RESOLVING STRATIGRAPHY OF THE POLAR LAYERED DEPOSITS WITH MARSIS AND SHARAD.

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Introduction: The Martian polar caps correspond to one of the principal targets for the ongoing radar sounding experiments [e.g. 1] due to the generally low electrical loss nature of water ice and the importance of characterizing their internal structure. Mapping the interior of the caps will provide constraints to crucial questions such as composition, heat flow, mechanics, and underlying lithospheric thickness, and it will likely yield important clues to the hydrologic and climatic histories of the planet.

Commencement of data acquisition by the Mars Advanced Radar for Subsurface and Ionospheric Studies (MARSIS) instrument aboard ESA's Mars Express (MEX) occurred at a time when the spacecraft orbital periapsis was at northern latitudes and near the evening terminator [2]. As such, this allowed only two passes over the Martian northern polar cap (orbits 1855, 1863) before the orbital geometry and the southward migration of MEX's periapsis latitude prevented further nighttime observations of the cap. Daytime observations are generally unsuitable for subsurface sounding because the ionosphere exerts severe distortion or altogether prevents the radar signal from reaching the surface of the planet.

In this abstract, we use the propagation model of [3] to contrast the published MARSIS data of the northern polar cap [2] with the expected performance of the SHAllow RADar (SHARAD) instrument (onboard NASA's Mars Reconnaissance Orbiter) in order to understand how well each will resolve the stratigraphy of polar layered deposits (PLD).

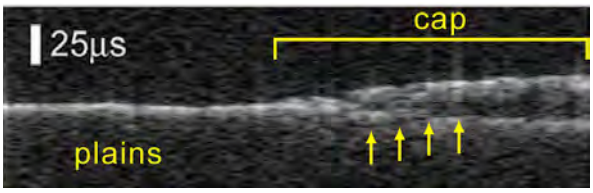

Fig. 1 – MARSIS Band 4 radargram of N Polar Cap from orbit 1855, modified from Fig. 1a of [2]. Yellow arrows show the basal reflector being overlain by a possible second intermediary subsurface reflector near the margin of the cap.

MARSIS Orbit 1855: The reflection time histories, or radargram, of the northern polar cap provided by MARSIS show the presence of a strong subsurface reflector, arriving 21 µs after and 10 dB weaker than the surface reflection at the end (right side) of the track [2]. Near the margin of the cap, however, this reflector (here dubbed "basal") appears to be overlain by a strong intermediary reflector, as seen in Fig. 1. The basal reflector (yellow arrows) is considerably weakened when below the intermediary reflector, which could be explained by a combination of increased attenuation in the material directly above it and transmission loss due to the effect of an additional dielectric interface in the propagation path of the radar wave. Also, we cannot rule out that some of the intermediary reflector, especially near the cap margin, may be exposed at the surface.

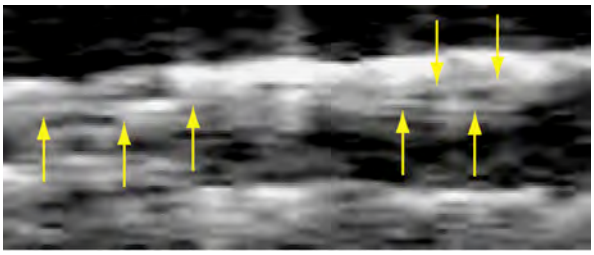

Fig. 2 – Processed image of a portion of the orbit 1855 radargram. There are at least two resolvable reflectors between the surface and the strong basal reflection. Strong intermediary reflector (Fig. 1) is in lower left of this image. Range across image is about 30 µs.

Fig. 2 shows an enlarged portion of the radargram of Fig. 1. There appears to be at least two internal reflectors (yellow arrows) in the ice. Internal layering is more apparent in MARSIS data from the South PLD, where data quality is better [4]. Internal reflections in both the north and south PLD are reasonable to expect, as the layering likely represents differing amounts of silicate inclusions in ice [e.g. 5] and an internal variability in the dielectric constant [3].

Modeling: Recent modeling by [3] suggests that SHARAD may be able to resolve the layering in the upper unit of the north polar cap down to a vertical resolution of ~20 m. The dielectric input to this model possesses finer layering, as obtained by a combination of MOC and MOLA data of a polar trough, the radiative transfer model of [6], and the Tinga-Voss-Blossey dielectric mixing formula [e.g. 7]. The stratigraphic sequence of the upper 500 meters is repeated downward to 2 km; this is intended to represent a possible repetitive signature due to climatic cycles, as suggested from albedo variations in the Upper PLD (UPLD) [e.g. 5] (the upper ice-rich unit in [8,9]). The portion of the model between 2 and 3 km in depth is uniform in composition and corresponds to the

Lower PLD (LPLD) (the lower sandy unit of [8,9]).

Fig. 3 shows the resulting radargram for the SHARAD chirped pulse (20 MHz center frequency, 10 MHz bandwidth, 85 µs pulse duration, and Hanning windowed to reduce sidelobes). Dielectric constant values for water ice and silicate inclusions are $3.2 + i\ 6.3\times10^{-4}$ and $8.8 + i\ 1.7\times10^{-2}$, respectively. Inclusion volumetric fraction in the upper unit of the cap varies from 1% to 10% according to ice albedo. Inclusion grains are assumed to be < 100 µm.

