DETERMINING THE COMPOSITION OF THE NORTH POLAR LAYERED DEPOSITS USING SHARAD OBSERVATIONS AND MODELING: CLIMATE IMPLICATIONS

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Introduction: The North Polar Layered Deposits (NPLD) are a 2 km thick formation of nearly pure water ice situated in the Planum Boreum region of Mars [1]. Within the NPLD, many sub-parallel internal reflectors are visible in orbital ground penetrating radar data from the Shallow Radar (SHARAD) instrument on the Mars Reconnaissance Orbiter (MRO) [2]. It is theorized that these reflectors contain a global climate record of the late Amazonian period, going back as far as five million years [3]. In general, reflectors are caused by sharp changes in the dielectric properties of a material, but the exact cause of these changes in the NPLD is still unidentified. Multiple hypotheses have been proposed to explain these reflectors, with the most common explanation being fluctuations in dust content with depth. These hypotheses are supported primarily by modeling and confirming them directly with observations has remained difficult [4].

The dust-variation hypotheses fall into two main groups: either the layers are formed by variations in atmospheric ice and dust deposition rates, or by sublimation lag deposits. Both attempt to tie reflectors to the orbital parameters of Mars, similar to Milankovitch cycles on Earth. In the first hypothesis, periods of low obliquity variation lead to increased ice deposition rates, which change the mixing ratio of ice and dust enough to cause reflections [5]. The lag deposit hypothesis claims that increased insolation during high amplitude obliquity oscillations sublimates ice and leaves behind a layer of nearly pure dust material at the surface. This dust is then cemented by the next layer of ice, and it is these layers of dust that appear as reflectors in SHARAD data [6].

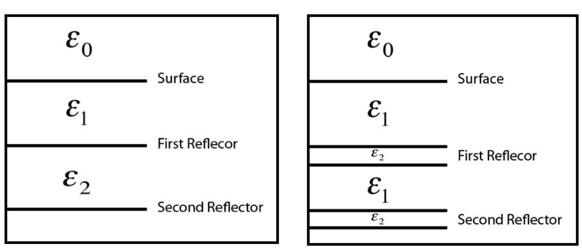

Fig. 1: Schematics of layer structure as proposed by variational deposition rate hypothesis (left) and lag deposit hypothesis (right). On the left reflectors are located at the interfaces between layers composed mostly of ice. On the right reflectors are located at the interfaces between ice layers and dust layers.

In the variable deposition rate hypothesis, layer composition is dominated by water ice, with dust fractions occasionally rising above the bulk value for the NPLD (at most 5%) [5]. This corresponds to a dielectric constant slightly above 3.15, the value for pure ice, and rarely above 4.0. The lag deposit hypothesis predicts reflectors caused by layers composed almost entirely of dust. The dielectric constant of such a layer depends on many factors, including the source of the dust, but values over 4.0 should be expected for such a configuration [6].

The Data: All data were acquired using the SHARAD instrument on MRO. SHARAD is an orbital sounding radar using an 85 μs chirped pulse with a 10 MHz bandwidth centered at 20 MHz. It has a theoretical vertical resolution of 8.4 m in water ice, though in practice this is closer to 10.0 m. The along track resolution of 0.3-1 km is achieved with synthetic-aperture data processing techniques [7]. All reflectors were mapped in the commercial seismic software Landmark Decision Space and all calculations were done in MATLAB.

The Model: In order to help determine what process is responsible for NPLD reflectors, we have applied a model similar to [8] to several reflectors in the top layer packet of the NPLD. We used this simple plane wave model to calculate effective dielectric constants of subsurface reflectors in the region of the NPLD connecting the main lobe to Gemina Lingula. This area was chosen for its flat topography, which reduces clutter and simplifies the identification and interpretation of reflectors. The model also assumes no surface roughness at SHARAD wavelengths and a lossless medium, both of which should be safe assumptions in the uppermost NPLD.

