SEARCHING FOR BURIED WATER ICE IN MARTIAN DUNES WITH RADAR AND THERMAL DATA.

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Introduction: Locating water ice in the near subsurface has long been an important element of the scientific exploration of Mars, given its climatological implications. Renewed interest in sending humans to the Martian surface provides a second impetus for finding water ice, which will be needed as an in situ resource. Evidence for buried ice comes in several forms: morphology from surface imagery and elevation data; spectrometer detections of neutrons scattered by hydrogen atoms bound up in water ice and buried within ~50 cm of the surface; temperature changes measured by thermal spectrometers that are driven by the thermal effects of ice buried within ~1–2 m of the surface; excavation of ice by fresh impacts up to several meters into the regolith; and reflections of radar signals from interfaces atop, within, or at the base of buried ices extending to depths of a few 100 m. Outside of the polar layered deposits, buried ice has been identified in several settings, including within sand dunes in the north polar region (e.g., [1]), ground ice within regolith (e.g., [2,3]), and glacial deposits buried under a cover of debris (e.g., [4,5]). Here, we focus on the radar results for sand dunes globally and their relationship to the thermal observations.

Data and Methods: Due to their scattering effects, dunes have not been targeted extensively by the SHARAD team. However, dunes often occur in conjunction with layered materials that are actively targeted, and the team is working toward infilling coverage globally to assess surface roughness. Thus, larger dune fields across the planet have at least some coverage, and those in the polar regions have dense coverage.

SHARAD transmits radar signals with a range (~vertical) resolution (wavelength) of 15 m above the surface and finer in the subsurface (e.g., ~8.5 m in water ice, ~5.5 m in basaltic materials), a cross-track resolution of ~3–6 km, and an along-track resolution of ~0.3–1 km [6]. Transmitted signals reflect from dielectric interfaces and are recorded back at the spacecraft. The strongest returns typically come from the nadir surface, and these may be followed by later returns from subsurface geologic boundaries and off-nadir surface topography. Roughness at interfaces within the footprint of the radar signal can induce scattering that reduces the power and coherence of the returns. These scattering effects are often encountered in SHARAD observations of dunes because many dune forms are on the order of the radar wavelength (e.g., those of the Olympia Undae). Pronounced scattering often precludes obtaining subsequent returns from interfaces that may exist below the surface of the dunes. Where dune forms are smaller or missing (e.g., sand sheets), SHARAD obtains strong surface returns and sometimes subsurface returns.

For each observation, the SHARAD team produces a radargram—a profile of returned power along-track vs. signal delay time. Because off-nadir surface topography often produces returns (termed *clutter*) in the radargrams that may interfere with or be mistaken for subsurface returns, the team also creates *cluttergrams* using a digital elevation model (DEM) of the surface, usually produced from Mars Orbiter Laser Altimeter (MOLA) observations [7]. True subsurface returns in a radargram will not have a corresponding feature in the cluttergram. In some instances, features appear in the radargrams at delay times later than the surface return with no corresponding cluttergram features, and these reflectors often are nearly parallel to the surface or each other, indicative of subsurface layering.

Observations of Olympia Undae, the largest dune field on Mars, by the Mars Global Surveyor Thermal Emission Spectrometer (TES) at ~3-km resolution and by the Mars Odyssey Thermal Emission Imaging System (THEMIS) at ~100-m resolution were used to derive apparent thermal inertia (ATI), variations of which indicate the presence of ice at a few decimeters depth [1]. The same methods are being used to evaluate whether a trend across southern latitudes in dune morphology [8] may be related to the presence of near-surface ice (see Hoover et al., this conference).

Results: Many dunes across the southern hemisphere, ranging from those found in Valles Marineris near the equator to those seen atop the south polar layered deposits, are of scales well below the SHARAD wavelength, and these produce strong surface returns. In some instances, such as in Lowell crater (Fig. 1) and in Ganges Chasma, subsurface returns from below the dune surfaces are evident in the radargrams. Here, we find a repeated sequence of very shallow reflections (the shallowest may be sidelobe artifacts [2]). In Lowell crater, we find a later more diffuse return that could be the base of the dunes or some other interface such as the top or base of ground ice within the dunes.

Olympia Undae abuts Planum Boreum at the north pole and has very dense SHARAD coverage. Many of those observations exhibit the low-power, diffusive returns expected for these largely SHARAD-wavelength-scale dunes, with little evidence of subsurface returns. However, in areas where the dunes are small or covered by smooth terrain (e.g., Olympia Planum),

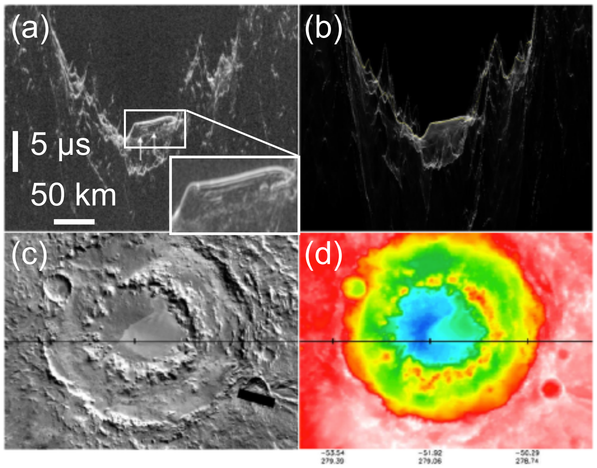

Figure 1. Radargram (a), cluttergram (b), THEMIS image mosaic (c), and MOLA DEM (d) for a portion of SHARAD observation 16080-01 over Lowell crater (279°E, 52°S). The dune field at the crater's center yields a strong surface return that is followed by more diffuse returns, including one (at arrows) at a delay of ~1.4 µs (86 m for a typical sand dielectric of 6), that could represent the crater floor beneath the dunes and/or other geologic boundaries (e.g., ground ice).

