ELECTROMAGNETIC PROPERTIES OF MARTIAN ANALOG MINERALS AT RADAR FREQUENCIES AND MARTIAN TEMPERATURES. David. E. Stillman and Gary R. Olhoeft. Colorado School of Mines, 1500 Illinois St., Golden, CO 80401. dstillma@mines.edu, golhoeft@mines.edu.

Introduction: The ability of radar energy to penetrate into the subsurface is dependent on the electromagnetic (EM) properties of the subsurface. Mars is believed to be a good ground penetrating radar (GPR) environment due to the lack of liquid water and the assumed low conductivity of the subsurface. However, dielectric and magnetic relaxation losses of materials in the Martian subsurface could cause significant attenuation of radar energy. These losses can also vary as a function of temperature [1, 2]. In this study, the EM properties of Martian analog minerals were measured at radar frequencies (1 MHz – 1 GHz) and Martian temperatures (180 K – 300 K).

Experimental Method: Dry soil samples were loaded into a 14-mm diameter coaxial waveguide, or sample holder, that was connected to an HP 8753D vector network analyzer via two phase matched cables. The sample holder and part of the cables were placed inside a So-Low Ultra-Low freezer where the temperature was adjusted from 180 K – 300 K. Data were acquired every 5 K – 10 K. The data were then converted into complex dielectric permittivity and complex magnetic permeability versus frequency [3] and temperature. Similar measurements have been made in the past but not at Martian temperatures [4, 5].

Analysis: If the sample contained a measurable EM loss, a nonlinear inversion was used to find the best fit Cole-Cole parameters at each temperature [7]. It was assumed that the time constant of relaxation was the only Cole-Cole parameter that changed as a function of temperature. The variation in time constant of relaxation with temperature was modeled using a generalized Boltzmann temperature dependence [8]. The generalized Boltzmann temperature dependence was then inserted into the Cole-Cole equation. The equation below is a model of the complex material property (either complex dielectric permittivity, ε*, or complex magnetic permeability, μ*), X_r^*, versus frequency and temperature: where X_r' is the real part of the relative material property, and X_r'' is the imaginary part of the relative material property, X_∞ is the high frequency limit of the real part of the relative material property, X_{DC} is the low frequency limit of the real part of the relative material property, i is the $\sqrt{-1}$, ω is angular frequency in Hz, τ_∞ is the time constant of relaxation at an infinite temperature, E is the activation energy of the relaxation, k is the Boltzmann constant, T is temperature in Kelvin, and α is the Cole-Cole distribution parameter.

$$X_r^* = X_r' - iX_r'' = X_\infty + \frac{X_{DC} - X_\infty}{1 + \left(i\omega\tau_\infty e^{E/kT}\right)^\alpha}$$

Table 1 lists these parameter values for samples that contained dielectric losses and the table in Figure 2 lists these parameters for a magnetite sample that contained temperature independent magnetic losses.

Discussion: Grey hematite possesses a significant temperature dependent dielectric relaxation loss mechanism (Fig. 1). Magnetite possesses a significant temperature independent magnetic relaxation loss mechanism (Fig. 2). Two other samples had minor temperature dependent dielectric relaxations. These demonstrate why EM properties of Martian analogs must be measured at Mars ambient temperatures if they are to be applicable for modeling GPR performance on Mars.

To demonstrate how these temperature dependent EM losses can impact MARSIS, SHARAD, and future GPR missions to Mars, Figure 3 shows the two-way attenuation rate (dB/m) versus frequency [9]. The upper limit of GPR depth of penetration (DoP) can be found by dividing the dynamic range of the GPR by the two-way attenuation rate. Assuming a dynamic range [10] of 50 dB and a Martian average temperature of 213K, the DoP for MARSIS is 1.6 km for grey hematite, 510 m for magnetite, 325 m for Pu'u Nene horizon D (the soil horizon directly beneath JSC Mars-1), and 1.0 km for JSC Mars-1 [11]. Using the same assumptions [12], the DoP for SHARAD is 55 m for grey hematite, 20 m for magnetite, 50 m for Pu'u Nene horizon D, and 175 m for JSC-1. However, if the temperature is reduced to 170 K, the DoP for grey hematite is reduced to 305 m and 15 m for MARSIS and SHARAD, respectively. The depths of penetration listed above represent an upper limit because geometrical spreading, scattering, and polarization losses are not considered.

Acknowledgements: This project was funded by NASA Grant 20119458 NAG5-12754. We appreciate the help of Steve Sutley of the USGS who conducted our XRD measurements. We would also like to thank Justin Modroo, Brianne Douthit, Beau Winters, Matt Hergert, Andy Kass, Ross Wagle, Paul Schwering, and Francis Li for their experimentation assistance.

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Table 1. Table of temperature dependent dielectric relaxation losses. Dielectric permittivity values have been density corrected to 1.60 g/cc [6].

