Measurements of dielectric properties of Mars analog soils with variable temperature and moisture content.

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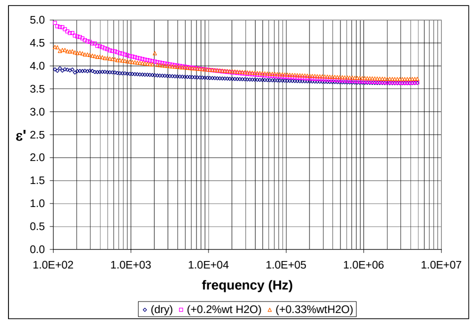
Introduction: The distribution and state of water in the Martian subsurface is a crucial component in the study of the planet's climatic, hydrologic, and geological history.

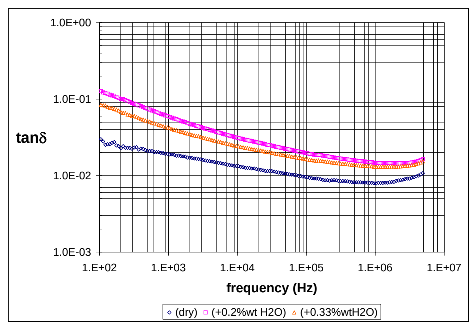
Radar sounding (such as the MARSIS instrument on the Mars Express spacecraft and SHARAD on Mars Reconnaissance Orbiter) is a valuable technique for probing the upper meters-to-kilometer of the subsurface for water in its various forms. However, unraveling the meaning of the reflected radar signals takes a strong understanding of the dielectric properties of the wide variety of regolith materials and the water contained within it. Laboratory study of the electrical properties of soils allows us to characterize the differences between water, ice, and other materials in the Martian subsurface, and is important in the interpretation of the sounding radar data.

Mars is globally covered by a layer of permafrost, soil permanently below the freezing point of pure water, 273K. This frozen layer can extend up to kilometers into the crust, depending on the thermal properties of the overlying layers, where geothermal heat can elevate the temperature above freezing. Water can exist in the Martian permafrost in a variety of forms. At high latitudes shallow ice is abundant [1]. Liquid water can only occur in warmer locations either below the permafrost or as brines within the permafrost [2]. Under the relatively dry conditions currently at the surface of Mars, adsorbed water (liquid-like thin films of water molecules adhered to the mineral surfaces) can still persist in abundance [3]. And water, particularly in liquid or liquid-like states, can have a pronounced effect on the dielectric characteristics of soil.

This work focuses on the laboratory measurements of the complex dielectric permittivity $\epsilon^* = \epsilon' - j\epsilon''$ of various Mars soils analog materials, performed under different condition of temperature and water content. The objective of this study is to understand how the dielectric properties of soils vary with the experimental conditions, in particular with adsorbed water content, to better understand the response of the Martian subsurface orbital radar signals. The real part of permittivity, ϵ', of the upper layer of soil, and the dielectric contrast at soil interfaces, allows for the transformation of the time scale measured by a radar into an actual depth. The imaginary part, ϵ'', constraints the signal attenuation, and is then related to the depth at which a radar signal can propagate.



(a)



(b)

Figure 1: Dielectric properties of a JSC1 samples with different humidity, at 26^oC. (a) ϵ' shows appreciable differences only at the lower frequencies, (b) $\tan\delta$ is higher for higher water content in all the frequency spectra.

Materials and Methods: We performed impedance spectroscopy on selected materials, from room temperature to $-45°C$ (228K), with an Agilent 4294A Precision Impedance Analyzer. The behavior of the complex impedance as a function of frequency is related to the electrical properties of the material-electrode system. Some of the properties are intrinsic to the material under test (relaxation processes), others are related to the material-electrode interfaces (polarization). We designed, built, and calibrated specifically for this experiment a capacitive cell equipped with a guard electrode, to reduce the edge effects [4]. We calculated the complex dielectric permittivity from the measured parameters, capacitance C_p and loss tangent $\tan\delta$, with real and imaginary parts given by, respectively, $\epsilon' = \frac{C_p}{C_0}$ and $\epsilon'' = \epsilon' \tan\delta$, with C_0 the empty cell capacitance. We measured the dielectric properties of the samples in dry conditions and with low water contents, to investigate the effect of both temperature and water content.

The tested materials are JSC-1 [5], JSC-Mars-1 [6], Kaolinite, and Borosilicate glass spheres (grain size: $150 - 180\mu m$) as a reference material. All the samples were dried in an oven before each measurement series. In order to control the adsorbed water content, samples were brought to equilibrium with water vapor at a fixed temperature and humidity. The concentration of adsorbed water varied depending on the humidity applied, the sample temperature, and the specific surface area of the sample. The water contents obtained in this way were very low ($\approx$ few % in weight) for almost all the samples. JSC-Mars-1, which has the largest surface area among the tested samples, collected a significantly higher amount of water ($15\%wt$).

Results and Discussion: For all the samples, we observed that increasing the water content mostly affects the loss tangent (Fig. 1b), while the differences in the real part of the permittivity (Fig. 1a) are only observable at lower frequencies. In most cases (see Fig. 2), a relaxation occurs at frequencies decreasing with temperature, compatible with the behavior of ice [7]. Ice in the sample occurs in small quantities when adsorbed water is equilibrated at warm temperatures and the sample is cooled. Such phase transitions are expected to also occur on Mars [8]. For some of the samples (not shown here) a second relaxation appears in the measurement frequency spectrum, possibly due to accumulation of ice on one of the electrodes, giving rise to a double layer [9].

The dielectric properties of the tested samples show a significant dependence on the presence of water, even at such small concentrations (few percent in weight), and a dependence on temperature. The behavior of adsorbed water, even at temperatures above freezing, is more similar to ice than to free water, with relaxation processes. In fact, $\tan\delta$ shows typical relaxation peaks moving toward lower frequencies when the temperature decreases (Fig. 2b) In addition, $\tan\delta$ varies across two order of magnitude in the explored temperature range, and such a variation can affect the penetration depth of radar signals.

References

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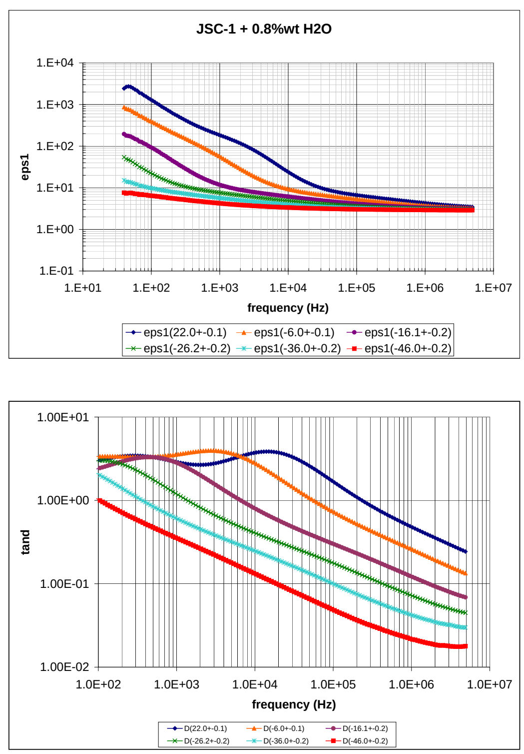

(a)

(b)

Figure 2: Dielectric properties of a JSC1 samples with $0.8\%wtH_2O$, at various temperatures.