SPLD-SEQUESTERED CO_2 DEPOSIT: RECENT CLIMATE IMPLICATIONS.

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Introduction: The Shallow Radar (SHARAD) instrument on the Mars Reconnaissance Orbiter (MRO) generates a chirped pulse of 15–25 MHz at a free-space center wavelength of 15 m (~5–10 m in the subsurface). With MRO's 255–320-km orbit, SHARAD achieves a lateral resolution at the surface of 3–6 km, reducible to 0.3–1.0 km in the along-track direction with SAR processing. SHARAD records returned signals that are reflected by the surface and by subsurface interfaces with a permittivity contrast, which may be provided by changes in material properties, either in their composition (e.g., variations in the lithic content of ice layers, CO_2 overlying water ice) or in their physical characteristics (e.g., density variations due to changes in pore volume). Lossy or highly scattering materials reduce the strength of transmitted signals and may mask underlying interfaces that might otherwise be detected.

SHARAD soundings of the north and south polar layered deposits (NPLD and SPLD) have yielded detailed internal structure to depths of a few kilometers. The characterization of water-ice deposits is richest in the north, where packets of internal layers can often be traced throughout Planum Boreum. In the south, while the water-ice layering is more complex and discontinuous (consistent with these deposits being substantially older), a newly discovered deposit of massive CO_2 ice has significant implications for recent changes in Mars' climate [1].

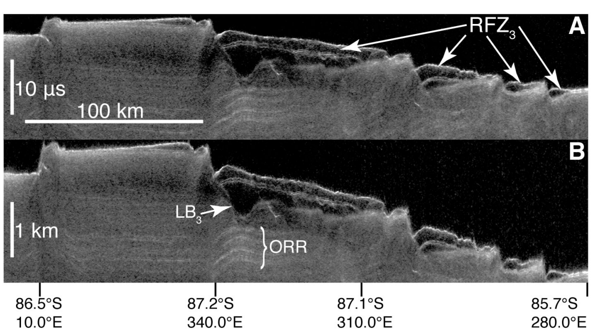

Figure 1. SHARAD radargram 5968-01 traversing RFZ_3 unit shown in original time-delay format (**A**) and converted to depth (**B**) using water-ice permittivity. "Organized radar reflectors" (ORR) and RFZ_3 lower boundary (LB_3) are indicated. Minimizing the distortion in the ORR sequence was the basis for estimating the permittivity of RFZ_3. From [1].

CO_2 Deposit: In the SPLD, organized sets of radar reflectors are limited to specific regions, and it is difficult to map SPLD-wide radar stratigraphy. SHARAD results do show four regional (nearly) reflection-free zones (RFZs) distinguished by their qualitative radar characteristics [1]. In one zone (RFZ_3, Fig. 1), which occurs beneath the South Polar Residual Cap (SPRC) and has a good spatial correlation with stratigraphic unit "AA_3" [2, 3], multiple techniques were used to invert for the real permittivity, ∑′, on 41 SHARAD observation sets. The resulting ∑′ range of 2.0–2.2 (σ of 0.1–0.2) is remarkably close to the laboratory-measured permittivity value of bulk CO_2 ice [4] and distant from the bulk water-ice value (∑′ = 3.15). The permittivity estimates yield a mean thickness of 200–230 m and a volume of 4,000–4,500 km^3 for RFZ_3 where it is observed by SHARAD. Unit AA_3, which shows good morphological evidence for CO_2 sublimation features, was used a basis for extrapolating poleward of ~87°S (where MRO's orbital inclination precludes SHARAD sounding), yielding a total volume estimate for RFZ_3 of 9,500 to 12,500 km^3 (Fig. 2).

