GEOMORPHOLOGICAL AND TOPOGRAPHIC CHARACTERISTICS OF BRAIN TERRAIN IN THE ISMENIUS LACUS QUADRANGLE, MARS. G. S. Meyer[1], Whyjay Zheng[1,2], M. E. Pritchard[1], [1]Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY, [2]Department of Statistics, University of California Berkeley, Berkeley, CA.

Introduction: Brain terrain (BT) is a type of mid-latitude martian cryospheric feature consisting of complex ridges, generally believed to have formed through water ice sublimation [1,2]. More recent studies propose, through comparison of Earth-bound analogs, that eolian processes may be the causation of these large-scale ridges as opposed to sublimation processes [4]. There are two comprehensive classifications for brain terrain: open cell and closed cell, based solely on visually assessable characteristics[1,2]. Closed cell brain terrain (CCBT) is characterized as having thick, tall (2-6m), widely spaced ridges [1]. Open cell brain terrain (OCBT) presents hyper-sinuous, tendril-like ridges that are much shallower (0.5-1m) and closer together than CCBT [1]. The primary topographical host for brain terrain is lineated valley fill (LVF) – ice rich flow features lining the mid-latitude channels of Mars – however, concentric crater fill and lobate debris aprons will commonly have brain terrain ridges present. [1,2] The relationship between lineated valley fill and the varying morphological types of brain terrain is not well understood.

In this study, we constrain the geomorphology and topography of brain terrain by presenting a detailed morphological analysis to limit possible formation theories. We analyze newly available HiRISE digital terrain models (DTMs) and associated orthoimages using ArcGIS and MATLAB.

Data: New DTMs containing lineated valley fill presenting with brain terrain allow revisions of current, somewhat limited, morphological definitions. All DTM's are obtained through HiRISE.
DTEEC_007795_2175_009588_2175_U01 (LVF1) 37.35°N, 24.64°E (Deuteronilus Mensae)
DTEEC_033165_2195_032875_2195_A01 (LVF2) 39.35°N, 24.72°E (Deuteronilus Mensae)
DTEEC_019358_2225_018857_2225_U01 (GLF1) 42.2°N, 50.53°E (Protonilus Mensae)
DTEED_009455_2215_008809_2215_A01 (GLF2) 41.27°N, 54.73°E (Protonilus Mensae)

Morphological Subclassification: A sub-classification of specific morphological groups is proposed to better categorize subsets of brain terrain based on ridge interspace (ridge density), average ridge height, ridge cohesion (discontinuous/ continuous), spatial position, and feature length (Tab. 1). *Looped (L)*: OCBT exhibiting a circular pattern wherein by ridges loop into completed ovals or circles. Loops present as independent circular structures but may be connected by a much longer, consecutive ridge. *Small Interspace Sinuous (SIS)*: OCBT with tendril-like narrow ridges, densely spaced. Interspace between ridge peaks is relatively small. *Large Interspace Sinuous (LIS)*: OCBT characteristic of SIS, however peak to peak distance (valley width) has increased greatly. Valleys are much deeper, and ridges are slightly larger. *Discontinuous Aligned (DA)*: OCBT narrow ridges that contain interspacing between horizontally oriented ridges but share general alignment in directional banding.

CCBT only subclassifies into two much more broad morphologies dependent on interactions with the host feature, modified from [1]. *Mantle Polygons (MP):* CCBT that presents in the shape of a polygon, independently. *Aligned Mantle Polygons (AMP):* CCBT aligned in the direction of the valley fill flow, creating a much more stretched but still polygonal feature.

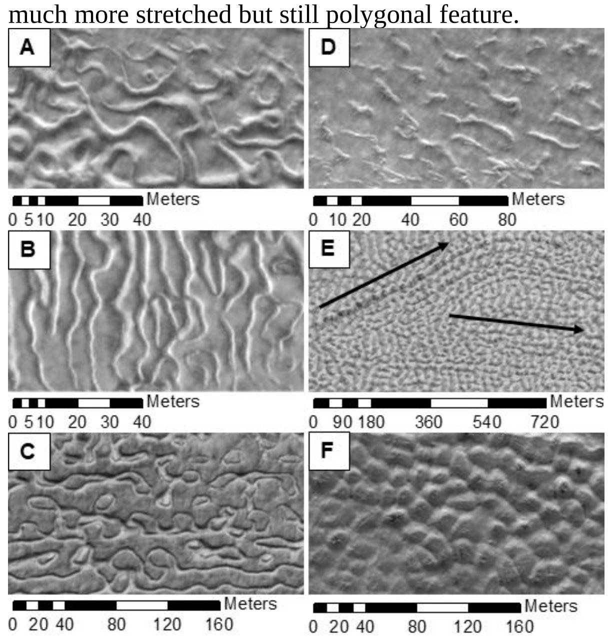

Figure 1a-f. A: SIS located near the mid-slope of LVF1; B: LIS found near the mid-flanks of LVF1; C: Looped open cell brain terrain present on LVF2; found in low region flanked by higher elevation closed cell brain terrain; D: DA transitioning from SIS on LVF1; E: AMP found on LVF2; arrows show alignment direction of polygonal pattern; F: MP lining the middle-most portion of LVF1. Image (A-F): NASA/JPL/UA.

