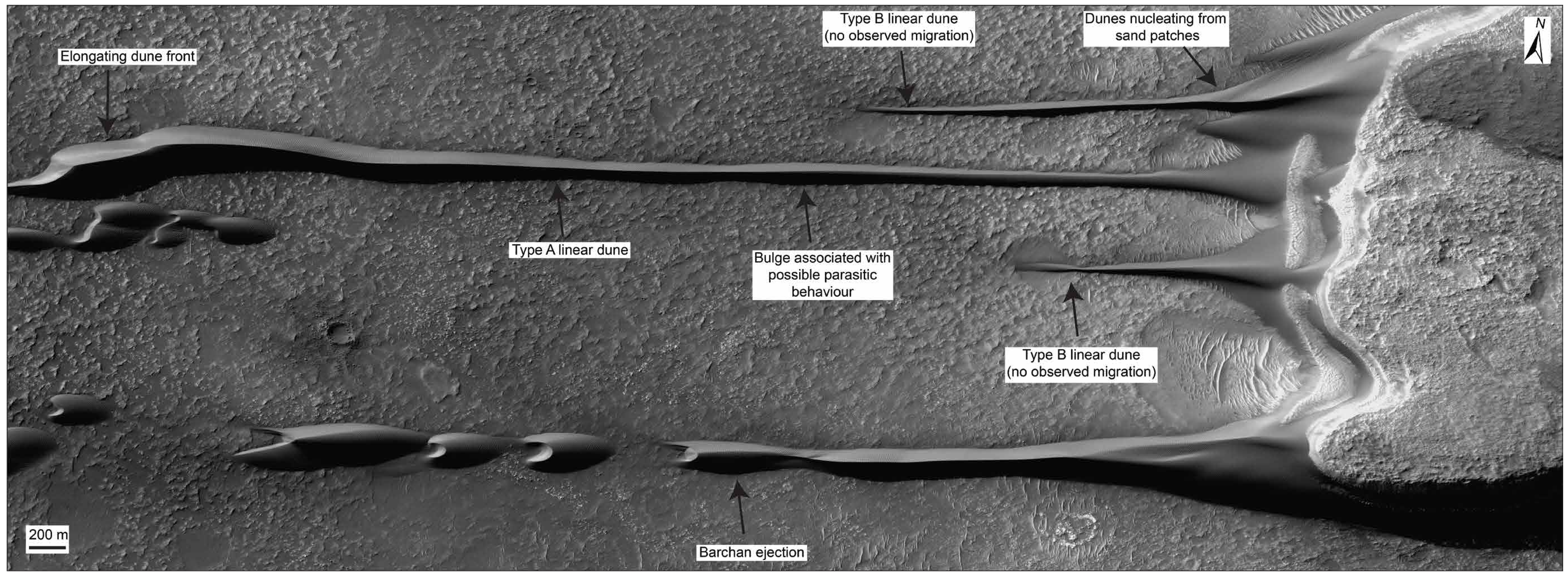

Figure 3. HiRISE image showing part of the Hellespontus Montes dune field. Linear dunes with different morphometrics are observed: Type A linear dunes increase or maintain a constant height and width in the downwind direction, whereas Type B linear dunes decrease in both height and width downwind. Only Type A linear dunes were observed to migrate over the 8 year time period. Parasitic behaviour seems to be occuring between different linear dunes. At the terminations of the linear dunes, barchan ejection is observed and sometimes new linear dunes segment.

3. Methods

- We used a combination of HiRISE and Context Camera (CTX; 6 m/pixel; [15]) image and topographic datasets to investigate the linear dunes at Hellespontus Montes and measure their morphometrics (length, width, height).

- We produced HiRISE and CTX DEMs according to the method of [16], which we used to produced precisely co-registered and orthorectified time series images.

- We then measured the displacement of the linear dune fronts to derive migration rates, as demonstrated by [9]. The crest height at the linear dune fronts was multiplied by migration rates to produce crest sand fluxes, as is standard for planetary aeolian studies [e.g., 1, 14].

4. RESULTS

4.1 Morphology and Morphometry of Hellespontus Linear Dunes

- The linear dunes at the Hellespontus Montes site nucleate from sand patches on the western (downwind) side of mesas.

- 12 developed linear dunes are observed throughout the dune field, which are 1-7 km long and have very low sinuosity along their lengths, except where they divert around local topographic obstacles.

- The heights (~ 0.5-30 m) and widths (~ 10-150 m) of the linear dunes is not constant along their lengths (Figure 3), and they do not keep a constant aspect ratio (height divided the half width).

- The linear dunes can be (broadly) divided into two morphometric categories: Type A, which are > 1 km in length and increase in both height and width along their length or stay roughly constant; and Type B, which are < 1 km in length and decrease in both width and height along the length of the dune through to the tip (Figure 3).

- Possible parasitic behaviour between dunes is observed, where sand is being transferred to the downwind linear dunes, associated with local bulges in the dunes (Figure 3).

- At the downwind end of the dunes, segmentation of the dunes occurs and new linear dunes form. Barchan ejection is observed at the termination of many dunes (Figure 3).

