

EARTH ANALOGUE IMPLICATIONS FOR BRAIN TERRAIN FORMATION ON MARS. S. M. Hibbard¹, G. R. Osinski², E. Godin³, N. R. Williams¹, and M. P. Golombek¹, ¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States 91109 (shannon.m.hibbard@jpl.nasa.gov), ²Institute for Earth and Space Exploration / Dept. of Earth Sciences, University of Western Ontario, ³Centre d'Études Nordiques, Université Laval.

Introduction: Brain terrain occurs in the mid-latitudes of Mars and is characterized by an anastomosing complex of ridges and troughs arranged in a “brain-like” pattern (Fig.1). Brain terrain has been proposed to form as glacial ice lag deposits initiated via thermal contraction cracks, followed by topographic inversion from the sublimation of underlying ice [1]. An alternative mechanism in the form of frost heaving similar to the formation of stone circles on Earth has also been suggested [2]. More recently, brain terrain has been proposed to form via aeolian and salt/evaporite weathering processes in the absence of ice [3].

We recently identified a landform, referred to as Vermicular Ridge Features (VRFs), in the Canadian High Arctic on Talluruti (Devon Island) [4,5] and Umingmat Nunaat (Axel Heiberg Island) [6,7] in Nunavut, Canada, that bears remarkable resemblance to brain terrain on Mars (Fig. 1). VRFs exhibit a circular, elongate, sinuous and/or anastomosing ridge and trough morphology in planform that shares many morphological characteristics to brain terrain on Mars [4,6,7].

We mapped the distribution of VRFs across Axel Heiberg Island using satellite imagery and found that they are widespread. Preliminary mapping observations, in combination with field observations of VRFs [4–7] are used to reflect on the VRF formation mechanism

proposed by [5] and to contemplate an alternative formation mechanism for this unique landform. Although we continue to explore the origin of VRFs, we assess the implications it has for brain terrain formation, distribution and ice stability, and apply it to a study site in Arcadia Planitia [i.e., 8,9].

Preliminary VRF Mapping Observations: VRFs were mapped across Axel Heiberg Island based on planform morphology in satellite imagery and comparison to field observations. Approximately 85% (~37,000 km²) of the island was mapped with the other ~15% having poor lighting or resolution, or glacial, snow or cloud coverage. VRFs covered a total area of 29.2 km².

VRFs are more common along the eastern side of the island, most of which occur above the marine limit. The eastern side of the island is composed predominantly of gently sloping meltwater channels. VRFs are consistently found alongside these meltwater channels and can form a string of VRF deposits extending over a few kilometers. The western side of the island is largely mountainous with many steep slopes and lacks VRFs.

Polygons are often present where VRFs occur and appear to be consistently larger in VRF deposits compared to adjacent non-VRF deposits (Fig. 1a), indicating an altered stress field. Based on field observations, we infer larger polygons on VRF deposits

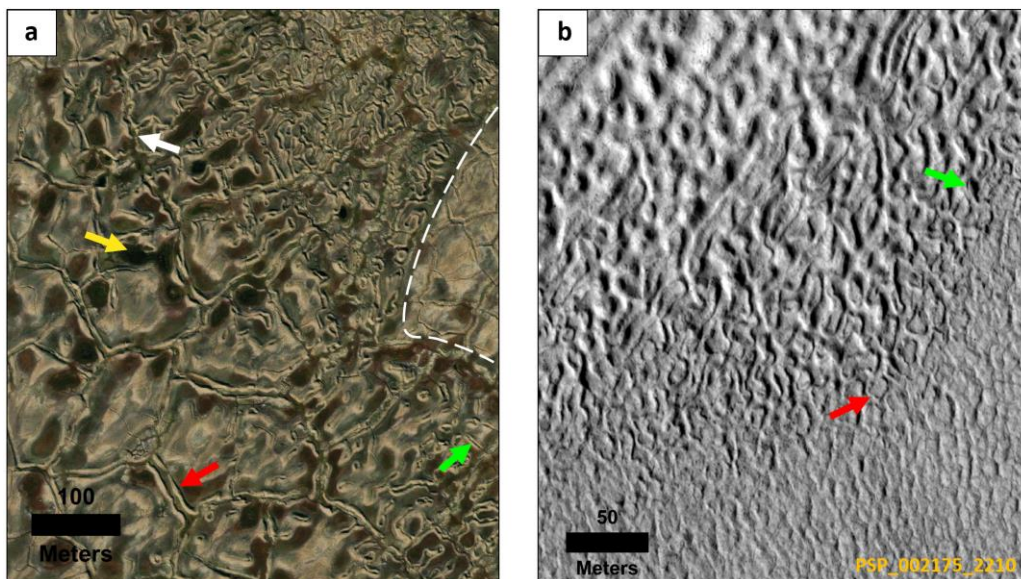


Fig. 1. (a) Example of VRFs mapped on Axel Heiberg Island. White dashed line separates non-VRF deposit from deposit with VRFs. Note difference in polygon size. White arrow – VRF cross-cut by polygon crack. Yellow arrow – thermokarst degradation. Green arrow – VRF ridge cut by thermal contraction crack. Red arrow – polygon shoulders sharing VRF ridges. (b) Example of brain terrain in Utopia Planitia from [1]. Green arrow – ridge intersected by groove. Red arrow – raised polygon shoulders.

could be due to coarse grain sizes causing it to be less frost susceptible. Polygon troughs cross-cut VRFs indicating thermal contraction cracking occurred *after* VRF deposition and formation (Fig. 1a). VRF ridges are also commonly found to share ridges with raised polygon shoulders (Fig. 1a). We interpret this to be the result of thermal contraction cracks splitting VRF ridges which artificially raises polygon shoulders. Additionally, active wedge formation may further contribute to the uplift of polygon shoulders.

