PATTERNED GROUND AS AN ALTERNATIVE EXPLANATION FOR THE FORMATION OF BRAIN CORAL TEXTURES IN THE MID LATITUDES OF MARS: HIRISE OBSERVATIONS OF LINEATED VALLEY FILL TEXTURES. E. Z. Noe Dobrea[1,2], E. Asphaug[1], Grant, J.A.[3] Kessler, M.A.[4], and M.T. Mellon[5], and. [1]Earth and Planetary Sciences Department, Earth & Marine Sci. Santa Cruz, CA 95064 edobrea@msss.com, [2]Planetary Science Institute, 1700 E. Ft. Lowell Rd. #106, Tucson, Arizona, 85719-2395, USA, [3]Center for Earth and Planetrary Studies, Smithsonian Institution, Washington, DC, 20013, [4]Institute for Arctic and Alpine Research, University of Colorado, Boulder, Colorado 80309, [5]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado, USA.

Introduction: The mid-latitude (0˚-30˚) regions of Mars, and in particular the fretted terrain, contain some of the most enigmatic landforms observed on the surface of the planet. For example, lineations consisting of ridges and grooves (~decameters in width and km in length) characterize fill within many steep-walled valleys and craters are common in this region. Formation of these lineations has been attributed in the past to downslope movement of wall material by viscous deformation of ground ice [1,2]. Higher resolution images (~1.5-6 m/pixel) show that their surfaces of these lineations consist of a complex pattern of labyrinthine ridges and troughs a few meters wide (also known as brain-coral terrain), whose origin has been interpreted as a thermokarstic lag deposit [2,3] (*e.g.*, Fig 1). However, most of the work on the origin and evolution of this terrain has been highly qualitative and a numerical model has yet to be implemented.

More recently, the High Resolution Imaging Science Experiment (HiRISE) aboard the Mars Reconnaissance Orbiter (MRO) has imaged both lineated valley fill and concentric crater fill at resolutions of ~30 cm/pix. In this work, we seek to demonstrate that the brain coral texture associated with these fills is not the result of degradational processes, but rather the result of self-organization processes of martian soils and rocks, akin to those processes that form patterned grounds on the earth.

Data sets: We used images from the Mars Reconnaissance Orbiter's (MRO) Context Imager (CTX), the Mars Global Surveyor's (MGS) Mars Orbiter Camera Narrow Angle detector (MOC/NA), and the High Resolution Imaging Science Experiment (HiRISE) aboard MRO. The resolution of the images from each of these cameras is approximately 6, 4.5, and 0.3 meters/pixel, respectively. For this report, we focused on observations of the floor of a crater located near 41.1˚N latitude, 261.7˚W longitude.

Observations: Observations of the brain-coral texture performed at ~1.5-6 m/pixel scale using CTX and MOC/NA show a stippled, labyrinthine surface associated with lineated crater fill (Fig 1). The pattern becomes muted and disappears in regions where the slopes become steeper, leading to a relatively smooth-looking surface (right of figure). The actual slope threshold for the disappearance of these features has yet to be measured. Inspection of the brain coral texture at ~30 cm/pixel using HiRISE images reveals that it consists of wide (~10 meters wide) labyrinthine and circular mesas separated by troughs of similar dimensions. Occasional stippling of the surface, particularly on the walls of the mesas, suggests the presence of some rocks at the pixel scale. However, most of the surfaces of these ridges and troughs appear unstippled, indicating that most rocks in the region are smaller than ~30 cm.

Further observations of the transition zone between the brain coral terrain and the smoother terrain to the east show that the appearance of the mesas is not sudden, but graded (Fig. 2). The "smooth" terrain (which is actually polygonally fractured at HiRISE scales) gives way to a set of narrow (~m) ridges that form labyrinthine shapes, sometimes in the form of circles ~20 meters in diameter. These ridges become progressively wider towards the center of the shapes until they merge, forming mesas of circular or amorphous shapes. These mesas constitute the bulk of the brain-coral texture. The ridges found at the transition zone are of particular interest because their shapes are reminiscent of patterned grounds (*i.e.*, sorted circles and labyrinths) found in polar and high alpine environments on the Earth (*e.g.*, Fig. 3).

