RADAR REFLECTORS ASSOCIATED WITH AN ICE-RICH MANTLE UNIT IN DEUTERONILUS MENSAE, MARS. David M. H. Baker[1] and Lynn M. Carter[2], [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771 (david.m.hollibaughbaker@nasa.gov); [2] Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721.

Introduction: The Deuteronilus Menase region of Mars (39.6-49.9ºN, 13.7-35.4ºE) is host to a suite of ice-rich features, including lobate debris aprons (LDA), lineated valley fill (LVF) and concentric crater fill (CCF), that are thought to be debris-covered glaciers (DCGs) formed within the last ~1 Ga [e.g., 1]. More recent accumulations of dust and ice-rich "latitude dependent mantle" (LDM) superposes most units within the region, including DCGs [2]. A recent study by Baker and Head [3] also documented and mapped the presence of a Middle Amazonian-aged plains unit, "Upper Plains" (Upl), which exhibits onlapping relationships with DCGs and older Lower Plains (Lpl) composed of volcanic and sedimentary materials. The Upl unit was interpreted [3] to be a thick (~50-100 m) dust and ice-rich mantle that accumulated near the time that flow within DCGs ceased. This interpretation has important implications for understanding the near-surface properties of DCGs, including the formation of surface textures, evolution of crater morphologies, crater retention ages, and depth to the underlying glacial ice.

To further assess the structure and composition of the Upl unit, we examined radar sounding data from the Mars Reconnaissance Orbiter (MRO) SHAllow RADar (SHARAD) instrument, integrated with MRO CTX images and MOLA topography. SHARAD has been particularly useful for characterizing the subsurface structure of mid-latitude excess ice and DCGs across Mars [e.g., 4,5,6]. The vertical resolution of SHARAD is 15 m in free space with a horizontal footprint of ~0.3-1 km along-track and ~3-6 km cross-track.

Data and Methods: We used morphological mapping of DCGs, Upl, and Lpl by [3,7] for unit delineation (Fig. 1a,2a). 279 SHARAD nightside radargrams (US Team, PDS archive, up to April 2015) were analyzed for subsurface radar reflectors at the locations of Upl. An additional 12 dayside observations were analyzed over a large isolated patch of Upl for comparison with crossing tracks (Fig. 1). Candidate reflectors were confirmed by comparing the radargrams (Figs. 1b,2b) with simulations of surface clutter (Figs., 1c,2c) [8], which can appear at time-delays coincident with real subsurface returns. Confirmed reflectors did not appear in the clutter simulations. All subsurface reflectors were manually traced; the trace was then automatically adjusted to the surrounding pixels of maximum power. Power values and time delays of the surface and subsurface returns were then recorded.

SHARAD Observations: 101 radargrams showed evidence of subsurface reflectors beneath Upl. Most of the additional 190 radargrams were obscured by surface clutter. Others did not show reflectors, possibly due to the unit being too thin to resolve (e.g., in the eastern portion of the region) or poor dielectric contrasts between Upl and underlying materials.

The two-way time delays of surface returns are variable across the mapped region from ~1 µs to ~7 µs, but tend to be clustered into a shallow and deep reflector at ~1.5 µs and ~3.5 µs, respectively. The shallow reflectors

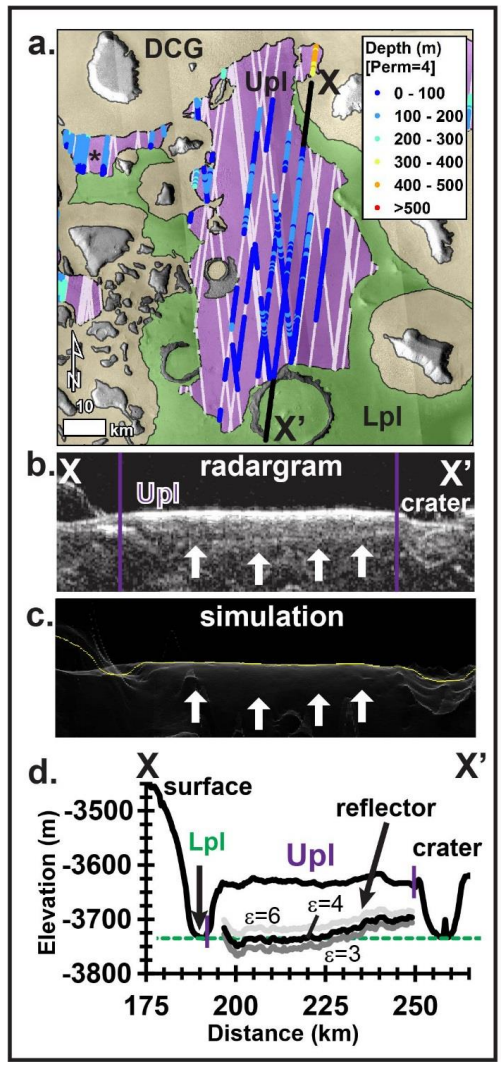

Figure 1. A patch of Upper Plains (Upl, purple) shows shallow reflectors. a) Mapped units (Upl, Lpl, and DCG) with SHARAD tracks colored based on depth to subsurface reflectors. White tracks are locations where no reflector could be identified. Centered at 44.1ºN, 27.1ºE. b) SHARAD radargram 03983101 with arrows pointing to a subsurface reflector. c) Clutter simulation. d) MOLA topography along track in (b), showing depth to the reflector assuming different permittivities (ε).

are associated with isolated patches of Upl that appear to directly overly Lpl (Fig. 1). Deep reflectors are generally associated with Upl surrounded by or near DCGs (Fig. 2). The power values relative to the surface reflection are also variable, with a mean value of near -15 dB. The power of returns are highest near contacts with DCGs.

