UNFROZEN GROUNDWATER IN THE MARTIAN CRYOSPHERE.

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Introduction: Unfrozen water is present as thin films surrounding soil or rock surfaces at subfreezing temperatures. On Mars, this unfrozen water will affect geochemistry and could provide microbial habitats. Unfrozen water may persist kilometers above the base of the cryosphere, or perhaps even transiently at the surface. We have begun a new research program to measure the unfrozen water content of subfreezing Mars-analog materials and, by comparison with theory, to infer the abundance of unfrozen water in the martian cryosphere. Broadband electrical measurements will provide the link to observations from ground-penetrating radar or low-frequency electromagnetics. We will infer the habitability of these thin water films from fundamental thermodynamics and by analogy with Earth's icy environments.

Empirical and Theoretical Relations: Continuous, unfrozen water separating ice from the mineral/organic phase in frozen soils [e.g. 1-3] is caused by electrical forces at pore walls and hence is related to adsorption and capillarity, which in turn are ultimately due to the dipolar nature of H_2O [4]. It is distinct from supercooling, an ice-nucleation phenomenon. Empirical fitting of terrestrial permafrost data [3,5] indicates that the principal factors controlling the amount of unfrozen water are absolute temperature T and soil type as manifested in specific surface area A_s of the soil. Basalt powder may be a representative Mars analog [6] with A_s intermediate between intact rock and results from the Viking gas-exchange experiment [7]. For surface temperature 211 K, geothermal gradient 10 K/km [8], and brine freezing temperature 252 K, the base of the cryosphere is 4.1 km. We assume a surface porosity of 20% that decreases exponentially with depth [9]. The computed unfrozen volume fraction at the surface is 0.2%, increasing to 4.9% at the base of the cryosphere. Water decreases with increasing depth below the cryosphere due to decreasing porosity.

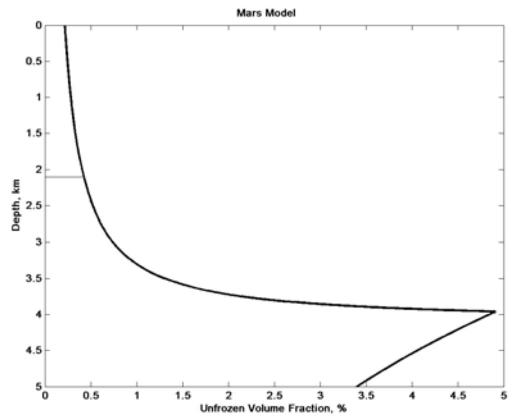

Figure 1. Modeled Mars unfrozen water content. Horizontal line illustrates arbitrary cutoff 20K below freezing.

The thermodynamic theory of unfrozen soil water [10-11] relates the *soil-freezing characteristic curve* (temperature vs. unfrozen water content) to the *soil-moisture characteristic curve* (capillary pressure vs. water content). In this way, parameters derived from the study of unsaturated soils [12] can be used to predict unfrozen water content. Such calculations can greatly extend the predictive range for Mars over empirical fits, particularly the effect of freezing-point depression due to briny groundwater.

Unfrozen Water Measurement: We will use nuclear magnetic resonance (NMR) to measure the unfrozen water content of Mars-analog materials. This approach was pioneered for permafrost two decades ago [13-14]; NMR is superior to calorimetry and time-domain reflectometry in accuracy and ability to nondestructively test both freezing and thawing cycles. In pulsed NMR, the "free-induction" decay of magnetic moments is measured after abruptly extinguishing the

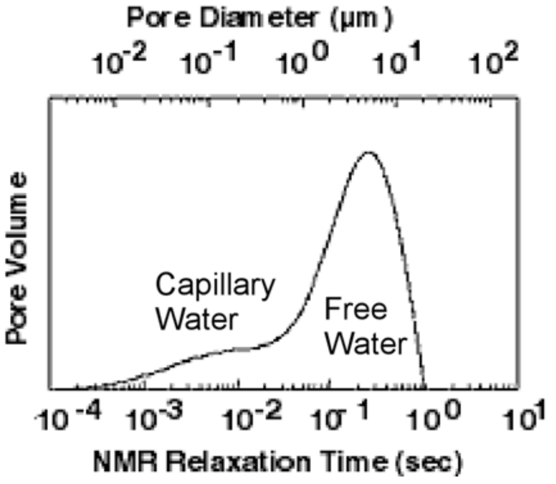

Figure 2. Borehole NMR spectrum, showing main peak due to free water and shoulder due to capillary water. In frozen soils, free water is absent and capillary water decreases with decreasing temperature.