The interpolate line function in ArcGIS can be used to generate an elevation map across identified zones of OCBT and CCBT. To estimate morphological variables such as peak to peak distance, ridge length, and ridge height we fit these profiles locally with a sine function and retrieve the least square parameters of the regression model in MATLAB. This makes it so that proposed subclassifications are not only visually assessed, but have numerical figures attached to them.

Table 1. Average ridge peak-ridge peak distance and average ridge height of each proposed subclassification of BT on LVF1, LVF2, & GLF1.

BT Type	$\bar{x}$ Ridge to Ridge Dist. (m)	$\bar{x}$ Ridge Height (m)
LIS	12.31	0.97
SIS	12.33	0.99
L	12.39	0.834
DA	12.35	0.56
MP	14.1	3.14
AMP	15.7	5.88

Ridge Direction: Brain terrain populating LVF2 appears to have a specific ridge direction. Glacial crevasse style mapping is applied to brain terrain valleys in ArcGIS revealing the orientation of ridges (Fig. 2).

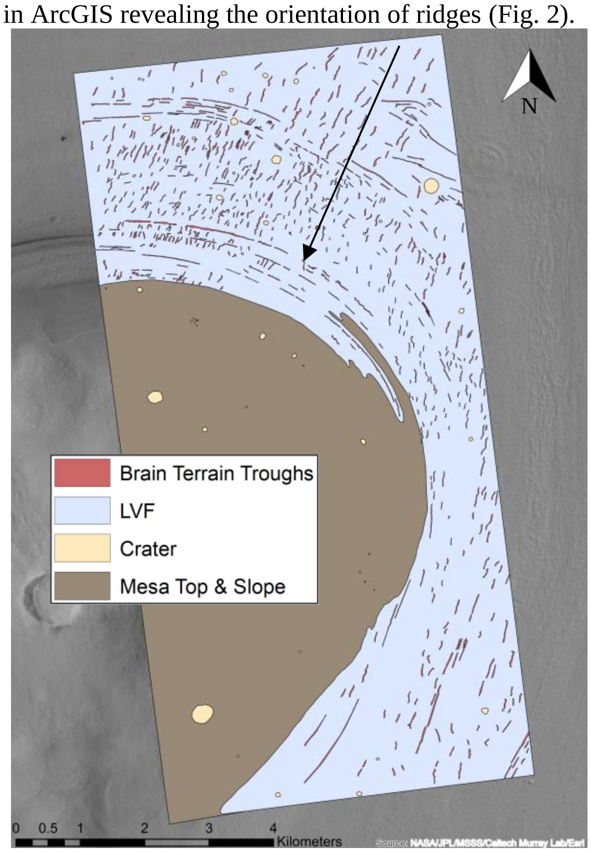

Figure 2. BT crevasse map applied to LVF2 showcasing NE-SW ridge orientation and proposed LVF flow direction (arrow). Image: NASA/JPL/UA.

When interpreting the trough map (Fig. 2), the ridge direction of BT on LVF2 trends in the same direction as the apparent lineated valley fill flow. Only in regions affected by other large-scale topography does the ridge direction change. The ridge direction changes from a north-east to south-west pattern to a curved east-west orientation following the base of a large sloping prominence (mesa) and again located further from the slope. The further-out orientation change can be attributed to large scale LVF movement, but the change directly flanking the large slope is especially likely to be caused by some interaction between the LVF and the slope; possibly glacio-tectonism.

Discussion: In mapping BT geomorphology it is apparent that OCBT is consistent with being a transitional feature, only generally found at boundaries of high-scale change in elevation – be that of a large sloping mesa or the host LVF itself; possibly related to sedimentary composition, controlled by nearby slopes. At points, OCBT looks ‘buried’, or as if it has been filled in by sediment, supporting a sedimentary-dependent origin. These transitional margins and their origin is better understood by applying the proposed subclassifications of OCBT (Fig. 1a-f) thus, revealing a trending pattern that typically sees LIS or SIS transition into DA brain terrain (Fig. 1d). Eolian processes might better explain the sinuous nature of these margins, especially if sedimentary density is a primary variable in ridge direction. [4]

Conclusions: Brain terrain geomorphology is highly variable, but classifiable, and appears to be influenced by local topography. OCBT ridges are numerically separated in scale and ridge distance from CCBT on average, in the order of several meters. BT formed at relatively the same time as their LVF host (100-500mya) [5] but may continue to change via either eolian or sublimation processes, controlled by an interaction caused from large-scale slope features.

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References: [1] Levy, J. S., Head, J. W., & Marchant, D. R. (2009a) *Icarus*, *202*(2), 462–476. [2] Levy, J. S., Head, J. W., & Marchant, D. R. (2009b) *Journal of Geophysical Research E: Planets*, *114*(1). [3] Hepburn, A. J., Ng, F. S. L., Livingstone, S. J., Holt, T. O., & Hubbard, B. (2020) *Journal of Geophysical Research: Planets*, *125*(2). [4] Cheng, R. L., He, H., Michalski, J. R., Li, Y. L., & Li, L. (2021) *Icarus*, *363*. [5] Morgan, G. A., Head, J. W., & Marchant, D. R. (2009). *Icarus*, *202*(1), 22–38.