PROPOSITION OF RADAR THROUGH THE MARTIAN POLAR LAYERED DEPOSITS. D. C. Nunes and R. J. Phillips, 1Lunar and Planetary Institute, Houston, TX 77058, 2Dept. of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130. (nunes@lpi.usra.edu)

Introduction: The Martian polar caps are among the primary targets for orbital radar sounders scheduled to acquire data in the next few years (e.g., SHARAD [1]). Several factors bolster the case for radar sounding of the caps. One is the enhanced spatial coverage provided by the nearly polar orbits of the spacecraft. Another is the relatively low dielectric constant and loss tangent values of H2O ice, the primary cap component, which should lessen signal attenuation. The polar caps also contain other species. CO2 ice overlies the Polar Layered Deposits (PLD), permanently at the Southern cap and seasonally at the Northern cap [e.g., 2]. Silicate inclusions are also present in the ice and are likely the source for the PLD dark layers [2]. Fig. 1 shows a section of a Northern PLD (NPLD) scarp. Two units are clearly distinguishable: the upper is bright and smooth, and the lower is rough and dark. Interpretations commonly assert that the upper unit is composed of relatively clean ice, while the lower unit is rich in sand [3].

The objectives of this work are (i) to determine to what degree the PLD strata can be resolved by SHARAD, (ii) to assess the contribution of the layering to signal attenuation via path and transmission losses, and (iii) to evaluate the effect of cap composition on the predicted radar reflections.

Figure 1. Section of MOC frame E0300889 showing the Upper and Lower units of the Northern PLD.

Propagation Model: We model the 1-D propagation of normally incident plane waves through a layered medium by solving the full wave equation, including the electrically diffusive losses due to medium conductivity [4]. The solution consists of an effective, complex impedance Z, which describes the full electromagnetic response of the subsurface and yields an effective reflection coefficient R at the surface. Coefficient values, however, are frequency dependent and collectively form a reflection spectrum. The convolution of the reflection spectrum with the radar reflection spectrum with the radar spectrum and the subsequent inverse Fourier transformation to time domain produce the time history of the radar reflections, or “radargram”. The radar signal has a center frequency of 20 MHz, bandwidth of 10 MHz, and consists of a 85-µs chirped pulse. Applying a Hanning window to the radar pulse reduces side-lobe amplitude substantially. The numerical layers in the model are smooth, horizontal, and have a uniform thickness of 2.5 m throughout the model domain, which is finer than and properly resolves the albedo variations that define the PLD strata.

Dielectric PLD Profile: The essence of modeling the dielectric profile of the PLD lies in (i) estimating the volumetric fraction ν of silicate inclusions in the ice, a free parameter, as a function of depth from the variations in brightness across the PLD strata, and (ii) using mixing formulae to obtain an effective dielectric constant for each ν value. We used the upper 250 m of the brightness-depth profile illustrated in [5], which derived from a trough in the NPLD. The ice in this trough section shows an overall darkening with depth, which could result from effects other than dust content [e.g., 6]. We subtract this darkening trend and, consequently, maximize the variation in dust content. We linearly scale the resulting brightness profile to the range in measured albedo and then use the delta-Eddington approximation to radiative transfer of [7] to obtain plausible depth profiles for inclusion fraction. The resulting dielectric profile derives from the Tinga-Voss-Blossey mixing formula for two phases [8], ice and silicates. The adopted values for the dielectric constants of ice and silicates are 3.15 + i 2.2×10^-2 [e.g., 9] and 8.8 + i 0.017 (from average shergottites, [10, 11]), respectively. This 250-m profile is repeated to a depth of 2 km so as to produce a model for the upper unit of the NPLD. The lower unit of the NPLD is more difficult to model because of its rough, platy structure, and we only represent it as uniformly sand-rich (ν ≈ 50%).

Results: Fig. 2 shows radargrams for the NPLD model and different ranges in inclusion fractions in the upper NPLD. The vertical dashed line represents the sensitivity threshold imposed by SHARAD’s dynamic range. The fine stratigraphic structure of the NPLD is detectable if dust fractions are larger than 1%, as the resulting variations in dielectric constants are sufficiently large to produce observable reflections. The repetition of the 250-m section is also evident, as the strong reflectors are easily seen at ~6 µs, ~13 µs, and ~20 µs. Weaker reflectors are harder to pick out be-
cause of multiple reflections, especially at later times. Greater silicate content also delays reflections because of the overall higher dielectric constant of the upper PLD. The unconformity between the upper and lower units of the NPLD (Fig. 1) also produces strong reflections in the cases illustrated, between 24 μs and 27 μs. The simulations in Fig. 2 adopt a sand-rich composition for the lower NPLD unit (ν ~ 50%), as suggested by [3], but the main point is that enough radar energy returns from the unconformity even when the upper unit is rich in silicates. Note also that the boundary between the PLD and a basaltic crust produces a strong reflection at ~40 μs.

Performing the same simulations as the ones in Fig. 2 with only the real portion of the dielectric constants serves to illustrate the relative contributions of path and transmission losses to signal attenuation. Not surprisingly, the greatest difference occurs for the ν = [10, 50]% case, as it has the largest effective loss tangent (tanδ = ε′/ε″) of all of the cases illustrated. Omitting path losses incurs in an increase of 8 dB in the power of the reflection generated at the unconformity (26 μs), and causing all strong reflections to be at the -10 dB level; path and transmission losses are each responsible for ½ of the attenuation in this case. Finally, placing a 10-m layer of CO₂ frost on top of the NPLD model has a noticeable effect on the simulations. The dielectric constant of dry ice depends heavily on its density and can be obtained via Raleigh mixing [12]. At 910 kg m⁻³ [13], the dielectric constant of CO₂ frost is 1.59 + i 9.78×10⁻⁷, which is lower than that of water ice (pure or with silicate inclusions) and serves to reduce the power of the surface reflection. Consequently, subsurface reflections are relatively stronger when an upper dry ice layer is present. Fig. 3 shows an enhancement of nearly 10 dB for the case of ν = [0.1, 1.0]% in which the strongest reflections from the upper PLD are barely detectable without the dry ice.

Figure 2. Radargrams for different compositions of the upper NPLD for a SHARAD type of signal.

Figure 3. Radargrams illustrating the effect of a surficial layer of CO₂ frost using a SHARAD-like radar pulse.

Synopsis: Mapping of the stratigraphic structure of the PLD appears to require dust fractions of at least 1% under optimal conditions. Path and transmission losses may not, a priori, prevent the mapping of the unconformity in the NPLD, provided that the silicate content in the lower unit is significantly greater than that of the upper unit. The presence of a dry ice layer at the surface may help in the detection of weaker subsurface reflectors.