

**PROGRESS IN PROSPECTING FOR NEAR-SURFACE H<sub>2</sub>O ON THE MOON AND MARS WITH DIELECTRIC SPECTROSCOPY.** R. E. Grimm and D.E. Stillman, Dept. of Space Studies, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (grimm@boulder.swri.edu; dstillman@boulder.swri.edu).

**Introduction.** Polarizable defects in the crystal structure of ice and charge transport associated with H<sub>2</sub>O-silicate interfaces result in diagnostic low-frequency electrical signatures. Dielectric spectroscopy – the broadband measurement of complex dielectric constant – responds uniquely to H<sub>2</sub>O and thus, unlike neutron spectroscopy, cannot mistake subsurface solar-wind implanted hydrogen or mineral-bound hydroxyl for ice. We have developed a library of over 100 dielectric spectra of H<sub>2</sub>O-salt-silicate mixtures, each down to –85°C (a further 60 measurements of natural and artificial ices are discussed in [1,2]). General interpretation of conduction and polarization mechanisms is reported in [3]; here we focus on inference of H<sub>2</sub>O content from the real dielectric constant. We find that, with knowledge of the host silicate mineralogy, H<sub>2</sub>O abundance can be determined to ±1-2%. With no site mineralogy, the accuracy is ±4%. In all cases the detection threshold for H<sub>2</sub>O is ~1%. Depth of investigation using a small antenna on a rover is tens of centimeters [8], whereas a static lander could sense to depths of several meters or more using remotely deployed electrodes [9].

**Background.** Hexagonal ice (Ih) is the norm for Mars. At the cold temperatures of permanently shadowed polar regions on the Moon, H<sub>2</sub>O condenses into amorphous ice (Ia). This Ia is metastable and converts to cubic ice (Ic) as a function of temperature (1 yr at 114 K and 1 Myr at 88 K: [4]). Therefore, Ia should not be present unless the ice is very cold and/or young. The electrical properties of Ic appear to be similar to Ih [5]. Ic can also exist at temperatures up to the melting point if it is formed in micron-scale pores [6]. We are developing a laboratory environment for measurement of lunar-analog Ia and Ic, but present results are restricted to Ih formed by freezing mixtures of (saline) water and silicates.

The unique properties of H<sub>2</sub>O give rise to diagnostic electrical properties. The migration of protonic point defects in Ih is well known [e.g., 7]. The finite speed with which these defects can respond to electric fields results in a dielectric relaxation: below the relaxation frequency, charges fully separate and ice manifests a large real dielectric constant (92 at 273 K), but above the relaxation frequency, defects cannot keep up with the alternating field and the real dielectric constant falls to ~3.15. The relaxation frequency increases with temperature according to an Arrhenius law. It also increases with the abundance of lattice impurities, until a saturation is reached [1]. When small

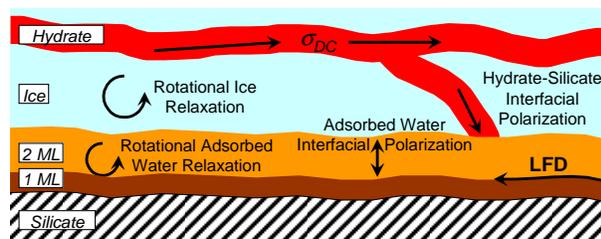
quantities of ice are present in silicates, internal electric fields cause additional defects in the ice and increase the relaxation frequency [3]. Radiation damage prior to diffusion or impact-gardening into the regolith may also increase relaxation frequency and strength.

Prior suggestions for detection of subsurface ice inferred that the ice dielectric relaxation would be the primary signature [8,9]. However, we have identified 5 different dielectric relaxations in ice-silicate mixtures, plus DC conduction [3; Fig. 1]. If sufficient salts are present in the original solution, termination of frozen hydrate channels against silicate grains gives rise to an interfacial polarization (Maxwell-Wagner effect). “Un-frozen” water, a few H<sub>2</sub>O monolayers thick between the ice and silicate [e.g., 10], can rotate, causing a dielectric relaxation. Movement of H<sub>3</sub>O<sup>+</sup> ions both across and along the interfacial layer generates additional relaxations. The last has been previously identified as a “Low-Frequency Dispersion” (LFD) and dominates dielectric properties when the H<sub>2</sub>O abundance falls to one monolayer (ML). The LFD is characterized by a slope in both the real and imaginary parts of the dielectric constant over a large bandwidth (extending to RF), such that the loss tangent can appear to be nearly constant [11,12].

