A FORMATIONAL MODEL FOR THE MARTIAN POLYGONAL TERRAINS;

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On Mars, polygonal terrains are present within the northern lowlands in both the Acidalia and Utopia Planitae. The polygons vary in appearance but generally are 5 to 25 km in diameter and are defined by boundary fractures. Neither desiccation of sediment, fracturing of cooling lava, frost-wedging, nor deep-seated, uniform horizontal tension is a solely satisfactory process for generating the polygons. Here we propose a mechanism for the origin of the polygonal terrains that is based on density-driven free convection of pore fluid in a 1.31 to 5.25 km-thick layer of wet sediment overlying a frozen subsurface and subsequent desiccation with fracturing occurring preferentially above subsurface topographic highs.

Several mechanisms for the origin of the martian polygonal terrains have been proposed that describe the polygon boundary fractures as desiccation cracks [1], columnar jointing in a cooled lava [2], or frost-wedge features [3]. These tension-induced cracking hypotheses have been addressed by *Pechmann* [4], who convincingly disputes these mechanisms of formation based on scale magnitude difficulties and morphology. *Pechmann* [4] suggested instead that the fractures delineating the 5 to 20 km-wide polygons in the northern plains are graben resulting from deep-seated, uniform, horizontal tension. The difficulty with this hypothesis is that no analogous polygonal forms are known to have originated by tectonism on Earth. Additionally, *McGill and Hills* [5] and *McGill* [6] proposed that the polygonal terrains on Mars resulted from either rapid desiccation of sediments or cooling of volcanics coupled with differential compaction of material over a buried irregular topographic surface. They suggested that fracturing was enhanced over the areas of positive relief; thus the size of the martian polygons was controlled primarily by the spacing of the subsurface topographic highs. However, the random positioning of crater rims, knobs, and mesas argues against them being the control for the overlying polygonal fractures which display a general regularity of spacing. We have developed a model, based on the Rayleigh free convection model of pore fluid developed by *Ray* [7], that provides a mechanism for the regularity of the northern-plains polygonal features. Our model is in accord with other martian geomorphological features and proposed environmental conditions.

It is generally accepted that the martian outflow channels were the result of catastrophic flooding caused by breaching of an impermeable confining surface layer by pressurized groundwater. The confining layer is thought to have been regionally- (and probably globally-) extensive ice-rich frozen ground. The catastrophically-released water deeply scoured and entrained large quantities of the martian surface material. Ultimately the water and the suspended material would have been deposited onto the frozen northern lowlands. Gradually this sediment and water package would have decreased in temperature due to the existing cold climate. Cooling of the sediment and water would have occurred first at the upper surface of the deposit. When the temperature of the surficial pore water reached 277K, cooler than the underlying water, an unstable density stratification would have been produced because at 277K, water is at its densest [7, 8] (Figure 1).

This martian scenario fits the free convection boundary conditions, modeled by *Ray* [7] for terrestrial application, which include the following: (1) a saturated porous medium, (2) a free upper surface that is maintained at 277K, and (3) an impermeable lower boundary that moves downward as melting occurs. This lower surface represents the preexisting frozen ground in the northern lowlands and is, therefore, the 273K isotherm. Rayleigh free convection of fluid through a porous medium, described by the above set of boundary conditions, is defined mathematically by the relationship between the dimensionless Rayleigh number, Ra, and the dimensionless wave number, a. The critical Rayleigh number is the ratio of buoyancy forces to viscous forces and defines the unique point at which convection initiates in the unstable system. The critical wave number, a, is the unique point that determines the dimensions of the initial convection cell. The exchange of fluid is most efficient when small convection cells are established; thus, many convection cells are formed rather than just one large cell [9]. In an isotropic medium a can be defined as

$$a^2 = l^2 + m^2 \tag{1}$$

where l and m are dimensionless horizontal wave numbers, perpendicular in the horizontal plane. The symbols l and m are proportional to the depth (L) to width (W) ratio of the threshold disturbance. In an isotropic medium,

$$l = m = \frac{2\pi L}{W} \tag{2}$$

Thus substitution of equation (2) into equation (1) gives

$$a = \sqrt{2}\left(\frac{2\pi L}{W}\right) \tag{3}$$

For the specific boundary conditions described above, the free convection model derives the values of a and Ra to be 2.33 and 27.1, respectively [7, 8]. Substituting the value of a into equation (3) allows the width-to-depth ratio for the convection cell to be calculated; thus, W = 3.81 L.

We propose that the pore fluid within the saturated martian outflow sediments, when perturbed, began to convect according to the Raleigh free convection model [7, 8, 10, 11]. The downwelling cooler surface water displaced the warmer, less dense water upward. Melting of the underlying preexisting permafrost was inhibited beneath the downwelling cooler water relative to the area beneath the warmer, upwelling water. This differential melting created an undulatory texture on the subsurface permafrost layer whose peak spacing was related to the size of the convection cell predicted above (Figure 2). The overlying sediments would have undergone compaction and bending stresses that would have produced drape folds on the flanks of the undulations. The greatest tensile stresses in the sediment cover produced by gravity and bending would have occurred above the peaks of the undulatory subsurface predicted by free convection; thus, weaknesses in the sediment cover were maintained above the subsurface topographic highs, similar to the behavior discussed by *McGill and Hills* [5]. We propose that subsequent desiccation of the wet sediments caused the soil to shrink uniformly and fracture; however, the spacing of the fractures was controlled by the large-scale preexisting weaknesses rather than occurring on a scale common for desiccation cracks. The 5 to 20 km-spacing of the fractures and the derived width-to-depth ratio of the convection cells allows us to estimate the thickness of the outflow sediment deposit in the northern basins to be 1.31 to 5.25 km. Our model for an undulatory subsurface controlling the surface fracture spacing satisfies the regularity of the polygons present in the northern lowlands of Mars.

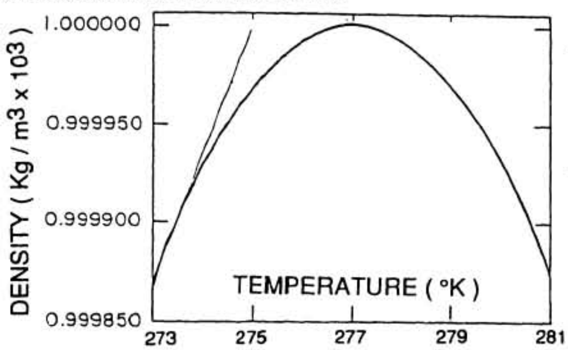

***Figure 1.** Density of water vs. temperature. Density maximum at 277K (after [7]).*

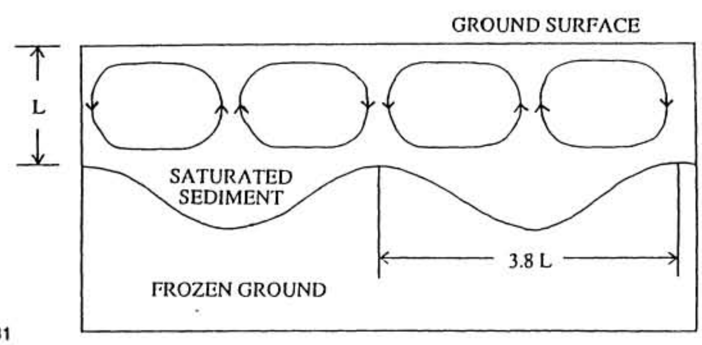

***Figure 2.** A schematic cross section of hexagonal Rayleigh convection cells (after [7]).*

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