4.2 Migration Patterns and Sediment Fluxes of Hellespontus Linear Dunes

- Like the downwind barchans, the linear dunes at Hellesptonus are migrating in a westard direction, elongating outward from the mesas.

- Manual measurements show that the Type A linear dunes are migrating at 1-3 m/EY, which gives crest sediment fluxes of 28-33 $m^3\ m^{-1}\ EY^{-1}$. Contrastingly, the Type B linear dunes show very little migration over the 8 year time period, although changing ripple patterns suggest these sand bodies are still highly mobile.

- Little to no lateral migration was observed along the length of any linear dune.

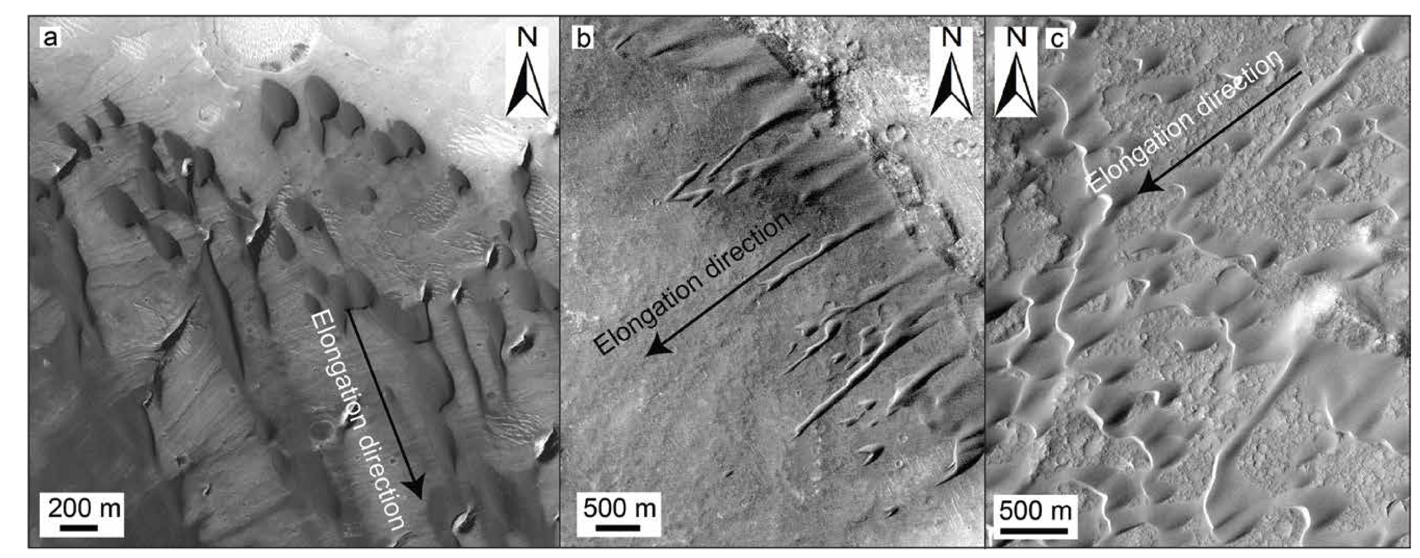

Figure 4. Other examples of elongating linear dunes in non-polar regions of Mars. (a) HiRISE image of upwind barchans trending into elongating linear dunes where sand has collected in the wind shadow of mesas at Capen crater. (b) CTX image of elongating linear dunes near Meroe Patera. Like at Hellespontus, barchan ejection is also observed. (c) HiRISE image of part of the Nili Patera dune field. Elongating linear dunes are observed where sand has collected in the wind shadow of mesas in the sand starved regions of the dune field.

5. Discussion

The observed lengthwise migration direction strongly suggests that the linear dunes are migrating by elongation only, consistent with the (1) lack of meandering observed along the length of the dune; (2) the orientation of the dune ripples (i.e., parallel to crest); and (3) the fixed sand source of the dunes. As in terrestrial examples, the fixed (and limited) sand source for the linear dunes appears to be limiting their ability to laterally migrate [9, 12]. These observed are consistent with the morphology of other linear dunes on Mars (Figure 4).

Recent numerical simulations by [12] suggest that linear dune morphometrics can be related to their maturity. The length and volume of the linear dunes are predicted to be a function of sediment input, which reach a maximum value with time. The observed elongation of the Type A linear dunes suggest they have not yet reached their maximum length.

Parasitic behaviour is also predicuted to occur between adjacent linear dunes [12], with sand being transferred to the downwind linear dunes, which is observed at Hellesptonus. Indeed, the largest linear dune at Hellespontus is downwind of two adjacent, smaller (Type B) linear dunes, which likely increased its downwind sediment flux, contributing to its increasing volume.

Contrastingly, steady state linear dunes are predicted to no longer elongate (having reached their maximum length), as the input sand flux is the same as the output sand flux, and consequently the dune volume decreases downwind, away the sediment source [12]. The decreasing volume of the Type B linear dunes and their lack of observed elongation over 8 EY suggests they may be at or near steady state.

As the Type A linear dunes are not in a steady state, their approximate age should be proportional to their lengths. Assuming a constant elongation rate, the longest linear dune at Hellesptonus Montes should have begun to form ~ 2,000-7,000 years ago.

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