Discussion: Patterned ground on the Earth is typically the product of frost heave which acts over repeated freeze/thaw cycles to laterally separate ground materials into stone-rich domains and soil-rich domains [4 and references therein]. In its essence, the process involves the frost heave that water-bearing soil experiences as a freezing front descends through it. The force exerted by frost heave is perpendicular to the freezing front, which itself is not necessarily horizontal: differences in conductivity between rocks and soil cause the freezing front to penetrate faster under rocks than under soil, effectively causing the expanding soil to heave individual rocks toward other nearby rocks. Subsequent thawing of the soil causes it to contract once again, resulting in vertical motion of the rocks. Additional processes, such as the formation of ice lenses and the hydration/dehydration of soil complicate the process, but the end result is the same: rocks experience a net horizontal motion toward zones with more rocks.

Numerical simulations that parameterize the physics of ground heave and subsequent deflation predict the formation sorted circles and labyrinthine ridges from non-sorted initial conditions [4, 5] (Figs. 5). According to these models, the formation of circles vs. labyrinths is primarily controlled by the fraction of soil to rocks, where greater rock abundances tend to form sorted circles [4, 5]. Figure 5 shows the variations in final shape of the sorted patterned ground as a function of the initial stone abundance, and comparisons between the middle portions of this figure and Fig. 2 show striking similarities.

The general low abundance of craters in brain-coral units suggests that the units are either relatively young or they have been recently exhumed. Additionally, the interiors of most of the small (<100 m) craters have been modified to a certain extent by either infilling or deformation, suggesting that modification of the terrain has been ongoing since the formation of these craters.

The process of frost heave requires the freezing and melting of a near-surface permafrost in order to maintain a ground heave cycle. Results from the Gamma Ray Spectrometer (GRS) aboard Mars Odyssey indicate water-equivalent hydrogen abundances near the surface of up to ~6% by weight [6]. Whether this hydrogen is actually found in the form of ice or hydrated minerals, and whether it is enough for this process to be active is still an open question. However, liquid water cannot exist near the surface under current martian conditions. Given this present environmental constraint, there are three viable solutions for the formation of the circular and labyrinthine ridges we interpret as patterned ground: (1) freeze-thaw cycles occur during periods of higher obliquity, or as a part of the obliquity cycle itself, (2) the formation of these features can be explained by other phenomena that do not involve frost-heave, (3) the patterned ground formed in ancient Mars, when water may have been stable at or near the surface, and is currently being exhumed [4].

Although the volatiles from the polar caps are expected to sublimate during periods of higher obliquity, increasing the atmospheric water vapor pressure [7**]**, it is not clear that the melting of subsurface ice is in fact sustainable on modern Mars during periods of higher obliquity [8]. Therefore, it may not be possible for frost-heave to occur in geologically recent Mars.

On the other hand, there are alternative, less studied processes that are thought to lead to self-organization and patterned ground on Earth. These ground swelling as a consequence of hydration/ desiccation of clays, and organization as a consequence of the cyclic processes that maintain thermal contraction polygons [9**].** The soil of the mid-latitudes is thought to be a seasonal reservoir for water vapor [10]. We speculate here that the passage of a hydration front through clay-bearing soils could lead to a ground heave processes similar to that which forms patterned ground on Earth, albeit via different physical means. However, it is not clear whether enough water can be absorbed, whether enough water-expansible material (*i.e.*, clays) is available, whether the expansion of soils via hydration is a viable process for pattern formation. Nevertheless, while the total abundance of water in the martian atmosphere may be too small to affect the required change, what is required is water flux from one near-surface reservoir to another (*e.g.*, from pole to mid-latitude), and not storage in the atmosphere.

