RADAR SOUNDING EVIDENCE FOR ICE WITHIN LOBATE DEBRIS APRONS NEAR HELLAS BASIN, MID-SOUTHERN LATITUDES OF MARS.
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Introduction: Features that indicate formation by viscous flow of ice or ice-rich mixtures on Mars based on observations of surface morphology are numerous [e.g., 1, 2, 3]. While new high-resolution imagery provides constraints regarding processes of formation, the question of composition, and in particular the quantity of ice persisting in the subsurface, can now be addressed with sounding radar.

The SHAllow RADar (SHARAD) instrument on Mars Reconnaissance Orbiter is an orbital, chirped radar on MRO, operating at a 20 MHz center frequency (15 meters free-space wavelength) with 10 MHz bandwidth and 85 μs pulse duration [4, 5]. Pulse compression yields a theoretical vertical resolution of ~ 8 m in water ice. Horizontal resolution is 0.3 – 1 km along-track and 3 – 6 km across track. Penetration in typical martian regolith is likely to be only a few hundred meters for SHARAD, but much greater in ice-rich deposits.

Features on Mars resembling glaciers on Earth (based on context and morphology) appear to be either dust/debris covered glaciers or rock glaciers, the primary difference being their interior composition. Glaciers consist of massive ice while rock glaciers are an unsorted mixture of rock and ice. MGS/MOC and especially HRSC imagery from Mars Express [e.g., 6] have greatly advanced our knowledge of these features. Newly resolved surface morphology is consistent with low viscosity materials in many cases, implying high ice content [e.g., 7]; however, the presence of massive ice (or very ice-rich mixtures) is impossible to confirm based on optical imagery alone, especially if a high degree of sublimation has occurred. The presence of such ice has important implications for the process of formation, subsequent flow, expected longevity, the planetary water budget, and access by future landed missions for sampling and water resources.

In the region just east of the Hellas impact basin there are numerous "lobate debris aprons" (LDAs), deposits indicative of ice-rich, viscously flowing materials and generally found flanking steep topography [1, 8]. Their origin and composition has been debated, but recent work indicates that they are likely to be ice rich flows [7, 9]. Based on MOLA profiles and the application of flow models, Li et al. [10] estimated the average thickness and length to be 0.28 km and 6.7 km. They also found morphological evidence that some may be much more recent than others.

Fundamental questions that remain for such features include: Is massive ice present, and if so, how thick is it? What is the state of degradation (i.e., sublimation)? What are the associated driving stresses? What is the basal interface like, and is there evidence for melting or significant erosion (i.e., over-deepening)?

Methods: Data from SHARAD passes crossing LDAs in the eastern Hellas region (Fig. 1) were processed with a focused synthetic aperture radar (SAR) technique in order to reduce along-track surface clutter. After post-processing, incoherent summing results in along-track sampling of ~ 300 meters. Given the size of these features relative to the cross-track footprint of SHARAD (not reduced by focused processing), multiple efforts are undertaken in order to determine whether echoes that appear to be from the subsurface are not in fact from off-nadir features on the surface (termed "surface clutter"). Clutter mitigation techniques include (1) examining multiple orbits crossing the same feature, and considering their geometry with respect to surface features, (2) creating simulated surface-only radar data based on available

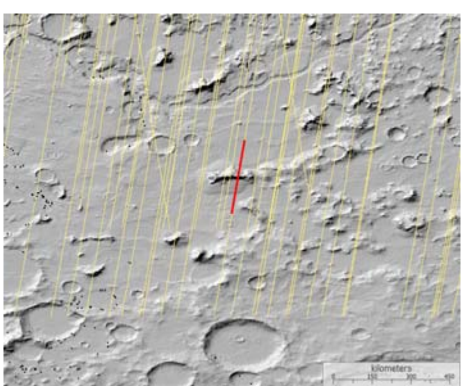

***Figure 1.** Coverage of multiple lobate debris aprons by MRO/SHARAD in the Eastern Hellas region. Radar data shown in Fig. 2 indicated by red line.*

digital elevation models, and (3) correlating across-track migrations of echoes with surface features [11].