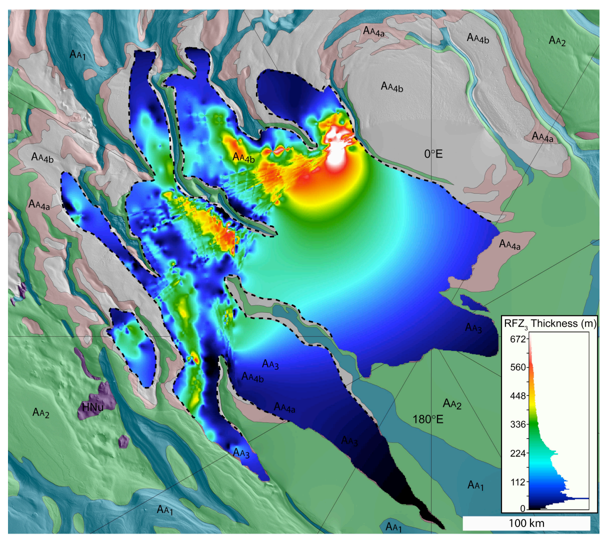

Figure 2. Bright colors show thickness data from the SHARAD-mapped RFZ_3 unit (using ∑′ = 2.1) extrapolated (smoother color pattern) over and constrained by the lateral extent of the AA_3 unit (dashed lines) by using a minimum-curvature interpolation function. The histogram shows relative occurrence of thicknesses. Base map (muted colors) shows SPLD stratigraphy [2,3]. From [1].

Climate Implications: If entirely released to the atmosphere, this volume of CO_2 would add 4–5 mbar, roughly doubling the current atmospheric pressure of ~6 mbar. Such a release is likely to have occurred at times of high obliquity. The most straightforward implications [1] are that the increased atmospheric pressure would (*i*) exceed the triple-point pressure at the surface in more locales, allowing liquid water to persist without boiling; and (*ii*) enable higher wind stresses, leading to increased frequency and intensity of dust storms. The situation is clearly more complicated than this, given the complex interplay between the dust, water, and CO_2 cycles.

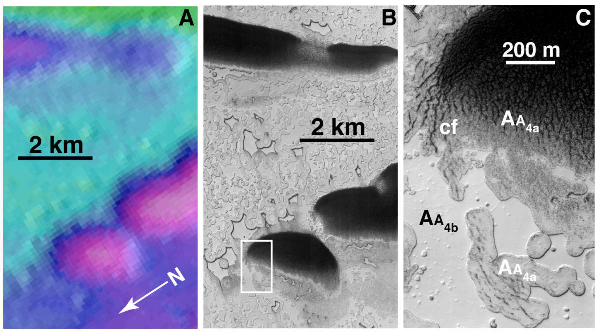

Figure 3. MOLA topographic image (**A**) in the vicinity of 87°S, 268°E, showing linear depressions or troughs in the AA_3 unit. The total elevation range of the image is ~75 m. The troughs are associated with circular pits (**B**, part of MRO HiRISE image ESP_014342_0930) and are thinly buried by the SPRC (**C**), with unit AA_{4b} (CO_2 ice) displaying sublimation windows into a fractured water-ice unit AA_{4a} beneath. Concentric fracturing (cf) is seen on the pit rim. From [1].

Evidence from imaging and radar observations suggests that the size of the SPLD CO_2 deposit has been decreasing (Fig. 3), implying that the atmosphere in the past had contained less than the present ~6 mbar of CO_2. The broader picture involves speculation that recent Mars operates with 10-12 mbar of CO_2 that is divided dynamically between (mostly) polar and atmospheric reservoirs, with the ongoing exchange between the two reservoirs driven largely by obliquity variations.

The general lack of radar reflections within the CO_2 volume implies that it was deposited with little accompanying dust. Climate models suggest that below a critical obliquity much of the atmosphere would "collapse" onto the polar caps [5], and perhaps the buried CO_2 volume was deposited during one of these episodes. Periods of low obliquity are also times of diminished dust storm activity, due to both a collapsing atmosphere and a weakening of the general circulation. These effects provide an explanation for the general lack of radar reflections within the CO_2 deposit.

Some Critical Questions: (*i*) How old is the buried CO_2 deposit? (*ii*) Does the CO_2 volume represent a single depositional event [a thin bisecting layer within RFZ_3 (Fig. 1) suggests otherwise]? *(iii*) What are the conditions under which the deposit has a loss rate consistent with its age or is at least quasi-stable? (*iv*) Are there other CO_2 deposits sequestered in the SPLD? (*v*) Is there any evidence for CO_2 deposits sequestered in the NPLD?

References: [1] Phillips, R. J., et al. (2011) *Science*, *332*, 838-841. [2] Tanaka, K. L., et al. (2007) *7th Int'l Conf. Mars*, Abstract # 3276. [3] Kolb, E. J., et al. (2006) *LPSC XXXVII*, Abstract # 2408. [4] Pettinelli, E., et al. (2003) *J. Geophys. Res.*, *108*(E4), 8029. [5] Armstrong, J. C., et al. (2004) *Icarus*, *171*, 255-271.