Results: So far our results closely match those predicted by the lag deposit hypothesis. All reflectors analyzed have had median dielectric constants over 4 and some have been over 5. This strongly suggests that these reflectors are caused by layers with a dust-dominated composition. Thus far we have not been able to identify any pattern or periodicity in dielectric constants with depth, but there is some evidence for spatial variations within individual layers. Specifically, some reflectors have higher dielectric constants at southern latitudes than at northern latitudes. This also corresponds to the gap between Gemina Lingula and the main lobe of the NPLD, so the exact cause of this gradient is unknown. One potential explanation is that winds play a larger role in dust distributeon than previously assumed. Recent modeling suggests the region mapped here has very low wind speeds, which could lead to deposition of any airborn dust particles. However, this is highly speculative and more detailed work is needed to explore this hypothesis. Regardless of the cause, this spatial variation is an interesting result as dust deposition was previously assumed to be relatively homogeneous over the NPLD.

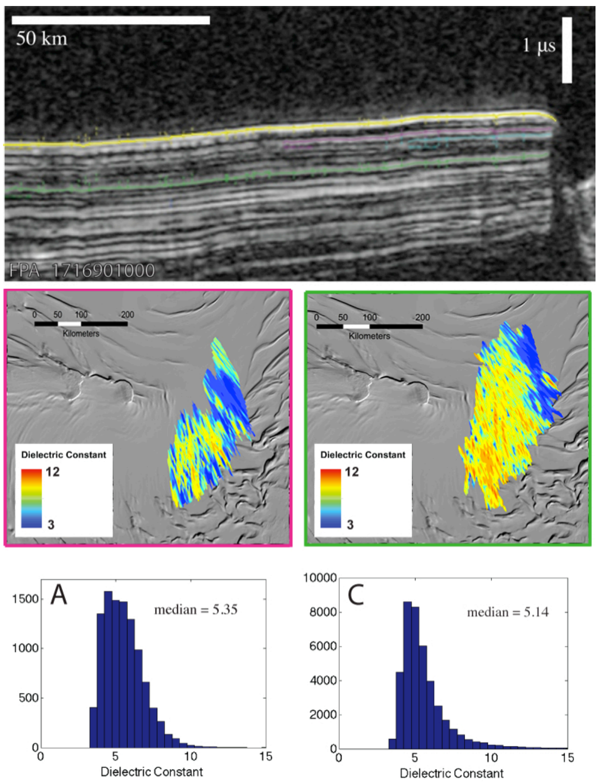

Figure 2: *Top: Radargram showing a cross section of the analyzed region. Bottom: Maps and histograms of the dielectric constants calculated for two different layers showing spatial variation. Map Borders correspond to reflector colors in top image to denote vertical position within the NPLD.*

Future Work: So far we have analyzed a small number of reflectors over a relatively small area. The next step forward for this work is to expand coverage in both depth and time so that patterns may be observed more easily. In addition, while our current results support the dust lag hypothesis, it is possible that reflectors are caused by more than one mechanism, and that our selection process preferentially resulted in selecting lag deposit reflectors. It is also possible that single radar reflectors are caused by multiple physical layers. We will use a wave propagation model to investigate the effects such a configuration would have on the observed data.

Once suitable data coverage is achieved, this analysis can be used to inform future modeling work and more accurately constrain the climate conditions resulting in NPLD accumulation. This method will also be used in a future effort to correlate subsurface reflectors with layers visible in optical outcrop data, as attempted previously [9], in order to confirm that reflectors are indeed caused by paleosurface interfaces. In addition to the methods previously used by [9], we will also make use of new split-chirp radar data and perform our analysis at a more favorable study site. Split-chirp data will allow us to observe any frequency-dependent behavior in the reflectors, which adds another criteria by which individual reflectors can be identified. The previous study site used in [9] had limited data available due to poor orbit geometries. Our new site includes many orbits crossing the outcrop at near-perpendicular angles, which helps trace reflectors to the outcrop wall.

Conclusion: In this work we have summarized a method by which we can estimate the effective dielectric constant of subsurface reflectors in the NPLD. Our results so far support the dust lag hypothesis of reflector formation, which has broad implications for Martian paleoclimate, specifically as it relates to the hydrologic cycle and orbital parameters of the planet. Our results are not yet conclusive, but this analysis coupled with other techniques shows the potential to answer many long-standing questions regarding the recent history of water ice on Mars.

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Acknowledgements: This work was supported by NASA MDAP grant NNX11AL10G. We also thank the SHARAD team.