REVEALING THE ICE CONTENT OF THE MARTIAN NORTH POLAR BASAL UNIT WITH SHARAD

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Introduction: The basal unit (BU) is a sedimentary deposit that underlies the north polar layered deposits (NPLD) of Mars [1-4]. The BU is easily distinguished from the overlying NPLD due to its characteristic aeolian strata and low albedo, both readily apparent in orbital imagery [1-4]. The two orbital radars, the Shallow Radar (SHARAD) and the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS), also detect the BU and reveal its internal stratigraphy [3,5-7]. This unit is the oldest in Planum Boreum and therefore records climate conditions and processes from more ancient times than the NPLD [3,4]. Prior studies involving imagery, spectrometry and individual radar profiles determined that this unit is composed of a mixture of water ice and siliciclastic sand and dust in roughly equal proportions [1-4]. Precise constrains on the composition of the BU are needed to reconstruct its accumulation history and understand the processed that shaped it to its observable morphology.

Radar profiles acquired by SHARAD reveal a deep reflector within Planum Boreum that we associate with the basal surface of the BU and use with an inversion technique to determine the relative dielectric constant (real part of electric permittivity) and, in turn, bulk composition of three different locales.

Methods: This study is based on tracking of reflectors within SHARAD radargrams [8] in three separate locations of Planum Boreum. In particular, we identify and trace the top and basal reflectors of the BU and the NPLD, and export the timing information associated with each of these surfaces. The top surface of the BU is determined by removing the thickness of the NPLD where present, assuming a bulk composition of water ice (ε_r=3.1, [9]), or directly derived from Mars Orbiter Laser Altimeter (MOLA, [10]) DEM where the unit is exposed. The BU basal elevation is derived by interpolating the surrounding VBi unit [4] MOLA shotpoints and SHARAD-derived elevations with a 9th degree polynomial. Where the delay time and elevation difference between the top and basal reflectors is known, the relative dielectric constant can be calculated with:

$$\varepsilon = \left(\frac{tc}{2h}\right)^2$$

where t is the two-way time delay, c is the speed of light in vacuum, and h is the thickness of the unit.

Basal unit main lobe: Multiple reflectors appear within SHARAD radargrams crossing the BU in the Planum Boreum main lobe (Fig. 1, region A). We interpret the lowermost of these as the basal contact between the BU and the top of the VBi unit. Our dielectric constant invertion results have a positively skewed normal distribution with a mean ε_r=3.61 and a standard deviation of 0.53 (Fig. 2). Assuming a two-phase BU mixture of siliciclastic material (e.g., non-porous shergottite basalt with ε_r=9.7, [5]) and water ice (ε_r=3.1, [9]), we calculate a bulk composition of water ice with only 7.7% siliciclastic impurities by volume. This result is compatible with the results of [7], who found that the BU composition is qualitatively similar to that of the NPLD based on MARSIS data.

Eastern Olympia Undae: Olympia Undae is the largest dune field on Mars, and MARSIS radargrams revealed its continuity with the basal unit underneath the NPLD [7]. SHARAD detects a deep reflector in the eastern end of Olympia Undae that we interpret as its basal surface (Fig. 1, region B). Our inversion exercise in this region results in a wide distribution of dielectric constant values with mean ε_r=7.61 and standard deviation 2.67. This is equivalent to a mixture of 28.9% water ice and 71.1% siliciclastic materials. These results are significantly different from those obtained for the BU main lobe, but the distribution and trending values are very similar to those obtained by [11] (for the main BU lobe using SHARAD). We also note that the dielectric constant tends to increase systematically with decreasing thickness moving towards the outskirts of Olympia Undae.

Lobe of cavi material: SHARAD reveals a thin lobe of cavi material underneath the NPLD and extending from western Gemina Lingula to Eastern Olympia Undae [12] (Fig. 1, region C). For this body we obtain a very wide range of dielectric constant values, with a mean ε_r=7.36 and standard deviation of 4.50, equivalent to a mixture of 35.7% water ice and 64.3% siliciclastic materials. The very large standard deviation most likely results from the small thickness of this body relative to the typical VBi surface roughness [4], which interpolation techniques cannot reproduce where no elevation data is available.

