EM Properties of Magnetic Minerals at RADAR frequencies. D. E. Stillman and G. R. Olhoeft, Department of Geophysics, Colorado School of Mines, 1500 Illinois St, Golden, CO 80401 (dstillma@mines.edu).

Introduction: Previous missions to Mars have revealed that Mars' surface is magnetic at DC frequency [1,2]. Does this highly magnetic surface layer attenuate RADAR energy as it does in certain locations on Earth [3]? It has beeen suggested that the active magnetic mineral on Mars is titanomaghemite and/or titanomagnetite [4]. When titanium is incorporated into a maghemite or magnetite crystal, the Curie temperature can be significantly reduced [5]. Mars has a wide range of daily temperature fluctuations (303K – 143K), which could allow for daily passes through the Curie temperature. Hence, the global dust layer on Mars could experience widely varying magnetic properties as a function of temperature, more specifically being ferromagnetic at night and paramagnetic during the day. Measurements of EM properties of magnetic minerals were made versus frequency and temperature (300K-180K). Magnetic minerals and Martian analog samples were gathered from a number of different locations on Earth.

Experimental Method: The majority of the samples were already in a soil form, although several rock specimens had to be crushed into soil using a nonmetallic mortar and pestle. Once the magnetic samples were in a soil form, they were dried in a vacuum at 3×10^{-4} mbar until the weight of the sample did not appreciably change with time (0.005% in 24 hours). The sample was then loaded into a GR-900 sample holder that was connected to an HP 8753 vector network analyzer via two phase matched cables. The sample holder and part of the cables were loaded into a So-Low Ultra-Low freezer where the temperature was adjusted from 303K-180K. The network analyzer recorded data every 5K – 10K. This data was then converted into complex dielectric permittivity and complex magnetic permeability versus frequency [6] and temperature.

Analysis: Most samples showed low losses at RADAR frequencies. However, a grey hematite sample from Keweenaw Peninsula, Michigan possessed a strong temperature dependent dielectric permittivity relaxation, Fig. 1. A nonlinear inversion was used to find the best fit Cole-Cole parameters at each temperature [7]. Only the time constant of relaxation changed as a function of temperature. This variation in time constant of relaxation with temperature was modeled by a generalized Boltzmann temperature dependence [8]. Using an Arrhenius plot, the activation enegy of the relaxation was found to be 0.145 eV. The generalized Boltzmann temperature dependence was then substituded into the Cole-Cole equation. The equation below is a model of the complex dielectric permittivity versus frequency and temperature, where ε^* is the complex relative dielectric permittivity, ε' is the real part of the relative dielectric permitivitty, and ε'' is the imaginary part of the relative dielectric permittivity, k is the Boltzmann constant of 8.6176×10^{-5} eV/K, T is temperature in Kelvin, ω is angular frequency in Hz, and i is the $\sqrt{-1}$.

$$\varepsilon^* = \varepsilon' - i\varepsilon'' = 7.162 + \frac{17.101}{1 + \left(i\omega\left(2.56\times10^{-13} e^{0.145/kT}\right)\right)^{0.861}}$$

This temperature dependent dielectric relaxation of grey hematite indicates that RADAR depth of penetration varies with temperature. To demonstrate its effect, the complex permittivity was converted into attenuation at MARSIS and SHARAD frequencies at Sinus Meridiani where grey hematite concentrations range up to 15% [9]. Since Sinus Meridiani does not contain 100% grey hematite, the Bruggeman, Hanai, Sen mixing formula was used (Sen, 1981). The grey hematite was assumed to be mixed into lossless basaltic sediments having a real part of the relative dielectric permittivity of 3. Once the mixed complex permittivity was found, it was then converted into attenuation. Figure 2 shows that the temperature and percentage of grey hematite can have huge affects on the attenuation of RADAR.

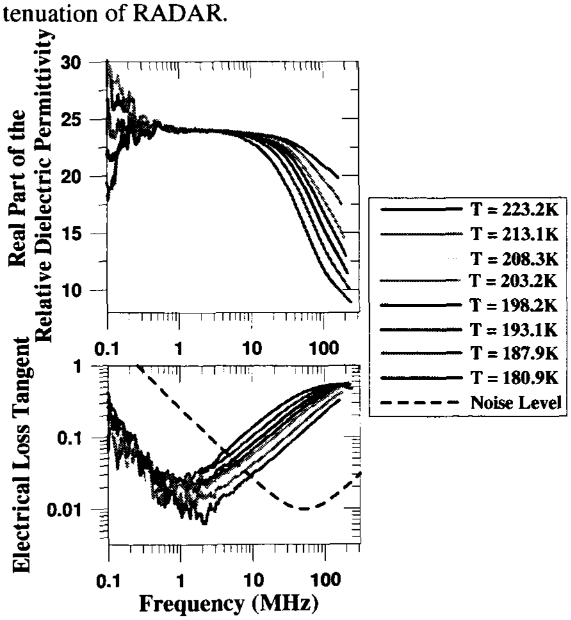

Figure 1. The grey hematite data as a function of temperature and frequency.

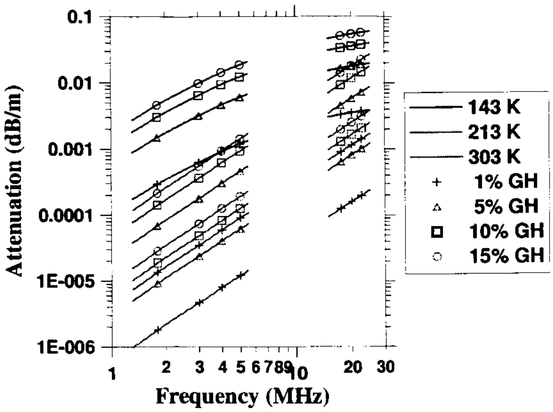

Figure 2. Attenuation at Sinus Meridiani at MARSIS and SHARAD frequencies assuming the only loss mechanism is the grey hematite dielectric relaxation loss (conductivity, scattering, geometrical spreading, and other losses were not included in this calculation). The color of the line represents its temperature while the symbol represents its percent of grey hematite. The symbols are marked at the center frequencies of MARSIS and SHARAD.

Conclusions: Most dry magnetic minerals have low loss in the RADAR frequency range. However, grey hematite contains a significant temperature dependent dielectric relaxation. This loss mechanism should be seen in MARSIS and SHARAD data from Sinus Meridiani. This frequency and temperature dependent loss mechanism could be used to find areas of subsurface grey hematite. This loss mechanism could also be used to estimate heat flow in the upper Martian subsurface if multiple measurements could be made at the same location at different temperatures.

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