Larmor-frequency perturbing field. The spin-spin relaxation time T_2 is the characteristic (1/e) time to come to internal equilibrium. Measured values of T_2 in variably saturated geological materials depend principally on pore size: in smaller pores, protons collide with pore walls more frequently and are under higher capillary pressure, resulting in shorter relaxation times [15-16]. Clay-bound water can also be detected, with even shorter T_2. A natural sample with a mixture of free, capillary, and clay-bound water will yield a spectrum of T_2 (e.g., **Fig. 2**). The conversion of T_2 to effective pore diameter (here, 20 μm/s) can be related to A_s [15]. Measurements of the distribution of the T_2 relaxations are all that is necessary to characterize the amount and type of water in a porous sample.

Electrical Properties: Greater volumes of unfrozen water increase ion mobility, which yield higher electrical conductivity. Both low-frequency electromagnetics [6] and ground-penetrating radar [17] will be very sensitive to the presence of unfrozen water. However, low-frequency EM will be able to penetrate fully and characterize saline groundwater, whereas GPR will be attenuated (**Fig. 3**). It is important to note that significant attenuation can be caused by small amounts of briny unfrozen water and does not necessarily indicate the presence of an "aquifer."

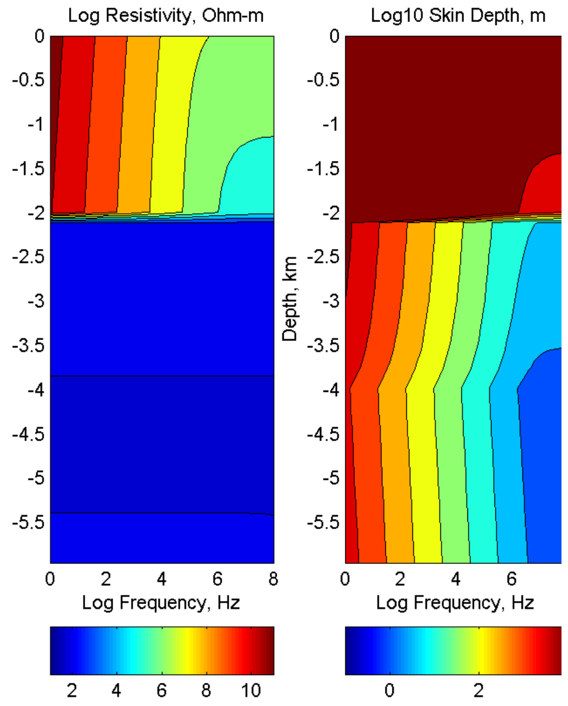

Figure 3. *Left:* Modeled resistivity of the upper martian crust. Base of cryosphere is at 4.1 km, but unfrozen brackish water results in low resistivity below 2.1 km. *Right*: Skin depths in zone of unfrozen water vary from 10s of m or less at radar frequencies 1-100 MHz to kms at <10 Hz.

We will measure the electrical properties of Mars-analog materials as a function of temperature and, through the NMR experiments, relate them to unfrozen water content. Measurements in the inductive regime (~10 mHz to ~1 MHz) will be performed using an impedance analyzer [e.g., 18] and those in the wave regime (~1 MHz to ~1 GHz) using a vector network analyzer [e.g., 19].

Habitability: Some terrestrial psychrophilic microbes can grow at temperatures above –10°C and can maintain metabolism above –20°C [20-21]. Such conditions are satisfied in the lower cryosphere. Furthermore, ice-rich regions at the surface of Mars may be habitable zones because of the periodic presence of unfrozen water due to obliquity-induced changes in surface temperature [22].

Our final area of study therefore is to explore plausible, thermodynamically-favorable redox reactions within Mars-analog fluids [23] that could provide metabolic energy for chemolithoautotrophic microorganisms residing in unfrozen thin liquid films. A model is under development to calculate whether or not adequate supplies of liquid water, energy, nutrients (C,N,O,H,P), and space exist in the thin-film environment for the sustainment of microbial life. Fluorescence microscopy will also examine the spatial distribution of bacterial-sized suspensions during and after the freezing process of brine sediment slurries, particularly with respect to mineral and ice crystal interfaces.

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