ON THE ORIGIN OF WIDESPREAD SUBSURFACE RADAR ATTENUATION AT MARS. R.E. Grimm[1] and D.E. Stillman[1], [1]Dept. of Space Studies, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80403, grimm@boulder.swri.edu.

Introduction: The orbital, surface-penetrating radars MARSIS and SHARAD were intended to image the interior of Mars to depths of several km [1] and several hundred m [2], respectively, with detection of groundwater a high priority. Except for ice-rich and/or low-density [3-5] regions, performance has generally fallen far short of these expectations. Orbital radars are susceptible to surface clutter due to large footprints, but this can be blamed only in rough terrain. Even in the smooth northern plains, signatures thought to be buried basins [3] have since been reinterpreted [6]. Subsurface scattering due to wavelength-scale heterogeneity could be important in regions of complex geology [7]. For vast regions of Mars, however, the paucity of subsurface radar reflections must be due to absorption of RF energy. We have previously suggested that absorption could significantly affect surface-penetrating radar on Mars [8-11]. Our recent laboratory experiments have demonstrated that the contribution of electrolytic conductivity to absorption at Mars temperatures is negligible [12]. Here we show that dielectric relaxations in adsorbed water on smectites could completely attenuate MARSIS or SHARAD signals, even when these clays are present only in small quantities. Magnetite is also a strong RF absorber at Mars conditions [10]; we further quantify that modest amounts of this common igneous accessory mineral could also restrict radar penetration.

Relaxation Mechanisms and Absorption. The finite speed of charge polarization creates frequency dependence of the complex dielectric constant ε. At low frequency, charges fully separate and wait, manifesting the maximum real dielectric constant, ε'. At high frequency, charges cannot separate and the real dielectric constant is a minimum. At some intermediate (relaxation) frequency, charges are always in motion, covering their maximum range. Therefore, maximum joule loss as well as the maximum in the imaginary dielectric constant ε'' occurs here. Analogous dispersion can occur in magnetic polarization.

The absorption coefficient η (dB/m) in the propagative regime can be related to loss tangent $\tan\delta = \varepsilon''/\varepsilon'$ and frequency f as $\eta = 9.1\times10^{-8}\sqrt{\varepsilon'}\, f \tan\delta$. Subsurface losses on Earth are approximately constant η (“GPR Plateau” [13,14])—and not constant $\tan\delta$—due to the dominance of electrolytic (DC) conductivity. However, most relaxations also contribute a constant absorption at frequencies sufficiently greater than the relaxation frequency (e.g., dashed line in Fig. 1b) At lower frequencies, absorption falls steeply (approximately as f^2). It follows that all relaxations well below the radar sounder frequency contribute a nearly frequency-independent dB/m loss, whereas higher-frequency relaxations generally can be neglected.