Permittivity and Thickness of Upl: A large patch of Upl occurs in the middle of the region and appears to directly superpose the surrounding Lpl unit (Fig. 1). We interpret the contact between Upl and Lpl to be the source of the shallow reflectors (Fig. 1b). From MOLA topography (Fig. 1d), Lpl occurs at a baseline elevation of near -3735 m. By assuming that the observed subsurface reflectors represent the contact between Upl and Lpl, the permittivity (ε) of Upl can be constrained by adjusting ε until the reflector is aligned with the Lpl elevation (Fig. 1d). We find that the best match for ε is near 4 (Fig. d). A permittivity of 4 is consistent with an ice-rich mantle interpretation for Upl and the unit having higher debris content than DCGs, which have an estimated permittivity of 3.15 [5,6]. A permittivity of 4 also yields an average thickness of 85 m for Upl (Fig. 1a).

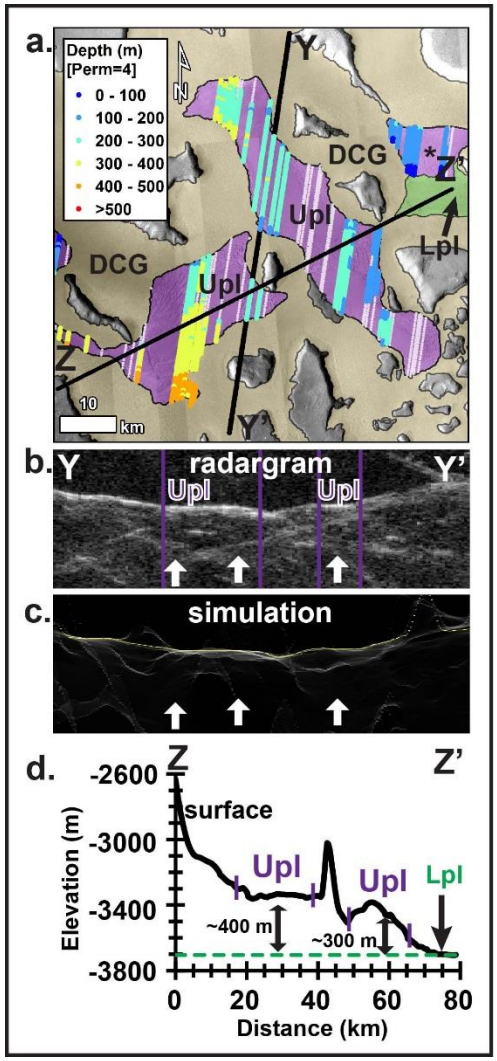

Figure 2. Upper Plains (Upl, purple) surrounding by glacial deposits (DCG) shows deep reflectors. a) Mapped units (Upl, Lpl, and DCG) with SHARAD tracks colored based on depth to subsurface reflectors. White tracks are locations where no reflector could be identified. Centered at 44.2ºN, 25.5ºE. b) SHARAD radargram 02152801 with arrows pointing to subsurface reflectors. c) Clutter simulation. d) MOLA topography along track in (b), showing the heights of the Upl surface above the Lpl basline elevation of -3705 m.

Buried Glacial Ice? Deep reflectors are observed beneath Upl that are surrounded by DCGs (Fig. 2; see asterisk in Figs 1a&2a to see where they co-locate). Assuming a permittivity of 4, the depth to these reflectors are 267 m on average. These depths are consistent with MOLA topography (Fig. 1d), but are much larger than the thickness of Upl calculated above (Fig. 1a). Further, these deep reflectors have higher average relative powers of -11 dB on average (compared to -16 dB for the shallow reflectors). These relative power values and depths are more consistent with those observed for the basal reflections of DCGs [6]. We tentatively interpret these reflectors to represent the base of DCGs or remnant ice deposits that extend beneath Upl at these locations. If this interpretation is correct, then at these locations, the termini of DCGs may extend several kilometers farther from their headwalls than suggested by surface morphology. The actual base of Upl, which would occur at shallower depths, is likely not observed in radargrams due to the poor dielectric contrast between Upl material and the supraglacial debris it contacts.

Summary and Future Work: SHARAD radar observations of a thick mantle unit within Deuteronilus Mensae suggest a permittivity near 4 and average thickness of 85 m, which is consistent with interpretations from morphological observations [3]. This unit may also be masking the termini of glacial deposits in some areas, suggesting more extensive ice deposits than can be inferred from surface morphology alone. Further investigation of the nature of deep radar reflectors below Upl is warranted to confirm this interpretation.

References: [1] Head, J.W., et al. (2010) *Earth Planet. Sci. Lett.* 294, 306–320. [2] Mustard, J.F., et al. (2001) *Nature* 412, 411–414. [3] Baker, D.M.H. and Head, J.W. (2015) *Icarus* 260, 269–288. [4] Bramson, A.M., et al. (2015) *Geophys. Res. Lett.* 42, 6566–6574. [5] Holt, J.W. et al. (2008) *Science* 322, 1235–1238. [6] Plaut, J.J. et al. (2009) *Geophys. Res. Lett.* 36, L02203. [7] Baker, D.M.H. and L.M. Carter (2016) *LPSC 47*, no. 1638. [8] Choudhary, P., et al. (2016) *IEEE Geosci. Remote Sens. Lett.* 13, 1285–1289.