# THE EFFECT OF SURFACE ROUGHNESS ON SHALLOW RADAR SOUNDING OF DEBRIS-COVERED GLACIERS IN DEUTERONILUS MENSAE, MARS.

E. I. Petersen[1], J. S. Levy[1], J. W. Holt[1], E. A. McKinnon[2], and T. A. Goudge[3], [1]Institute for Geophysics, University of Texas at Austin, Austin TX (eric_petersen@utexas.edu), [2]Bureau of Economic Geology, University of Texas at Austin, [3]Jackson School of Geosciences, University of Texas at Austin

**Introduction:** Lobate debris aprons (LDA) are abundant in the northern and southern mid-latitudes of Mars where they surround the bases of high mesas and massifs [1]. Many LDA exhibit basal reflectors in MRO Shallow Radar (SHARAD) sounding data, consistent with a composition of nearly pure water ice under a debris cover no thicker than 10 m [2,3]. These LDA are now referred to as debris-covered glaciers (DCG).

Not all LDA are confirmed via geophysics to be DCG. LDA in the northern mid-latitude region of Deuteronilus Mensae exhibit varied SHARAD results that correlate well with longitude: features in the west generally exhibit strong, clear basal reflectors while features in the east exhibit weak or non-existent basal reflectors (see fig. 1).

Ongoing work in flow modeling [4] and geomorphic characterization is being used to test whether these differing radar properties are a result of differing bulk compositions or of differing physical properties of the surficial debris layer. In this work, which focuses on 4 LDA complexes in Deuteronilus Mensae (2 each with SHARAD detections and nondetections), we show that surface morphologies attributable to glacial processes may play a strong role.

**Methods:** *HiRISE Geomorphology:* Surface geomorphology is mapped at the tens to hundred meter scale using 3-4 HiRISE images over each site. Surfaces are characterized into 3 broad categories and 8 subcategories based upon general appearance, surface roughness, and hypothesized formation mechanism. These include brain terrain, polygons, and other.

Brain terrain exhibits high roughness at the tens of meters scale, with buttes typically five meters in height. This scale is relevant to SHARAD as it produces incoherent signal losses and scattering. Brain terrain is hypothesized to form via infilling of extensional or thermal cracking in ice with overlying sediments, followed by ice table lowering [5]. Brain terrain is thought to be unique to debris-covered ice.

Polygons are formed as a result of thermal contraction-cracking of the debris-covered ice in the LDA itself or in subsequent deposits of latitude-dependent mantle [6]. Polygons are very smooth at the scale relevant to SHARAD and may serve to mask or smooth out underlying and neighboring morphologies.

Other morphologies include clast-rich flow lineations, deflated smooth surfaces bereft of polygons, and frozen dunes. Most miscellaneous morphologies are

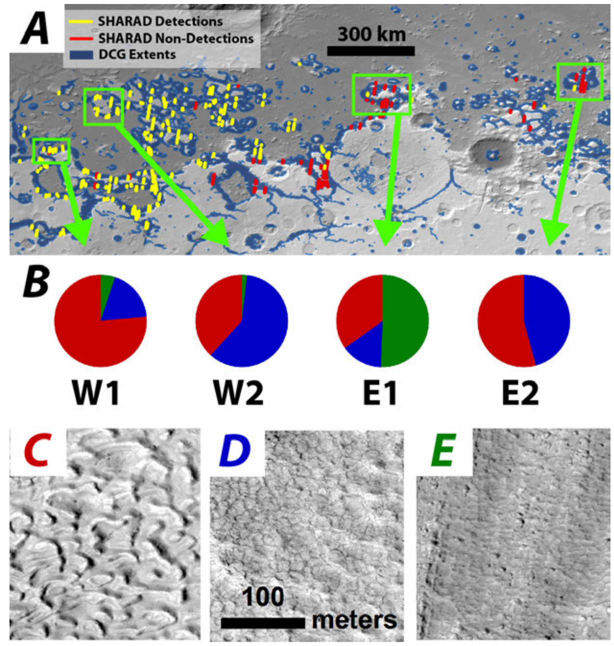


Figure 1: *(A) MOLA-derived map of Deuteronilus Mensae with confirmed detections and non-detections of LDA basal reflectors mapped. Selected LDA, designated W1, W2, E1, and E2, are highlighted in green boxes. (B) Results of HiRISE geomorphic mapping for each LDA site, displaying percentages of (C) brain terrain in red, (D) polygons in blue, and (E) other in green. (C), (D), and (E) are displayed at the same scale, with the lighting coming from the south-by-southwest.*

smooth at the scale relevant to SHARAD.

*HiRISE DTM Surface Roughness:* One HiRISE observation on E1 is available in stereo. We produced a DTM for this using the Ames Stereo Pipeline [7,8], giving reliable results for the topography of features on the tens of meters scale. Roughness height deviation is produced by subtracting the mean elevation in a surrounding 50 meter wide square cell from each DTM pixel.

