STRATIGRAPHIC MAPPING OF THE NORTH POLAR LAYERED DEPOSITS ON MARS FROM RADAR SOUNDINGS.

N. E. Putzig[1], R. J. Phillips[1], J. W. Holt[2], A. Safaeinili[3], J. J. Plaut[3], S. E. Smrekar[3], R. Seu[4], D. Biccari[4], B. A. Campbell[5], L. M. Carter[5], A. F. Egan[1], E. Giacomoni[4], F. Russo[4], M. Cutigni[4], O. Fuga[4], and the SHARAD Team; [1]Southwest Research Institute, Boulder, CO 80302 (email: nathaniel@putzig.com); [5]Inst. for Geophysics, J. A. and K. G. Jackson School of Geosciences, U. Texas, Austin, TX; [3]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109; [4]INFOCOM Department, U. Rome "La Sapienza," 00184 Rome, Italy; [5]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560.

Introduction: Sounding radar instruments in orbit around Mars are yielding a wealth of subsurface data, with the richest information coming from the icy layered deposits in the polar regions to depths of several kilometers. Here, we describe preliminary, radar-based stratigraphic mapping of the ice-rich layers in Planum Boreum, at the north pole of Mars. The geometry of these reflectors and their correspondence to layered units observed in surface images is key to assessing their geologic history and evaluating their implications for the past and present climate of Mars [e.g., 1–3].

Background: The most prominent polar features are 2–4-km-thick stacks of finely layered materials that are nearly centered on each pole and are cut by large, arcuate chasmata and smaller reentrant troughs. These materials are likely to be composed primarily of water ice with a variable amount of darker lithic inclusions, whose contrast with ice reveals the layered nature of the deposits on the periphery and within the chasmata (see [4] and references therein). Recent studies of the NPLD using surface images [5,6] show 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 much less continuous [6]. From the image data, the BU is inferred to extend beneath the main lobe of the polar cap but not beneath the Gemina Lingula lobe.

MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding, onboard *Mars Express*) provided the first subsurface profile from Planum Boreum, with a strong radar return from the base of the deposits [7]. Later results from SHARAD (the Shallow Radar instrument onboard the *Mars Reconnaissance Orbiter*) show a weaker, diffuse radar return from the base, but many more internal reflections from overlying layered materials [8,9]. These instruments are complementary, with MARSIS providing greater depth of penetration and SHARAD finer vertical resolution (~10 m in water ice vs. ~100 m for MARSIS). The mapping work presented here will focus primarily on the SHARAD results, which provide greater detail of internal structures and allow a more direct comparison to image-based geologic interpretations [9].

Observations: An aggressive and ongoing NPLD campaign for SHARAD is yielding increasingly dense coverage in this region, with observations acquired on nearly 1000 orbits through December 2007 (yellow lines in Fig. 1). The data are typically displayed as radargrams, with distance along track shown horizontally and power vs. delay time displayed vertically in an image format (see Figs. 2 and 3). While delay time is roughly analogous to depth, a geometric distortion occurs largely because the surface is not flat, which leads to varying path lengths in free-space and typical

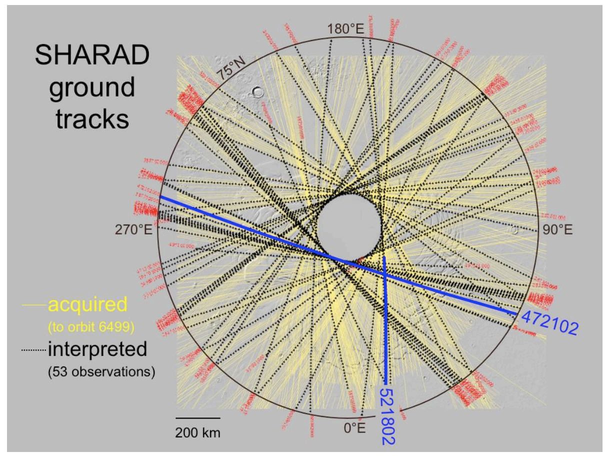

Figure 1: Location map showing SHARAD coverage (yellow lines) poleward of 75°N through December 2007. Blue lines show ground tracks for radargrams in Figs. 2 (521802) and 3 (472102). Black dotted lines show ground tracks for radargrams used in producing the map in Fig. 4. Background is MOLA shaded relief.