SHARAD does often detect deeper returns (see Fig. 1 of [6]). In those instances, the deepest interface corresponds to a basal reflector found more extensively under Planum Boreum by the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) [9].

In the thermal study of southern hemisphere dunes, the initial expectation was that the thermal data would exhibit behaviors consistent with a dry layer of sand over ice or ice-cemented sand at depths increasing with latitude, similar to the behavior found at the Phoenix landing site and in Olympia Undae (Fig. 2a-b). Surprisingly, many of the >150 dune fields examined instead show thermal trends consistent with the presence of a few cm of duricrust at the surface. Such is the case at Lowell crater, where the best fit to TES seasonal variations in ATI is with a model of 1.7 cm of duricrust over dust. It remains possible that ice is located at greater depths, but at least in some cases, the shallow crusts appear to be dominating the thermal behavior.

Discussion: With coarse lateral resolutions, the utility of SHARAD and TES data is limited to the analysis of larger dune fields. Moreover, radar scattering by wavelength-scale dunes often prevents detection of subsurface features. Fields with smaller dune forms or sand sheets do allow the radar signal to penetrate into the subsurface and reflect off of interfaces below. These cases may reveal layering within or beneath the dunes, and thereby provide data of relevance to dune formation and evolution as well as constraints on climate and its history where the interfaces can be related to presence of ice. With the radar vertical resolution of ~5–10 m and thermal skin depths up to ~1–2 m, these datasets examine different zones in the subsurface. The thermal data provides information about the shallower subsurface, sometimes revealing the upper surface of buried ices. In contrast, radar detections of non-polar buried ices have been generally regarded as basal.

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References: [1] Putzig N. E. et al. (2014) *Icarus 230*, 64-76. [2] Putzig N. E. et al. (2014) *JGR 119*, 1936-1949. [3] Bramson A. M. et al. (2016) *GRL 42*, 6566–6574. [4] Holt J. W. et al. (2008) *Science* 322, 1235-1238. [5] Plaut J. J. et al. (2009) *GRL 36*, L2203. [6] Seu R. et al. (1997) *JGR 112,* E05S05. [7] Choudhary P. et al. (2016) *IEEE GRSL 13*, 1285-1289. [8] Fenton, L. K. & Hayward R. K. (2010) *Geomorphology 121*, 98–121. [9] Selvans M. M. et al (2010) JGR 115, E09003.

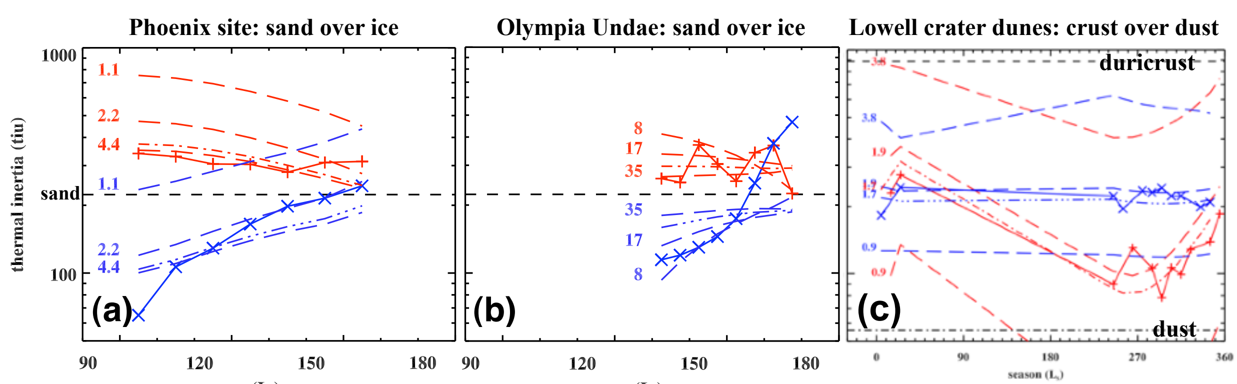

Figure 2. Seasonal variations in apparent thermal inertia from TES data (+, × symbols) and layered models (dashed lines) at 2AM (blue) and 2PM (red) local times at 3 locations. Best-fitting models shown with dash-dotted lines. (a) A 4.4 cm layer of sand over ice at the Phoenix site matches the lander-observed depth to ice. (b) A 27 cm layer of sand over ice in Olympia Undae accounts for the thermal behavior of the dune field. (c) A 1.7 cm layer of duricrust over dust atop the Lowell crater dune field is most consistent with its thermal behavior. (a) and (b) after Fig. 5 of [1].