Thermokarst degradation is also commonly observed in VRF deposits (Fig. 1a) suggesting the presence of subsurface ice. Additionally, thaw slumps have exposed continuous massive ice (~15 m thick) directly underlying a thin (~1–5 m) VRF deposit near the Axel Heiberg VRF field site [6,7]. We cannot confirm the origin of the underlying ice (e.g., segregated ice vs. glacial ice).

VRF Formation Hypothesis: Our current leading hypothesis for VRF formation is based on field and preliminary mapping observations coupled with landform comparisons from [5]. We propose that VRFs are a product of ablation and disintegration of buried continuous massive ice or ice blocks that is likely glacial in origin that was initially deposited in an ice-marginal setting. These original glacial landforms then subsequently undergo periglacial modification, such as thermokarst degradation, differential upheave, thermal contraction cracking and solifluction. However, the glacial depositional environment may not be consistent for all VRFs even if the mechanism (i.e., ablation of buried ice) is consistent. For example, Devon Island VRFs [4,5] may have formed from abandoned glacial ice largely covered by supraglacial debris, such as an ablation moraine. Axel Heiberg VRFs [6] may have formed from abandoned glacial ice largely covered by glaciofluvial sediments, such as a kame terrace.

Implications for Brain Terrain: If we apply our hypothesized VRF formation mechanism to brain terrain on Mars, then it would suggest that brain terrain on Mars forms from the disintegration of buried massive glacial ice. This would suggest buried ice is, or was, present at one point in time where brain terrain is present. It is unclear whether brain terrain is an active or relict landform. Therefore, extant massive ice may not be inferred from the presence of brain terrain alone; however, ice loss can be inferred. This hypothesis supports a glacial origin [1]; however, we suggest thermal contraction cracking is not necessarily responsible for the formation of brain terrain, as suggested by [1], but is a product of periglacial modification of the deposit that occurs after and possibly concurrently with brain terrain formation via ice ablation.

Arcadia Planitia Case Study: The distribution of brain terrain [7,8] and glacial-related features [9] have been mapped in Arcadia Planitia. We used these datasets to explore the spatial and latitudinal distribution of brain terrain at Arcadia Planitia to test our brain terrain formation hypothesis.

Ice has been detected [10] and observed [11] in Arcadia Planitia, yet a wide variety of surface morphologies are present [e.g., 9,12]. In our mapping area in Arcadia Planitia [i.e., 8,9], we see that brain terrain occurs within a narrow latitudinal band (~38°N and 42°N) among widespread polygonal terrain. North of ~41°N brain terrain begins to transition into a bumpy morphology. Additionally, brain terrain is observed in the south-facing slopes of secondary crater walls south of ~41°N in available HiRISE images. These observations indicate brain terrain may be associated with near-surface ice sublimation.

However, brain terrain is distinctly less prevalent on the glacial units mapped by Hibbard et al. [9]. Instead, these glacial units are largely characterized by a polygonized surface. However, brain terrain in our mapping area exhibits thermally bright properties that account for the moderate thermal inertia values similar to the values seen on the glacial units [9]. These relatively high thermal inertia values could represent a thin lag deposit overlying massive ice, or could represent a high stone concentration on the surface, as is seen in VRF deposits, covered by a thin layer of dust. In the latter scenario, ice could still exist in the subsurface but may be too deep for GRS, THEMIS and TES to detect.

The presence of brain terrain at Arcadia Planitia likely indicates that widespread buried massive ice either exists and is undergoing near-surface ice ablation via sublimation or existed in the past. The depth to the ice is unclear but, based on VRF observations, would be greater than the brain terrain ridge height (>~2 m based on [1]). The glacial units mapped by [9] could represent areas where less near-surface ice ablation and disintegration has occurred and potentially where ice is shallower from the surface.

References: [1] Levy J.S. et al. (2009) *Icarus*, 202, 462–476. [2] Noe Dobrea E.Z. et al. (2007) *7 Int. Conf. Mars*. [3] Cheng R.L. et al. (2021) *Icarus*, 365. [4] Hibbard S.M. et al. (2019) *LPS L*, Abstract #2126. [5] Hibbard S.M. et al. (2021) *Geomorph.*, 395. [6] Hibbard S.M. et al. (2020) *7 ICMPSC*, Abstract #2029. [7] Hibbard S.M. et al. (2021) *RCOP & 19 NSERC Perm. Net AGM*. [8] Williams N.R. et al. (2017) *AGU*, Abstract #2497. [9] Hibbard S.M. et al. (2021) *Icarus*, 359. [10] Morgan G.A. et al. (2021) *Nat. Astron.*, 5, 230–236. [11] Dundas C.M. et al. (2021) *JGR Plan.*, 119. [12] Williams, N.R. et al. (2017) *LPS XLVIII*, Abstract #2852.