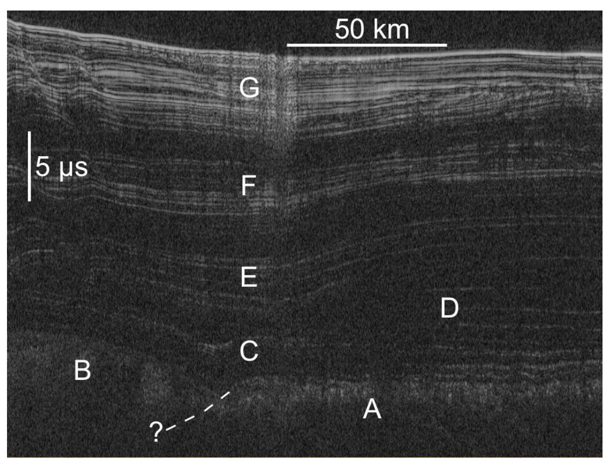

Figure 2: Portion of focused SHARAD radargram 521802, crossing the topographic saddle between the main lobe (left) and the Gemina Lingula lobe (right). Letters represent radar unit designations as described in the text. Upper contact of Unit A is inferred to extend beneath Unit B under the main lobe. Delay time shown corresponds to ~ 2 km vertically, assuming water ice.

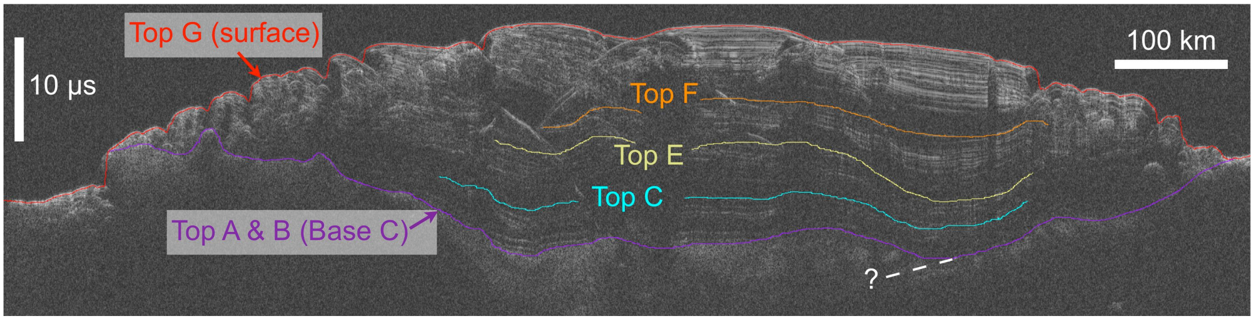

Figure 3: Unfocused SHARAD radargram 472102, extending from the edge of the main lobe near 270°E to the saddle region near 60°E. Colored lines represent contacts between radar Units described in the text. White dotted line represents an inferred contact between Units A and B, which are seen here as a diffusely reflective zone near the bottom of the radargram.

geological materials (e.g., regolith or water ice). Furthermore, the possibility that reflections from off-nadir surface features may arrive at delay times similar to those from true subsurface interfaces demands a careful analysis of potential sources of such surface clutter.

