LOW RADAR REFLECTIVITY IN PLANUM AUSTRALE POINTS TO PAST EPISODES OF MARTIAN ATMOSPHERIC COLLAPSE.

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Introduction: Using the Mars Reconnaissance Orbiter Shallow Radar (SHARAD), Phillips et al. [1] discovered several regions in Planum Australe with sequences containing little or no reflectivity (termed "reflection-free zones" or RFZs) extending hundreds of meters below a thin surface cover and underlain by reflective layered sequences. One such zone, RFZ_3, resides beneath the south pole residual cap (SPRC) in Australe Mensa and coincides with a previously mapped geologic unit, AA_3 [2,3]. This unit is composed of a massive deposit of CO_2 ice, an assertion supported by geometric considerations of underlying radar returns and by sublimation features seen in surface imagery [1]. Another zone, RFZ_1, resides in Promethei Lingula and while it has similar properties to RFZ_3, its composition has not been fully constrained. We present new mapping at both locations (Figs. 1 and 2) along with thermal and climate modeling results that explain the formation and preservation of the RFZs.

Background: Orbital parameters strongly force the Martian climate [4,5], evidenced by layering of polar deposits of water ice, which are transferred via the atmosphere to lower latitudes at times of high obliquity [6,7], and in thin seasonal deposits of CO_2 ice, which are transferred between the high northern and high southern latitudes each year [8,9]. Longer-term cycles also occur for CO_2 deposits. The SPRC is an ~8 m deposit that is largely in a sublimation regime and may be as young as a few hundred years [10]. The AA_3 deposit is much larger and if sublimated at higher obliquities [11] would increase atmospheric surface pressure by 5 mbar or more [1]. Modeling of CO_2 accumulation at both poles shows that much of the atmosphere may freeze out during periods of low obliquity. At the coldest periods, the surface pressure drops to as low as 0.1 mbar, but the atmosphere does not collapse completely. In the interim, the atmosphere may return to its full state or to a lower pressure state if CO_2 ice is sequestered as at present. These cycles follow the obliquity period of ~120 ka, likely occurring many times in the last few million years [4,12,13].

Radar Observations: Hundreds of SHARAD observations have been acquired over Australe Mensa and Promethei Lingula, providing cross-sectional views with lateral resolution of 460 m and vertical resolutions of 8.5 m in water ice and 10 m in CO_2 ice.

Australe Mensa. Previous mapping of RFZ_3 on 79 SHARAD observations estimated the volume of this material at 4500 km^3 within the detection area and 9500–12,000 km^3 when extrapolated to the mapped bounds of AA_3 [1]. Sparse coverage did not fully constrain the unit, so we updated the mapping to 380 observations, with enhanced processing. We find a very close correspondence between the bounds of the radar-detected RFZ_3 and the optically mapped AA_3 (cf. Fig. 1 with Fig. 3 of [1]). The new map includes previously unmapped outliers (red arrows in Fig. 1) and a refined base of RFZ_3 (bright colors in Fig. 1) that