Alternatively, the processes that maintain thermal contraction polygons [9] are also known to transport large stones to the edges of the polygons. Once again, we speculate that it may be possible that over long enough times scales, these rocks will accumulate to form landforms akin to those we observe on Mars.

Finally, there is the possibility that these patterned grounds formed in ancient times when water may have been stable at or near the surface. These terrains could have then been buried and are not being exhumed. The presence of the relatively smooth, polygonally fractured material that seems to overlie or mute parts of the brain coral texture suggest that this texture may in fact currently being exhumed from under a manltle. However, it is not clear why exhumation of such ancient terrains would have reached the same extent throughout such a large area (*i.e.* most mid-latitude valley and crater floors) when exhumation of smaller units in other regions of mars appears to be spatially inhomogeneous.

It is clear that we do not yet understand the processes via which these patterned units form. However, based on our observations, we recognize that self-organization and pattern formation is a viable method of formation for the brain-coral texture. At this point, it is important to numerically test alternative physical processes that may form such patterns and determine which of these processes may be viable. Whether any of these alternatives can be applied to the observed patterns remains to be seen.

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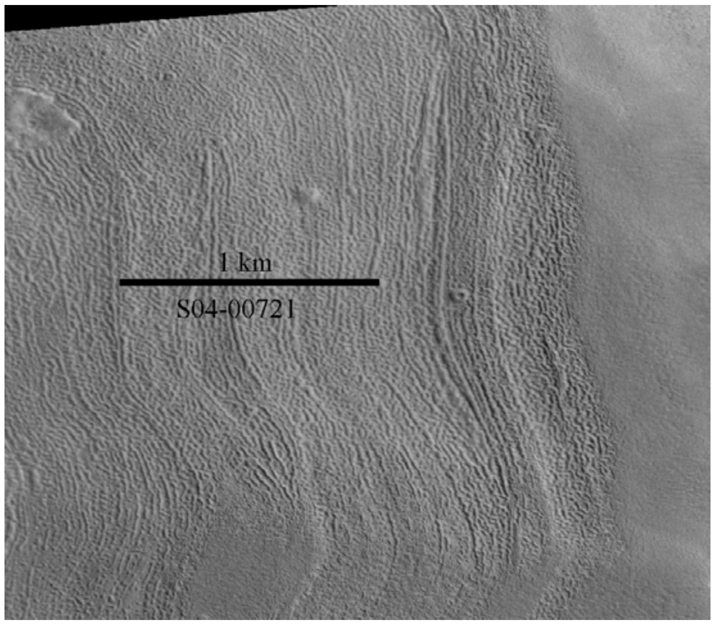

Fig. 1. Fine scale texture on lineated fill, commonly known as "brain coral" appears predominantly in low-lying flat areas such as valley and crater floors. Note apparent "mantling" unit to the right where the brain-coral texture is absent. North is up, sunlight is from left.

