INTERNAL STRUCTURE OF THE NORTH POLAR LAYERED DEPOSITS FROM RADAR SOUNDING.

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Introduction: Understanding the structure and stratigraphy of polar ices is an integral part of unraveling the history of their formation and its implications for past and present climate [e.g., 1,2]. Earlier studies of the North Polar Layered Deposits (NPLD) in Planum Boreum (PB) on Mars have provided valuable insight into the nature of these materials [3], but a complete characterization of the layers has been precluded by a lack of subsurface data.

With the advent of active-source radar instruments in orbit around Mars, direct information about subsurface electrical properties—the contrasts of which typically correspond to geological interfaces—is now becoming available, to depths of several kilometers. The Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) onboard the *Mars Express* (*MEX*) spacecraft provided the first direct look into the martian subsurface, and observations over the NPLD showed strong radar returns that likely delineate the base of the deposits [4]. MARSIS yields a limited number of radar returns internal to the NPLD, which may prove to correspond to boundaries between major packages of layering within the deposits.

In the Fall of 2006, the Shallow Radar (SHARAD) instrument onboard the *Mars Reconnaissance Orbiter* (*MRO*) began to acquire additional, higher frequency subsurface data in the polar regions, and the results show many more details within the NPLD, allowing a more direct comparison of image-based geologic interpretations with radar sounding results [5]. This poster will highlight the structure and stratigraphy that is evident in SHARAD results for the NPLD.

Background: The MARSIS instrument transmits chirped radio pulses of 1-MHz bandwidth centered at 1.8, 3, 4, and 5 MHz. The *MEX* orbit is highly elliptical (265 × 11550 km), and subsurface sounding is therefore limited to near-periapsis observations, yielding a horizontal ground resolution of 5-10 km along-track (with synthetic aperture processing) by 10-30 km cross-track. In contrast, SHARAD transmits a 10-MHz-wide chirped pulse centered at 20 MHz, and its platform (*MRO*) has a nearly circular orbit (255 × 320 km), giving a horizontal ground resolution of 0.3-1 km along-track by 3-6 km cross-track. Vertically, MARSIS subsurface resolution is limited to about 75 m whereas that of SHARAD is about 7.5 m (assuming a dielectric constant of 4). Depending on scattering and transmission loss, the depth of signal penetration in the martian regolith is expected to be limited to a few kilometers for MARSIS and to a few hundred meters for SHARAD. Penetration depths several times greater were anticipated for low-loss materials such as nearly pure, cold water ice, an expectation borne out by early NPLD results from both MARSIS and SHARAD [4,5].

The most prominent features of the polar regions of Mars are thick (2-4 km) stacks of finely layered materials, more or less centered on the pole in each hemisphere and cut by large arcuate chasmata and smaller reentrant troughs. These materials are believed to be predominantly composed of water ice with a variable amount of lithic inclusions that darken their appearance, thereby revealing their layered nature on the periphery and within the chasmata (see [6] and references therein). Recent studies of the NPLD [7,8] reveal a major division between the upper Amazonian polar layered deposits (Apl) and a lower basal unit (BU), where the lower unit is typically much darker and its layers are much less continuous [8]. It has been suggested that BU is the likely source of dune-forming materials that dominate the surface of Olympia Undae and the polar erg in general [7,8].

As discussed by Clifford et al [7], the continuity of the layers and their structure within the NPLD has important ramifications for understanding the age and flow history (if any) of the deposits, which in turn speak to the climate history of the planet as a whole. A complex internal structure with features such as angular unconformities and folds will lend support to formation models that include cycles of erosion and deposition, and makes an argument for a greater age of the deposits. Relatively undeformed horizontal layers would suggest a stagnant ice cap with little or no flow and a relatively young age, given the likelihood of large, chaotic obliquity cycles occurring on time scales of a few thousand to a few million years [9].