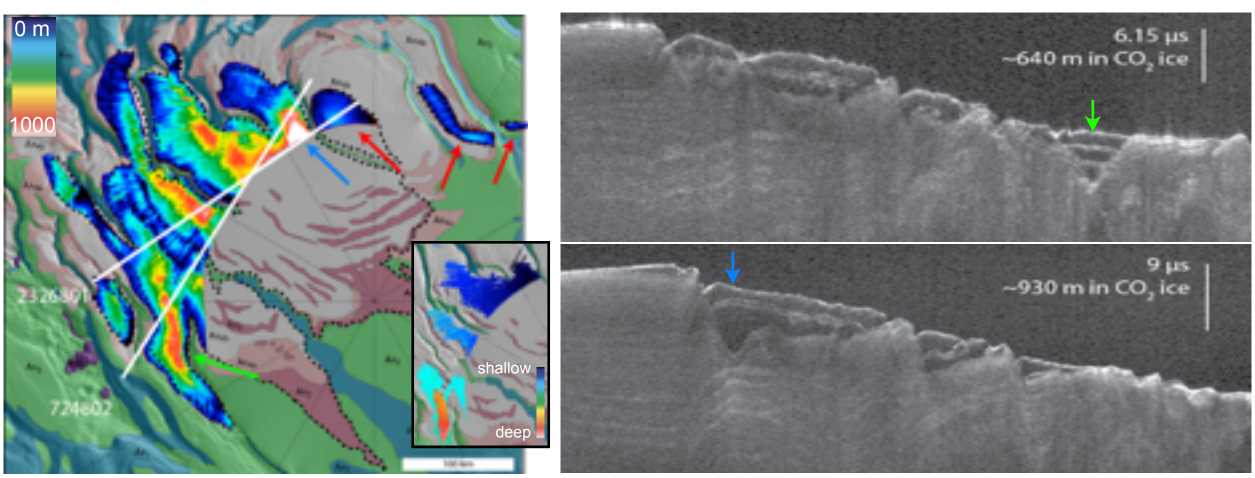

Figure 1. Map of Australe Mensa (left), showing RFZ_3 depth variations (bright colors) interpolated to a continuous volume where RFZ_3 deposits are observed. Depths are calculated using a dielectric constant of 2.11. Base map (subdued colors) shows geologic units [2,3]. *Dashed lines are boundaries of unit AA_3 where partially buried. MOLA shaded-relief base map. Orbits preclude SHARAD and MOLA data poleward of ~87°S. Inset shows bisecting layers (orange is BL_2). SHARAD ground tracks (white) correspond to radargrams for observations 7248-01 (top) and 23268-01 (bottom), showing transects of RFZ_3 with one or two (green arrow) bisecting layers. The location of the thickest part of RFZ_3 is shown at the blue arrows. Radargram scale bars show depths to base of RFZ_3.*

increases the maximum depth from ~700 m to ~1000 m (blue arrows in Fig. 1). The earlier work identified a bisecting layer (BL_1) separating two subunits of RFZ_3 in many locations. We delineate a second bisecting layer (BL_2) in one location (green arrows in Figs. 1 and 2, orange in Fig. 1 inset). BL_1 and BL_2 are not exposed on the surface, so constraints on their material properties are limited. Likely compositions include water ice and a dust lag [1]. Our updates increase the measured detection-area volume to 7,700 km^3 (Fig. 1) and the extrapolated volume to 14,800 km^3. If this volume were sublimated, it would more than double the current atmospheric surface pressure of 6.1 mbar.

Promethei Lingula. Prior mapping of RFZ_1 in Promethei Lingula was very limited [1]. For this conference, we are mapping all 222 available observations and will produce a volume estimate. While the character of RFZ_1 (Fig. 2) is largely similar to that of RFZ_3, we find no bisecting layers, and the more subtle basal structure and interfering surface clutter do not allow the correlation or straight-line-fit tests used to constrain the dielectric for RFZ_3 [1]. Crossing-track summing [14] or full 3D processing of the SHARAD data [15] may eventually provide a means to resolve this problem. An alternative hypothesis is that the Promethei Lingula RFZ consists of exceptionally pure water ice laid down during a period with little or no atmospheric dust, perhaps during a climate transitioning to atmospheric collapse.

Thermal Modeling: To estimate the sublimation rates of buried CO_2 ice, we used a three-layer thermal model with the buried CO_2 at the base, a covering insulating layer of dust or water ice, and a capping layer where seasonal CO_2 condenses and sublimates. The model was run with a fixed latitude of 86°S and present-day orbital parameters. Details of the thermal model will be presented in Thomason et al. [16].

Since atmospheric CO_2 should saturate the pores in the overburden, there is no significant diffusion barrier for the CO_2 ice. Even for very low permeabilities, the diffusion rate is orders of magnitude higher than the sublimation rate [16]. The modeled sublimation rate goes to zero as the capping layer thickness in seasonal thermal skin depths reaches 1.5 (~8 m of water ice) or 2 (~0.4 m dust). These results are largely insensitive to the model time step, layer thicknesses, and emissivity.

Conclusion: SHARAD RFZs in Planum Australe are remnants of recent atmospheric collapse and indicate that the Martian atmosphere is currently in an interim state, with over half of its CO_2 sequestered below a veneer of water ice and dust.

