RADAR SOUNDING OF THE POLAR TERRAINS OF MARS: PAST AND PROLOGUE. J.J. Plaut, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, plaut@jpl.nasa.gov

The ice-rich polar layered deposits (PLD) and the adjacent terrain contain records of past martian climate that remain to be deciphered. The upper surfaces of these deposits are active today, the shallow subsurface likely records late Amazonian events, and evidence remains in older units of volatile transport as far back as the Hesperian. The composition of the polar materials is varied, including both H_2O and CO_2 ice, as well as fine grained materials (dust to sand), and lithic-dominated material containing varying fractions of ice. Significant insight into the internal structure and composition of the polar units has been obtained with the radar sounders MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) on Mars Express and SHARAD (Shallow Radar) on Mars Reconnaissance Orbiter. These radars have been observing the polar regions for over a decade, and continue to operate at present. This paper presents a review of the key results obtained from these observations, and looks to the future of both MARSIS and SHARAD, as well as potential follow-on systems that can fill gaps in our understanding of the links between polar stratigraphy and climate.

The difference in operating frequencies of MARSIS and SHARAD results in a complementary trade between resolution and depth of penetration. MARSIS provides greater penetration and detection of deep interfaces, while SHARAD provides a detailed picture of the layers in the upper 1-2 km of the PLD. The barriers to deep penetration in SHARAD data appear to be primarily a scattering effect, although some frequency-dependent compositional attenuation cannot be ruled out. Regardless of the cause, it is clear from hundreds of MARSIS and SHARAD polar observations that MARSIS is capable of detecting the basal interface between the PLD and the substrate over the vast majority of the PLD, while SHARAD typically only detects this interface in thinner PLD and/or near the margins. An exception is the Gemina Lingula lobe of the NPLD, where SHARAD has successfully mapped most of the basal interface. The lower, dust- and sand-rich "basal unit" of the NPLD is generally opaque to SHARAD but is penetrated by MARSIS. The topography of the basal interface below the basal unit in the north is seen by MARSIS to be almost uniformly flat, closely matching an interpolated surface of the surrounding Vastitas Borealis formation. The south, on the other hand, is a much more complex and varied terrain, both external to the SPLD and as mapped by MARSIS below the SPLD. Further complicating the picture in the south is the presence of the enigmatic Dorsa Argentea Formation (DAF), which surrounds much of the SPLD and clearly appears in much of the MARSIS data to extend beneath the SPLD. MARSIS detects interfaces in the DAF as deep as 1 km. Some of these interfaces are seen well below the "basal" interface of the SPLD, i.e., the generally continuous bright reflector that lies at or near the expected position of the pre-existing topography. While the origin of the DAF is generally thought to be related to volatile transport in the Hesperian, the current presence of ice in the unit has yet to be confirmed.

The polar orbiting platforms of MARSIS and SHARAD have allowed dense mapping coverage of the polar regions. This coverage has provided the opportunity to assemble three-dimensional image volumes of both MARSIS and SHARAD radargrams. 3-D processing provides a means of suppressing surface clutter to better isolate subsurface returns, and to map internal layers in a straightforward way. SHARAD 3-D volumes have been used to detect potential buried impact craters [1] and MARSIS 3-D volumes are being used to detect and map enigmatic deep reflectors beneath the familiar basal interface [2].

Compositional constraints have been obtained from the radar sounding observations. The combined reflective, transmissive and wave velocity properties of the PLD generally indicate a relative pure H_2O composition, with a lithic fraction less than 10% in much of the PLD. However, the presence of numerous internal reflectors indicates concentrations of lithic material (likely dust) in certain PLD layers [3]. The north basal unit appears lithic-rich in image data, and its radar properties are generally consistent with this composition, though its opacity to SHARAD may be the result of scattering from internal inhomogeneities. Perhaps the most surprising compositional result from the radars was the detection of extensive thick lenses of buried CO_2 ice within some of the near-polar SPLD [4]. Further mapping of this unit indicates that it sequesters an amount of CO_2 greater than the current uncondensed atmosphere [5]. Trapping and retaining large volumes of CO_2 ice in the PLD remains to be explained. While bright reflectors at the base of the SPLD were observed early in the MARSIS data, recent analysis of full-resolution raw mode MARSIS data allowed isolation of a particularly reflective basal patch ~20 km in size, at a depth of 1.5 km [6]. The reflective properties of this patch are interpreted to indicate the presence of liquid H_2O at the basal interface, the presence of which likely requires an anomalous recent endogenic source of heat [7].

The large amount of MARSIS and SHARAD data already acquired, and the continued operation of radars at Mars, indicates great potential for new discoveries and refinement of current ideas. The 3-D volumes have only received initial scrutiny, and those constructed from MARSIS data are still undergoing processing. Progress has been made in pinning certain PLD layer sequences to climate events [e.g., 8], but much remains to be done at both poles. Future mission concepts to address the open questions include higher frequency radar imaging and sound to characterize the upper 10s of m of regolith in the polar regions and in icy terrains across the planet. As noted at recent conferences [9], the highest priority measurement for polar science is compositional sampling of the vertical stratigraphy of the PLD. By analogy to ice coring climate studies on terrestrial ice sheets, there is no substitute for directly sampling the ice deposits themselves to read the climate story recorded their layers.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] Putzig et al., 2017, Icarus 308. [2] Plaut 2018, 49th LPSC. [3] Lalich et al., 2019, JGR-Planets,in press. [4] Phillips et al., 2011, Science 332. [5] Bierson et al., 2016, GRL 43. [6] Orosei et al., 2018 Science 361. [7] Sori and Bramson, 2019, GRL 46. [8] Smith et al., 2016, Science 352. [9] Smith et al., 2018 Icarus 308.

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