Sample	Grey Hematite	Pu'u Nene Horizon D	JSC Mars-1
Mineralogy	Hematite	Plagioclase	Plagioclase
ε_{DC}	9.86	8.23	7.20
ε_∞	2.91	2.69	3.07
τ_∞(ns)	0.000256	0.0601	0.8086
E (eV)	0.145	0.100	0.167
α	0.86	0.20	0.12
R_{DC} (kΩm)	>15	>15	>15
μ_r	1.00	1.00	1.00

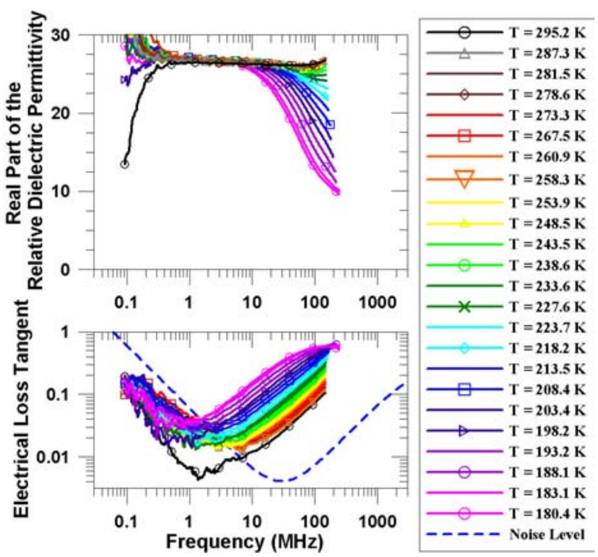

Figure 1. The grey hematite data as a function of temperature and frequency. Density of the grey hematite sample was 3.03 g/cc and the μ_r = 1.

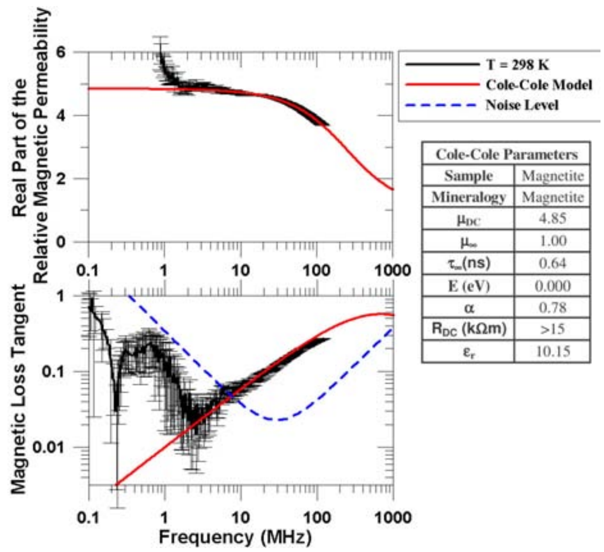

Figure 2. Temperature independent magnetic relaxation losses in magnetite (density = 2.62 g/cc). The error bars represent the 68.2% confidence intervals or ±1 standard deviation. The parameters for the Cole-Cole model are listed below the legend.

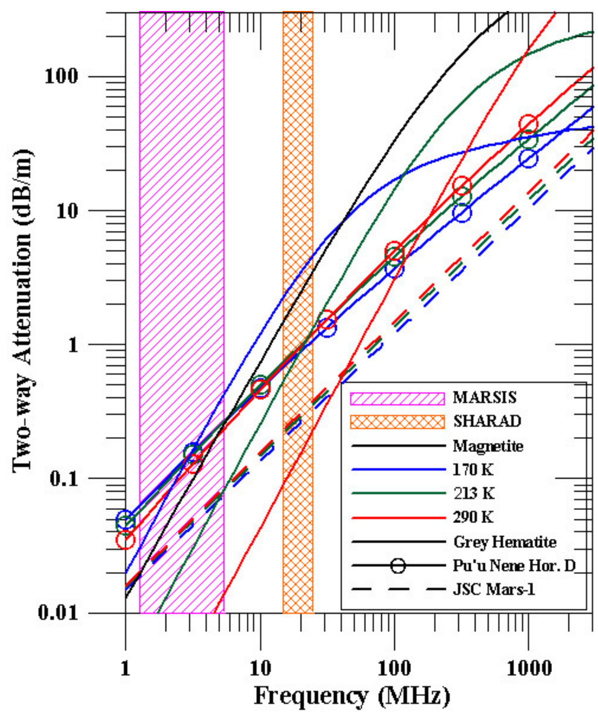

Figure 3. Two-way attenuation versus frequency for the lossy samples. Each sample, with the exception of magnetite, is shown in three different colors which represent the temperature extremes on Mars and the average Martian temperature. Since magnetite is not temperature dependent it is shown in black.