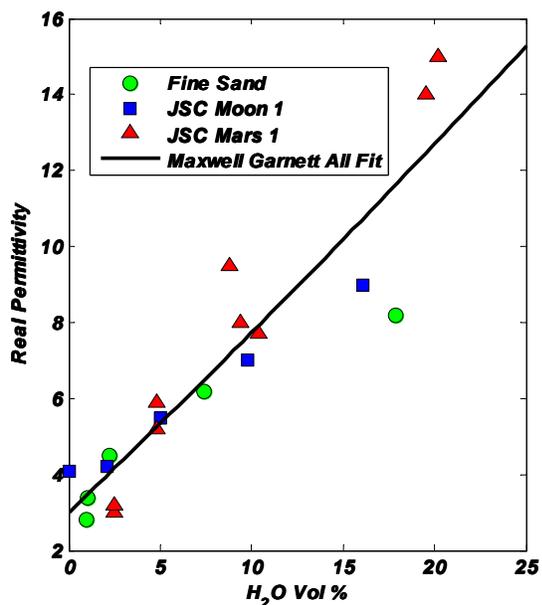
**Electrical Properties.** Laboratory methods for the measurement of frozen H<sub>2</sub>O-salt-silicate systems are described in [3]. We do not know the salt content of martian or lunar ices; measurements reported here use either deionized water (DI) or 1 mM CaCl<sub>2</sub> as a “stabilizer.” We have three materials so far for which several H<sub>2</sub>O contents were measured: fine sand, JSC-Mars-1, and JSC-Moon-1 (other measurements focused on adsorbed water only). In the fine sand (Fig. 2), the ice relaxation can be identified down to 1% (vol) H<sub>2</sub>O. In contrast, the presence of clays in JSC-Mars-1 implies that a substantial fraction of the H<sub>2</sub>O is present as just a few adsorbed monolayers, and so the LFD becomes more important. Therefore, in JSC-Mars-1 the ice dielectric relaxation is weak below 20% H<sub>2</sub>O, and the LFD dominates below 9% (Fig. 2). JSC-Moon-1 (not shown) lacks these very fine materials and responds more like the sand. A variety of smectites were measured with a controlled 3 ML (this is nonetheless 10-18% vol H<sub>2</sub>O): the LFD is present at the frequencies formerly occupied by the ice relaxation, and DC conduction dominates at lower frequencies.

**Dielectric Mixing.** We fit Maxwell Garnett mixing models [13] to the individual measurements and to the ensemble. The RMS error in predicting H<sub>2</sub>O vol-

ume for an individual sample is 0.6–1.9% using single frequency data (Fig. 3). If multiple relaxations are fit using broadband data [3], the error is reduced. With a larger library, a specific sample could be selected if the site mineralogy was known. The RMS error when simultaneously fitting all measurements is 2.6%. This is more representative of unknown site mineralogy. The error is closer to 4% when additional data from the existing library are incorporated.



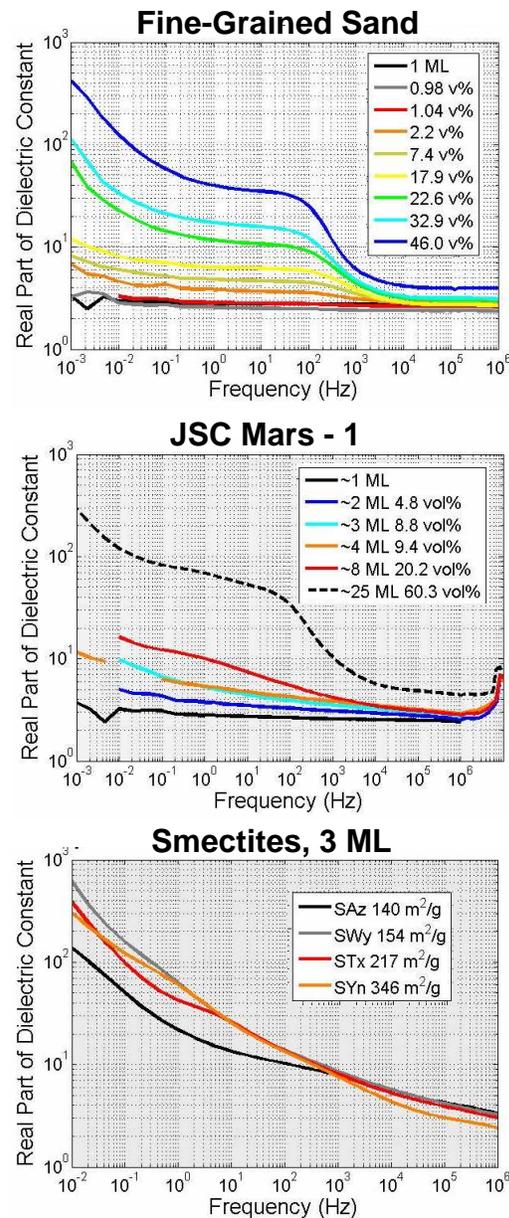
**Fig. 1.** Cartoon of the 5 low-frequency dielectric mechanisms plus DC conduction ( $\sigma_{DC}$ ) in ice-silicate mixtures [mod. from ref. 2]. See text for explanation. The Low-Frequency Dispersion (LFD) dominates fine-grained materials at low  $H_2O$  content and can be detected in a single water monolayer.



**Fig. 3.** Real permittivities at  $-85^\circ C$ , with Maxwell Garnett mixing model fit to all data.

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**Fig. 2.** Dielectric spectra as functions of  $H_2O$  volume for (top 2 panels) and spectra as function of smectite type at fixed 3 monolayers (ML) of  $H_2O$  (bottom panel). Ice relaxation (sharp slope at a few hundred Hz) is evident in fine-grained sand down to  $\sim 2\%$   $H_2O$  but fades in favor of LFD with increasing specific surface area.