Results: In Planum Boreum, SHARAD radargrams show a sequence of closely spaced, strong reflections to ~5 µs delay time below the surface. These reflections are often nearly conformal with the surface return, but may include apparent angular unconformities (upper right of Fig. 2). The packet of strong reflectors is usually underlain by a low-power quiescent zone of ~2–3 µs delay time. Several similar sequences of packet–inter-packet reflections typically follow at later delay times, reduced in number, frequency, and power. The individual reflectors and the packets of reflectors represent two periodicities that can be related to global climatological cycles of Mars (driven by orbital and rotational dynamics), providing a lower bound on the age of the NPLD of 10 Ma [9]. Beneath the packets, SHARAD radargrams typically show a diffusely reflective zone, 5–10 µs in duration beneath the main lobe and 1–3 µs beneath Gemina Lingula and the topographic saddle between the two lobes.

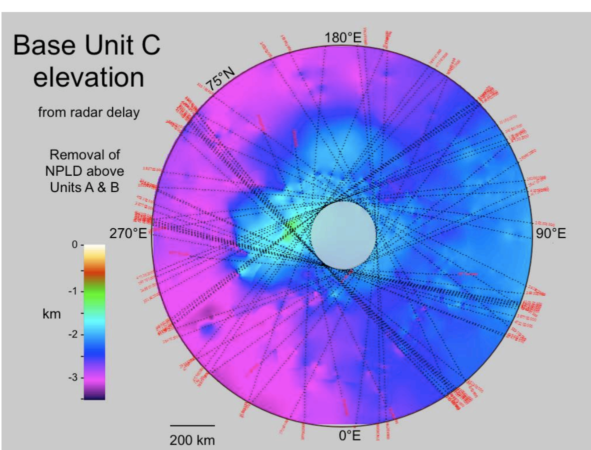

Figure 4: Elevation map of the deepest interface (purple contact in Fig. 3) interpreted in 53 SHARAD radargrams (black dotted lines). Beyond the cap edge, the surface return is mapped out to 75°N.

We designate a working set of radar-based geologic units (Fig. 2), beginning with Unit A as the thinner diffusely reflective zone, which we interpret as a likely extension of the Vastitas Borealis Interior Unit (ABvi) [10] beneath Gemina Lingula. Unit B, the thicker diffusely reflective zone, has been correlated with the BU discussed earlier [8,9]. Although not evident in the SHARAD data shown here, Unit A extends beneath Unit B and sometimes displays a weak reflection under the main lobe, and this same contact yields the strong basal reflections seen by MARSIS. Units C–G each represent a single packet–inter-packet sequence, with Unit D confined to Gemina Lingula.

Using subsurface data analysis software (SeisWare, from Zokero Inc.), we interpreted the unit contacts on a subset of the SHARAD radargrams. We then mapped and interpolated the contacts for the surface return and for Units A and B throughout Planum Boreum. Converting delay time to depth using a real dielectric constant of 3.15 (appropriate for water ice), we mapped the elevation of Units A and B in Planum Boreum together with the surrounding surface. The latter is predominately mapped as ABvi [10], which is ostensibly contiguous with Unit A (Fig. 4). Due to disruption by signal losses and surface clutter, delineation of the other internal contacts (e.g., tops of Units C, E, and F; see Fig. 3) beyond the saddle region will require a combination of higher SNR data acquisition and more sophisticated processing techniques.

References: [1] Morse et al. (1998) *GRL 25(17)*, 3383-3386. [2] Welch B. C. and Jacobel R. W. (2003) *GRL, 30(8),* 1444. [3] Fishbaugh K. E. and Head III J. W. (2005) *Icarus 174,* 444-474. [4] Clifford S. M. et al. (2000) *Icarus 144*, 210-242. [5] Byrne and Murray (2002) *JGR 107(E6)*, 5044. [6] Fishbaugh and Head (2005) *Icarus 174*, 444-474. [7] Picardi G. et al. (2005) *Science, 310,* 1925–1928. [8] Phillips R. J. et al. (2006) *AGU Fall Meeting*. [9] Phillips R. J. et al. (2008) *Science,* submitted. [10] Tanaka et al. (2007) *Icarus,* submitted.