Observations: MARSIS coverage for any given location is constrained by the migration of the *MEX* periapsis latitude over time, and useful subsurface data is generally restricted to nighttime observations due to ionospheric interference. Since *MRO*'s near-circular orbit allows more frequent observations and SHARAD's higher frequency band allows daytime subsurface returns, SHARAD coverage is expected to rapidly outpace that of MARSIS. An aggressive NPLD campaign for SHARAD is in progress and promises to yield dense coverage in this region (see Figure 1 for present coverage ground tracks). For the purposes of this abstract, we focus on a single observation from SHARAD, with ground track shown in Figure 1 and corresponding radargram in Figure 2.

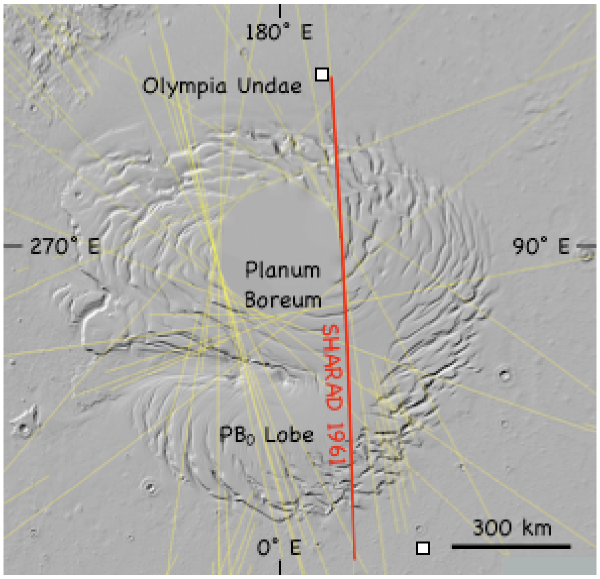

Figure 1: MOC wide-angle image mosaic of the North polar region (75-90°N), with ground tracks for March 2007 SHARAD coverage (yellow) and that of observation 1961 (red) shown in Figure 2.

Results: In the Planum Boreum region, SHARAD data show deep reflections corresponding to those interpreted in MARSIS results as coming from the base of polar layered deposits [4], despite the nominally shallower penetration depth of SHARAD (Figure 2). These results confirm the assertion by Picardi et al. [4], based on the strength of the putative basal reflections seen with MARSIS, that the materials must be cold and low-loss (and therefore relatively pure ice). However, it is worth noting that the corresponding radar returns from SHARAD are much more diffuse and even absent in some areas where MARSIS sees strong, coherent reflections [5]. Such comparisons demonstrate the complementary nature of these instruments and the value that each brings to improving understanding of the martian subsurface.

The greater depth resolution of the SHARAD results is apparent in Figure 2, where distinct packages of laterally continuous reflectors can be traced through much of the NPLD. Efforts are underway to correlate these reflectors to the layered units identified from surface images, including the contact between the Apl and BU units discussed above [5]. Meanwhile, a closer examination of the apparent layering evident in the SHARAD radargrams reveals intriguing structural features that may go toward addressing some of the outstanding issues concerning the internal deformation of the NPLD [6].

In many areas, chasmata and troughs disrupt the radar returns, complicating interpretation, but elsewhere the NPLD surface is uninterrupted. Figure 3 shows a portion of SHARAD observation 1961 over one such region, crossing the topographic saddle between the main cap and the lobe that extends southward at 0° longitude (PB$_0$). While the radar returns closest to the surface appear relatively continuous and conformal with the surface reflection, several internal structural elements are evident at greater delay times.