Results: Figure 2 shows one example from a lobate debris apron crossed by multiple parallel orbits. All crossings exhibit multiple radar echoes consistent with both a surface and a subsurface return. The difference in time delay between the LDA reflectors on this feature reaches 4.65 μs, corresponding a depth range of 0 – 800 meters in water ice. The total height of the LDA is ~1200 meters above the nearby surface. No obvious off-nadir surface features are present that could cause the appearance of the secondary radar reflector. The simulation based on MOLA data show no secondary echo corresponding to the putative subsurface echo. Other clutter mitigation efforts as described above are ongoing.

Radar attenuation through the material is low, on the order of 5 dB/km based on initial results. This is consistent with a composition dominated by the dielectric properties of ice, rather than typical rock. This and the lack of significant volume scattering supports the hypothesis that this feature is not a boulder-ice mixture such as might be found in a rock glacier, rather an ice-dominated deposit covered by a thin (meters thick) layer of regolith. More analysis is required to further constrain the proportion of ice in an ice/rock mixture.

All LDAs examined in this region to date exhibit a similar result. The simplest explanation is that all are of a similar ice-rich composition, although further work is required to verify surface clutter impacts on each.

Conclusions: SHARAD observations of lobate debris aprons in the Eastern Hellas region of Mars indicate that these deposits are primarily composed of ice-rich material, supporting a glacial origin. They were therefore likely formed during a recent climatic episode favorable to glacial processes at these latitudes. It appears that a large portion of the glacial ice is preserved underneath a thin layer of regolith.

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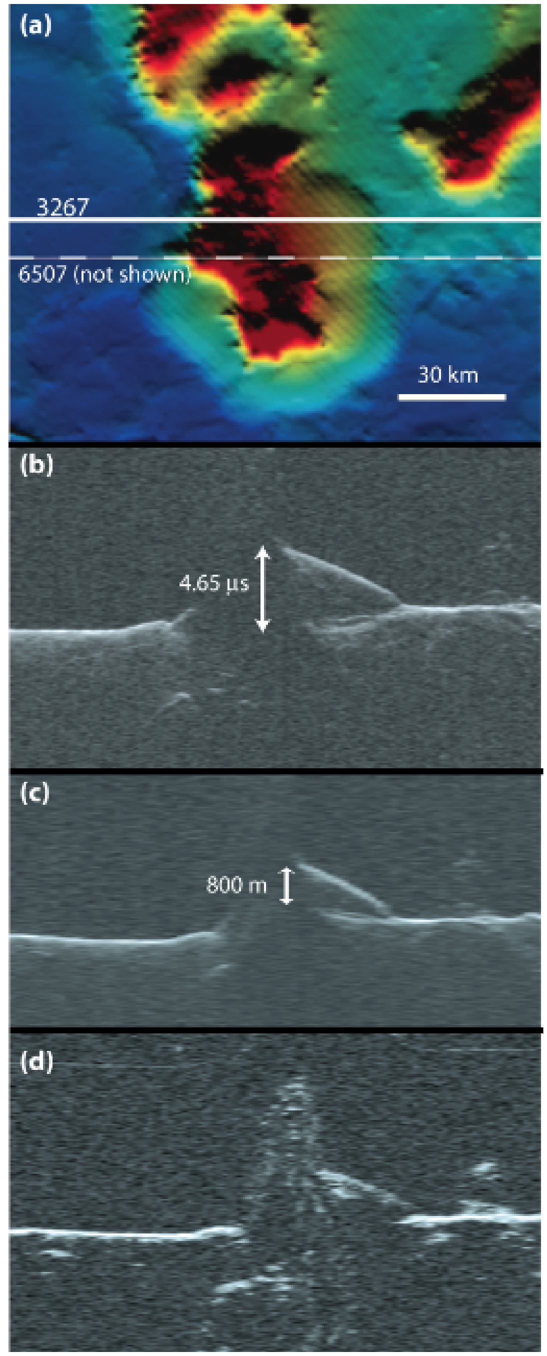

Figure 2. *Example of SHARAD data from orbit 3672_01 crossing lobate debris apron in Eastern Hellas region at 45S, 105.5E.* ***(a)*** *Ground track of spacecraft on shaded-relief MOLA topography.* ***(b)*** *SHARAD data after focused SAR processing. Vertical axis is time delay.* ***(c)*** *Same data after conversion to depth, assuming a subsurface composition of water ice.* ***(d)*** *Radar simulation based on MOLA topography. Only surface echoes can result from the simulation, so this supports the subsurface interpretation of the secondary radar echo at the location of the lobate debris apron.*