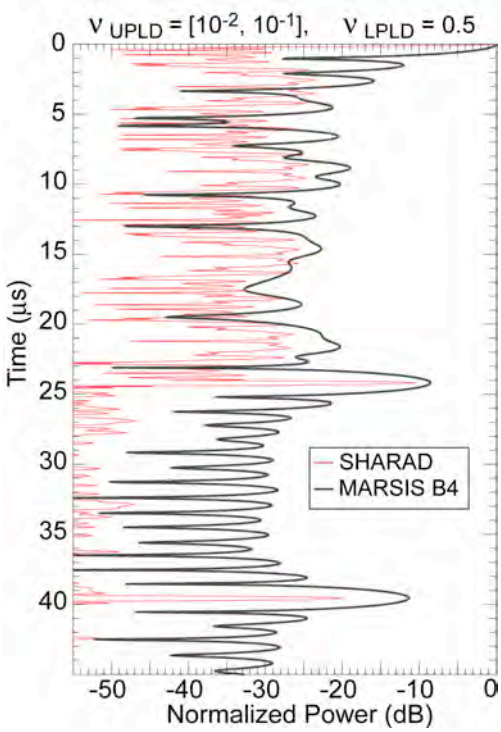

Fig. 3 – Radargrams from simulations adopting the NPLD model of [3] and with chirped pulses of both SHARAD and MARSIS Band 4. UPLD inclusion fractions range 1-10%; LPLD is uniform with an inclusion fraction of 50%. Substrate consists of basalt. Major peaks at 24 µs and 39.5 µs correspond to UPLD-LPLD and LPLD-Substrate interfaces, respectively.

Fig. 3 also displays the radargram of the same dielectric model obtained with the MARSIS Band 4 pulse (5 MHz center frequency, 1 MHz bandwidth, 250 µs pulse duration, and no Hanning window), corresponding to the data band in Figs. 1 and 2.

In both of the cases depicted, strong reflections occur at 24 µs and 39.5 µs due to the contrast in dielectric constant at the UPLD-LPLD and LPLD-Substrate interfaces. The much higher power in the MARSIS radargram for the LPLD (25-40 µs) is due to prominent sidelobes, as no Hanning window was applied to the signal. In the UPLD, reflection powers are not as disparate between the two radargrams, but the MARSIS return tends to group the individual reflectors detected by SHARAD into broader and somewhat stronger (≤ 5 dB) powered peaks. Applying a Hanning window to the MARSIS signal reduces sidelobes by at least 10 dB but causes peak broadening. The interaction among the broader reflection peaks in this case leads to greater peak clumping and further degradation in resolution. Much of the stratigraphic information can be lost in this manner. Lastly, while SHARAD is likely able to detect the repeating sequence of layers in the model stratigraphic column, MARSIS does not in this simulation.

Discussion: The main difference between the modeled radargrams in Fig. 3 and the one from orbit 1855 is the absence of a reflector in the 35-40 µs range. This can be explained by one of the following: *i*) the absence of the LPLD in the longitude range of the ground track, which would corroborate with the lack of observed LPLD outcrops at or near the margins of the cap between 0° and 90°E [2] (absence at the margins does not necessarily mean absence at 100 km into the cap domain, however); or *ii*) similarity in dielectric properties between the LPLD and the underlying Hesperian deposits. This will likely be resolved once orbital geometry allows for the nighttime observations of the northern cap at longitudes between 90° and 270°E, where the LPLD is prominently exposed [9].

Another point worth of noting is the relative strength (-10 dB) of the 24 µs reflection in Fig. 3, which is similar to that of the basal reflector in the orbit 1855 radargram. While [2] concluded that the integrated signal loss through the UPLD constrains the net dust fraction at < 2%, our modeling with a finely layered UPLD suggests that individual layers can hold up to ~10% of dust by volume with the same loss level.

Finally, and perhaps most importantly, is the issue of resolution, side-lobe control, and stratigraphic mapping. While MARSIS does an outstanding job in characterizing major (and deep!) dielectric units in the polar stratigraphic column, SHARAD's major contribution will likely be the resolving of the fine-scale stratigraphy that is necessary in answering some of the unresolved questions about the Martian polar caps. Based on our knowledge of the stratigraphy of the UPLD, the internal reflections observed in Fig. 2 most likely represent an integration of the response of a number of layer interfaces.

References: **[1]** Seu R. et al. (2004) *Planet. Space Sci.*, *52*, 157-166. **[2]** Picardi G. et al. (2005) *Science*, *310*, 1925-1928. **[3]** Nunes D. C. and Phillips R. J. (2006) *JGR*, in review. **[4]** Plaut J. J. et al. (2006) *LPSC XXXVII*, this CD. **[5]** Thomas P. et al. (1990) in *Mars*. **[6]** Kieffer H. H. (1990) *JGR*, *95*, 1481-1493. **[7]** Ulaby F. T. et al. (1986) *Microwave Remote Sensing, Vol. III*. **[8]** Byrne S. and Murray B. C. (2002) *JGR*, *107*, 5044. **[9]** Fishbaugh K. E. and Head III J. W. (2005) *Icarus*, *174*, 444-474.