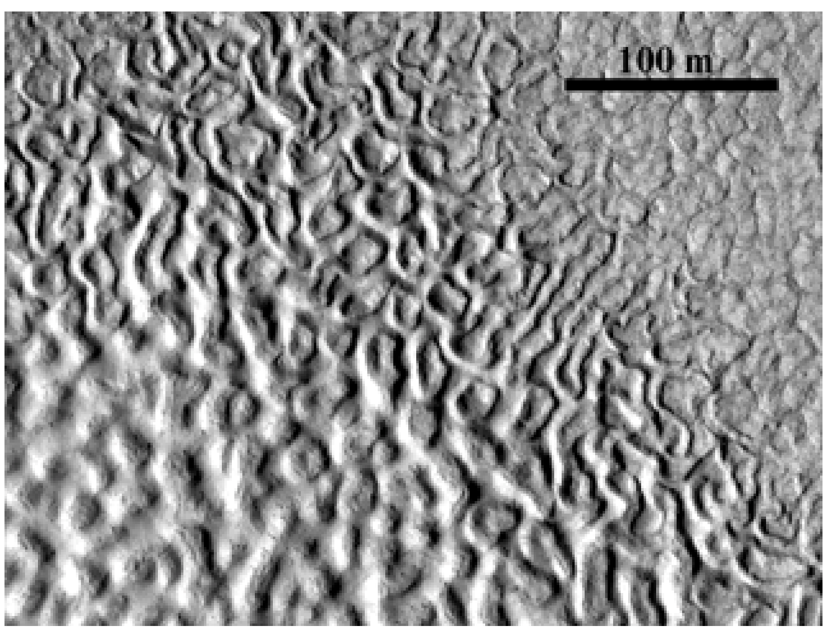

Fig. 2 HiRISE view of the transition zone between the "smooth" terrain described in Fig. 1 (right) and the "brain coral" texture (lower left). Note the appearance of labyrinthine and circular ridges (center) which progressively

thicken towards the bottom left. Also note the light stippling on some of the surfaces near the lower left, indicative of rocks whose size is near the resolution of the image (~30 cm/pixel). The absence of stippling in the rest of the image suggests that the rocks making these ridges are smaller than ~30 cm across. North is up, sunlight is from lower left.

Fig. 3. Sorted circles in western Spitzbergen.

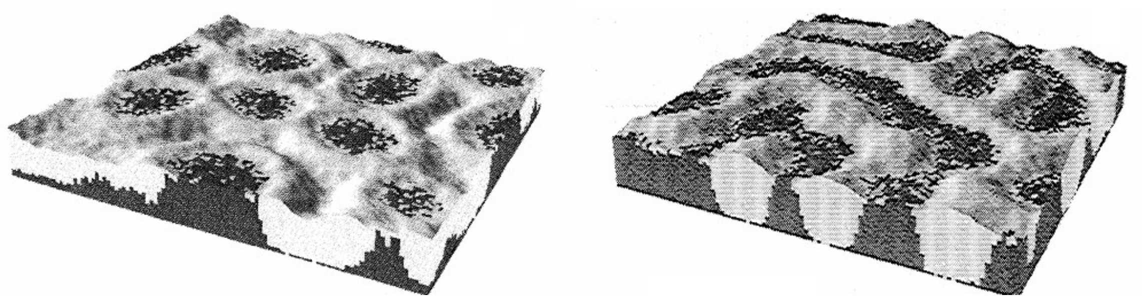

Fig. 5. Model results for sorted stone circle formation on a 10x10 meter surface. Light tones represent rocks and dark tones represent soil. (a) Given an initial 0.6 m stone layer overlying a 0.4 meter soil layer. (b) Given an initial 0.6 m stone layer overlying a 0.6 m soil layer. A decrease in the stone-to-soil fraction leads to the formation of labyrinthine features rather than circles. Figure adapted from [5].

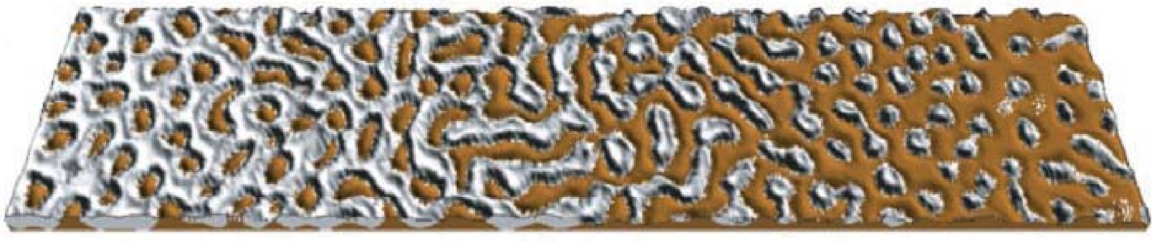

Fig. 6. Sorted patterned ground simulations showing pattern transitions with variations in initial stone abundance. In this model, stone concentration decreases left to right from 1400 to 100 stones / m^2. Note similarity between labyrinthine terrain at center of this figure to terrain in Fig. 2. Figure adapted from [4].