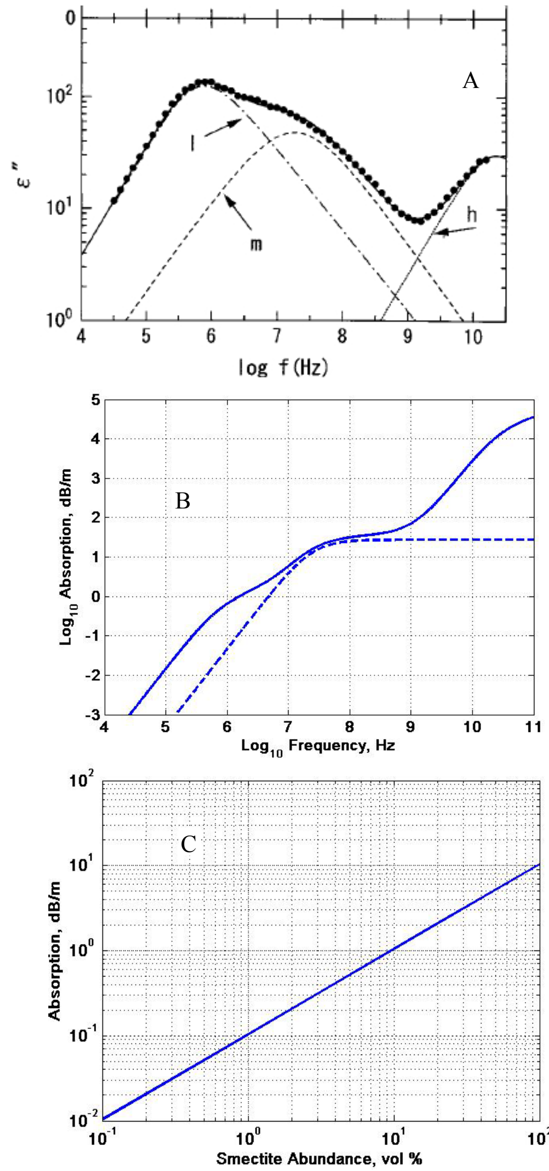

Figure 1. (**A**) Imaginary dielectric spectrum of moist montmorillonite, with DC conductivity subtracted [18]. Relaxations at 600 kHz ("l"), 18 MHz ("m"), and 22 GHz ("h") are due to interfacial polarization, bound-water rotation, and free-water rotation, respectively. (**B**) Computed absorption (dB/m), from complete spectrum (solid) and from bound water only (dash). (**C**) Absorption at 20 MHz (SHARAD) computed from bound-water relaxation and complex refractive index mixing with zero-loss background silicate. Losses exceed 100 dB/km one-way for smectite abundance >1%. Losses at 4 MHz (MARSIS) are 100 dB/km for 10% smectite.

Water. The unique nature of H_2O engenders numerous relaxations in water-silicate mixtures [15]. The rotation of adsorbed water is partly inhibited and therefore its relaxation frequency is depressed to the 10-100 MHz range. Interfacial polarization between water and host minerals leads to Maxwell-Wagner relaxations, often near 100 kHz. Surface polarization occurs where counterions in the electrical double layer are tangentially mobile and relax at 0.1-1 MHz, but low electrolytic conductivity mentioned above probably rules this out for Mars. The dielectric relaxation loss due to crystal defects in ice is too small to affect GPR in the high-latitude regions where ice is stable. The 20-GHz free-water relaxation is negligible at MARSIS/ SHARAD frequencies, although it limits terrestrial GPR performance at several hundred MHz and above.

The bound-water rotation and interfacial polarization signatures will be maximized where specific surface area is highest, i.e., in clays, particularly smectites. Smectites (nontronite and montmorillonite) and chlorite (chamosite) are evident in Noachian terrains and are inferred to have formed during Mars' water-rich era [16,17]. Smectites could be ubiquitous in small quantities in the subsurface because of alteration due to early water circulation and due to subsequent hydrothermal activity or cryospheric interactions.

We explore the possibility that smectite-adsorbed water could attenuate RF energy on Mars using high-quality measurements of moist montmorillionite at 20ºC from the literature [18; Fig. 1a]. Measurement of the dielectric properties of H_2O-silicate mixtures at Mars temperatures is ongoing in our lab; room-temperature data are nontheless a useful first approximation because part of the adsorbed water persists to low temperatures and is still rotationally mobile [19]. The absorption due to the dielectric relaxation of bound water (Fig. 1b) is 10 dB/m at 20 MHz (SHARAD) and 1 dB/m at 4 MHz (MARSIS). Although large by expectations for Mars, these values are small compared to the upper limit of ~300 dB/m for clays [13]. The dynamic range available in the ground for the Mars orbital radars is ~40 dB.

The complex dielectric constant of a mixture of montmorillonite and host rocks is computed using the refractive index model [20]: $\varepsilon^{1/2} = f_m\varepsilon_m^{1/2} + (1-f_m)\varepsilon_r^{1/2}$, where f_m is the volume fraction of montmorillonite and ε_m and ε_r are the complex dielectric constants of montmorillonite and the host rocks, respectively. Where there is a strong contrast in dielectric properties, the RI model predicts that the absorption coefficient is directly proportional to the volumetric abundance of the high-loss material. At 20 MHz, the loss due to montmorillionite (Fig. 1c) is η (dB/km) = 100 f_m (vol%); the loss is 1/10 this at 4 MHz.

Magnetite. Magnetite is now thought to be the dominant magnetic carrier on Mars, comprising a few percent of the dust and a few-to-several percent in rocks [21-23]. Magnetite has a magnetic relaxation caused by domain-wall displacement that is temperature-independent from 180–300 K [11]. At 20 MHz, η = 1.2 dB/m; the RI mixing model indicates that the loss associated with say 5% magnetite might be ~60 dB/km. At 4 MHz, the absorption is ~5 dB/km. A better mixing model may be required for magnetite, whose relaxation is heavily dependent internal magnetic interactions that in turn depend on magnetite abundance.

Conclusion: Even a small background abundance of smectite could contain sufficient adsorbed water to attenuate subsurface radar sounding on Mars. Ironically, this may be the principal groundwater detection for these instruments: for water adsorption 100 m^2/g, 1% smectite abundance, and a 10-km thickness of altered crust, the global equivalent water layer is 10 m. Magnetite could also strongly influence radar losses. Inferred common penetration depths of tens of meters are Earth-like, but difficult to extract in large-footprint data. Orbital sounders are useful in specialized terrains on Mars, but in general ground-penetrating radar is best suited to rover-based investigations of shallow electrical properties and geology [e.g., 24-25].

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