The roughness height values are then used to calculate the expected transmission losses in a subsurface return due to incoherency produced as it passes through the surface, following the methods of [9]:

$$\sigma_\phi = \frac{4\pi\sigma_h}{\lambda}(\sqrt{\epsilon}-1),$$

$$\rho = e^{-\sigma_\phi^2} I_0^2(\frac{\sigma_\phi^2}{2})$$

Where $\sigma_\phi$ is the rms phase delay in the SHARAD sig-

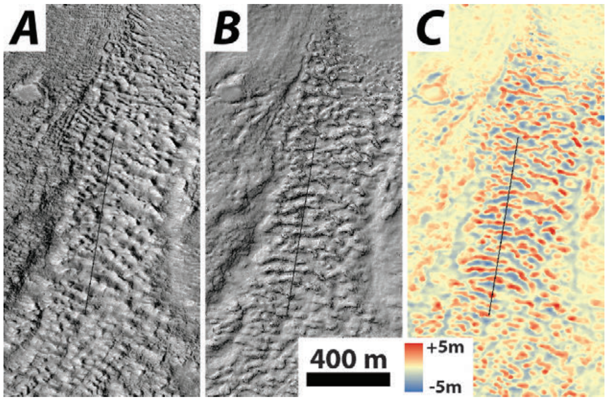


Figure 2: *(A) Field of brain terrain in HiRISE images ESP_035327_2255 and ESP_035327_2255 on site E1. Light from SW. (B) Hillshade produced from HiRISE Stereo DTM. Light from NW. (C) Roughness deviation heights derived from DTM.*

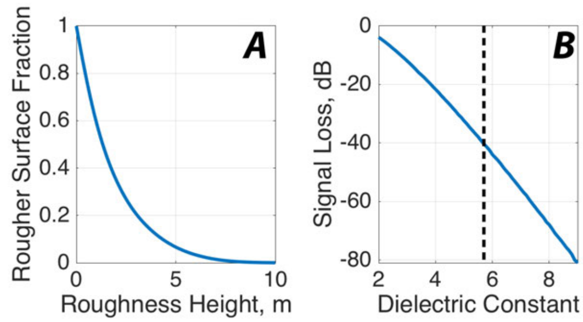


Figure 3: *(A) Roughness heights and (B) subsequent SHARAD signal loss as a function of dielectric constant calculated from HiRISE DTM on E1 produced from ESP_ 035327_2255 and ESP_035327_2255 (Fig. 2). The black dashed line in (B) corresponds to the dielectric expected for a debris layer composed of basalt clasts with 30% porosity (see text).*

nal calculated from the roughness height $\sigma_h$, SHARAD wavelength $\lambda$ (15 m), and the dielectric constant of the debris layer $\epsilon$. The signal loss $\rho$ is then calculated from $\sigma_\phi$ using the zeroth-order Bessel function of the first kind, $I_0$.

Theoretical transmission signal loss is then calculated as a function of the dielectric constant assumed for the surface debris layer, using the cumulative roughness results from the HiRISE DTM.

**Results:** *HiRISE Geomorphology:* Geomorphic characterization revealed that W1 is dominated by brain terrain and altered by ejecta from a nearby synglacial crater, W2 is dominated by polygonal mantle deposits, E1 is dominated by flow lineations and deflated troughs, and E2 is dominated by polygons punctuated by large fields of tall brain terrain buttes.

All exhibited a significant amount of brain terrain. In order of most to least, site W1 had 76%, E2 had 54%, W2 had 42%, and E1 had 35%. Shadow measurements were used to estimate maximum butte heights of up to 8m for W1, 9m for E1 and E2, and 4.5m for W2. Typical butte heights are closer to 2-3m for W1, 5m for E1 and E2, and negligible for W2 due to the paucity of shadows. W2's brain terrain has been heavily softened by extensive polygonal mantle deposits.

*HiRISE DTM Roughness:* Roughness heights produced from the HiRISE stereo DTM on E1 (Fig. 2) confirm estimates produced from shadow measurements and provide more extensive statistics for the E1 site (Fig 3A).

Theoretical rough-surface transmission losses can be quite significant for SHARAD (Fig. 3B). If we assume a debris layer formed of basaltic clasts ($\epsilon = 9$) with a porosity of 30%, we can estimate the effective dielectric constant to be $\epsilon = 5.7$ from the Maxwell-Garnett mixing formula [10]. Transmission losses for this value are calculated at -40 dB. If we assume the debris layer is dusty or formed of a porous mixture of sandstone clasts ($\epsilon = 5$), with a resultant dielectric constant of $\epsilon = 3$-4, then transmission losses are reduced to -12 to -20 dB.

**Discussion:** The presence and extent of brain terrain on LDA surfaces does not correlate with SHARAD performance (Fig. 1), which would seem to indicate that it is not a primary control. However, differences in brain terrain butte heights and debris composition may play a much stronger role than extent.

SHARAD's SNR performance is nominally -50 dB relative to a specular reflection from a $\epsilon = 3$ surface [11]. We have shown that measured roughness on the surface of LDA study site E1 can reduce the signal of a basal reflection by up to 40 dB from transmission losses. We therefore judge surface roughness to be a strong candidate to explain the lack of basal detection at this site.

HiRISE stereo coverage exists on LDA study site W1, however we have not yet produced a DTM product that faithfully captures its terrain on the scale of less than 20 m. When this is accomplished we can more directly compare the sites to assess if surface roughness can fully explain the difference in radar properties of LDAs.

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