LOW RADAR REFLECTIVITY IN PLANUM AUSTRALE POINTS TO PAST EPISODES OF MARTIAN ATMOSPHERIC COLLAPSE. N. E. Putzig¹, R. J. Phillips¹, I. B. Smith¹, C. J. Thomason¹,², M. T. Mellon¹, B. A. Campbell¹, and S. E. Wood⁴. ¹Southwest Research Institute, Boulder, CO, ²University of California, Santa Cruz, CA, ³Smithsonian Institution, Washington, DC, ⁴University of Washington, Seattle, WA. Email: nathaniel@putzig.com.

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, RFZ₃, resides beneath the south pole residual cap (SPRC) in Australe Mensa and coincides with a previously mapped geologic unit, Aₐ₃ [2,3]. This unit is composed of a massive deposit of CO₂ ice, an assertion supported by geometric considerations of underlying radar returns and by sublimation features seen in surface imagery [1]. Another zone, RFZ₁, resides in Promethei Lingula and while it has similar properties to RFZ₃, 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 CO₂ ice, which are transferred between the high northern and high southern latitudes each year [8,9]. Longer-term cycles also occur for CO₂ 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 Aₐ₃ deposit is much larger and if sublimated at higher obliquities [11] would increase atmospheric surface pressure by 5 mbar or more [1]. Modeling of CO₂ 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 CO₂ 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 CO₂ ice.

Australe Mensa. Previous mapping of RFZ₃ on 79 SHARAD observations estimated the volume of this material at 4500 km³ within the detection area and 9500–12,000 km³ when extrapolated to the mapped boundaries of Aₐ₃ [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 RFZ₃ and the optically mapped Aₐ₃ (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 RFZ₃ (bright colors in Fig. 1) that

Figure 1. Map of Australe Mensa (left), showing RFZ₃ depth variations (bright colors) interpolated to a continuous volume where RFZ₃ 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 Aₐ₃ where partially buried. MOLA shaded-relief base map. Orbits preclude SHARAD and MOLA data poleward of ~87°S. Inset shows bisecting layers (orange is BL₂). SHARAD ground tracks (white) correspond to radargrams for observations 7248-01 (top) and 23268-01 (bottom), showing transects of RFZ₃ with one or two (green arrow) bisecting layers. The location of the thickest part of RFZ₃ is shown at the blue arrows. Radargram scale bars show depths to base of RFZ₃.
increases the maximum depth from ~700 m to ~1000 m (blue arrows in Fig. 1). The earlier work identified a bisecting layer (BL1) separating two subunits of RFZ1 in many locations. We delineate a second bisecting layer (BL2) in one location (green arrows in Figs. 1 and 2, orange in Fig. 1 inset). BL1 and BL2 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 RFZ1 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 RFZ1 (Fig. 2) is largely similar to that of RFZ2, 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 RFZ1 [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 sublimes. 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.


Figure 2. (a) Map of Promethei Lingula showing where SHARAD finds a reflection-free zone (RFZ1) 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 base shallows by ~20% if we assume water ice everywhere (not shown). The lack of pronounced structure at the base of RFZ1 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 RFZs.