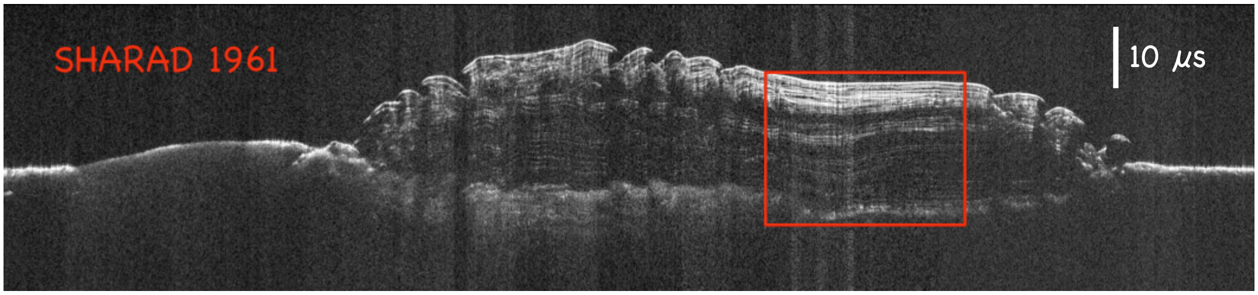

Figure 2: Radargram corresponding to the SHARAD ground track shown in Figure 1, extending from Olympia Undae on the left, across the main cap, and beyond the PB$_0$ Lobe on the right. Vertical dimension is two-way delay time, with approximate depth to a diffuse basal reflector of 2 km. Red box corresponds to segment shown in Figure 3. Horizontal extent is ~ 1200 km left to right.

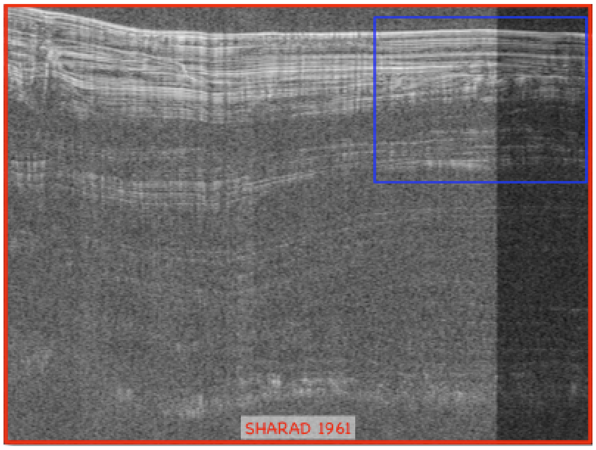

Figure 3: ~ 170 km × 25 µs segment of SHARAD observation 1961 corresponding to the red box shown in Figure 2. Blue box corresponds to the detail segment shown in Figure 4.

These include an increase in the concavity of the reflecting horizons beneath the saddle at intermediate times, an apparent angular unconformity within the package of strong, near-surface reflectors (upper right), and some rather more complicated radar returns, with cross-cutting reflectors that may be related to out-of-plane features in the surface or subsurface (upper left). The apparent angular unconformity, shown in detail in Figure 4, is particularly intriguing, since it is suggestive of a major climatological shift or event, potentially representing an earlier period of net loss and erosion or ablation, followed by a more recent period of net accumulation. Detailed subsurface mapping to fully characterize these and other features in three dimensions, using the increasingly dense grid of observations over the NPLD, is in progress.

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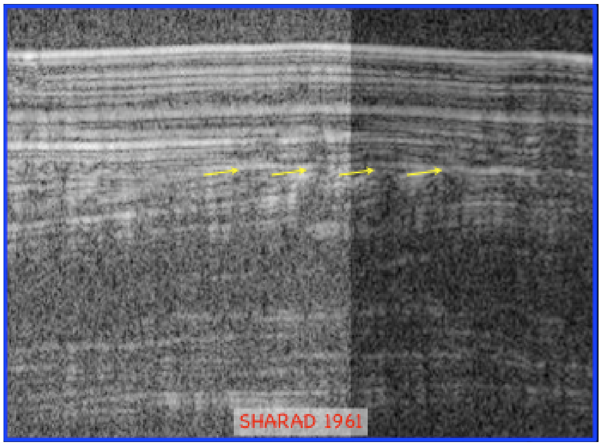

Figure 4: ~ 70 km × 10 µs segment of SHARAD observation 1961 corresponding to the blue box shown in Figure 3. An apparent angular unconformity (yellow arrows) may be the result of a climatological shift or event.