References: [1] Phillips R. J. et al. (2011) *Science, 332,* 838–841. [2] Kolb E. J. et al. (2006) *LPS XXXVII,* Abstract #2408. [3] Tanaka K. L. et al. (2007) *7th Mars Conf.,* Abstract #3276. [4] Laskar J. et al (2004) *Icarus, 170,* 343–364. [5] Levrard B. et al. (2007) *JGR, 112,* E06012. [6] Head J. W. et al. (2003) *Nature, 426,* 797–802. [7] Madeleine J.-B. et al. (2009) *Icarus, 203,* 390–405. [8] Hess S. L. et al. (1979) *JGR, 84,* 2923–2927. [9] Tillman J. E. et al. (1993) *JGR, 98,* 10,963–10,971. [10] Byrne S. and Ingersoll A. P. (2003) *Science, 299,* 1051–1053. [11] Forget F. et al. (2006) Science, 311, 368-371. [12] Manning, C. V. et al. (2006), *Icarus, 180,* 38–59. [13] Wood S. E. (2012) *Mars Recent Climate Workshop*, NASA Ames, May 15–17. [14] Campbell et al. (2015), *LPS XLVI* (this conf.). [15] Putzig N. E. et al. (2014) *8th Mars Conf.,* Abstract #1336. [16] Thomason C. J. et al. (2015) Modeling and Radar Observations of the Subsurface CO2 Deposits on Mars South Polar Cap, *in prep.*

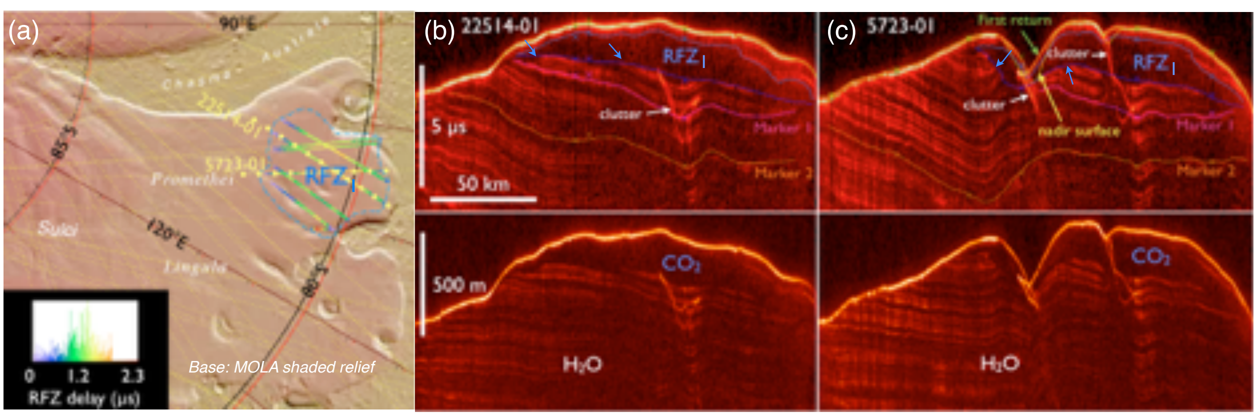

Figure 2. (a) Map of Promethei Lingula showing where SHARAD finds a reflection-free zone (RFZ_1) atop a low dome (yellow dotted lines are observation ground tracks). (b, c) Radargrams for two observations show delay-time (top panels) and depth sections (bottom panels). Delay-time sections show the nadir-surface delay calculated from a MOLA map in yellow, the actual first return from the surface in green, the top and bottom of the RFZ in blue, and two laterally extensive "marker" reflections in magenta and orange. Underlying layers are truncated by the RFZ base (blue arrows). For the depth sections, we assume real permittivity of CO_2 ice (2.11) in the RFZ and that of water ice (3.15) elsewhere. The RFZ_1 base shallows by ~20% if we assume water ice everywhere (not shown). The lack of pronounced structure at the base of RFZ_1 and interference from off-nadir surface clutter (white arrows) make it difficult to apply the techniques that Phillips et al. [1] used to constrain the material properties of RFZ_3.