Discussion: Our inversion exercise resulted in a wide distribution of dielectric constant values for the BU (Fig 2). In the main lobe, where the BU is thicker, water ice appears to be the dominant fraction at 92.3%. This exceeds by far the maximum observed porosity of aeolian sand deposits (50%, [13]), unless low permittivity materials other than basalt make up the non-ice fraction. Gypsum has been detected in the north polar region [14], and may have a lower permittivity than basalt at SHARAD frequencies (ε_r=5.4 at 2 MHz and 230 K, derived from [15]), but extremely large quantities would be needed to obtain a mixture where water ice doesn't exceed typical sand porosities. Eastern Olympia Undae and the cavi lobe, instead, appear to have water ice fractions of 28.9% and 35.7% respectively, compatible with moderately and poorly sorted sand deposits [13].

Based on resulting spatial trends and correlation between dielectric constant and thickness, we hypothesize that relatively pure water ice packets make up the thickest parts of the BU, which extend beneath Olympia Undae. A thinner mantle of aeolian sands with interstitial ice covers large portions of the BU and extend outside of it making up the cavi lobe and the top of Olympia Undae. This surficial mantle is not thick enough to significantly increase the bulk permittivity of the thickest parts of the BU, but is detected where the thickness decreases and by geophysical techniques that probe the surface of the unit, explaining the results of [11] in the Boreales Scopuli region.

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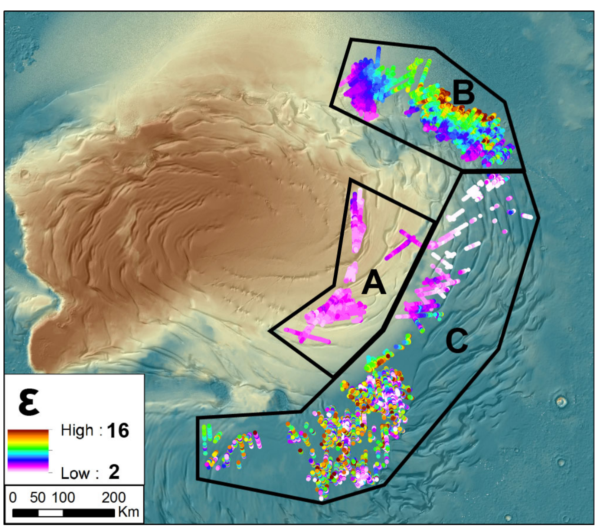
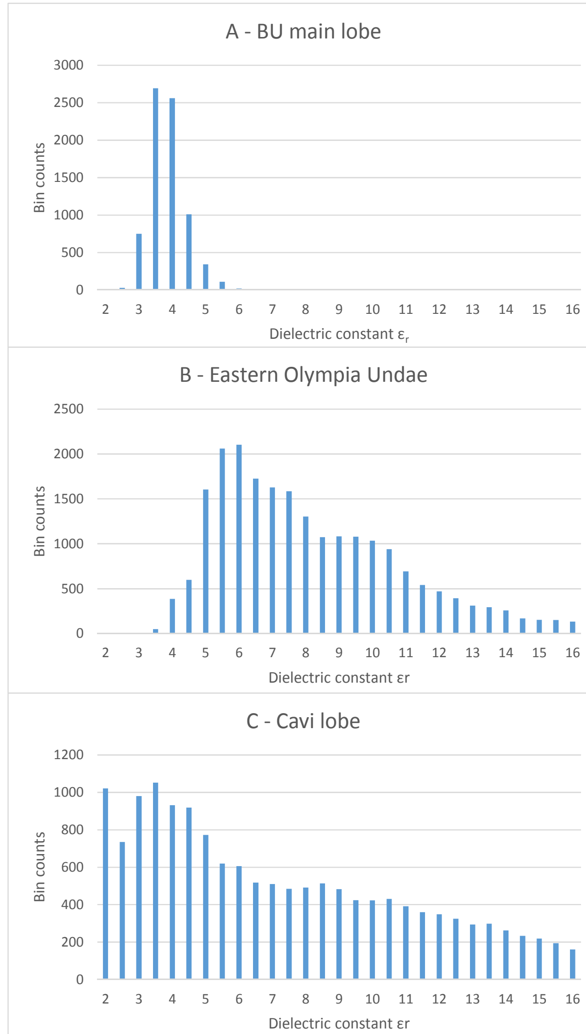


Figure 1: Map view of computed dielectric constant across Planum Boreum. Brown colors in the background represent BU thickness, with superimposed shaded relief of the modern Planum Boreum topography. The sectors delineate the three areas of study: A, BU main lobe, (B) Eastern Olympia Undae, (C) cavi lobe.



	BU main lobe	Olympia Undae	Cavi lobe
Data points	7516	21834	15874
Avg. thickness (m)	605	167	61
Mean ε_r	3.61	7.81	7.36
Standard deviation	0.53	2.67	4.50
Median ε_r	3.55	7.24	6.27
Interquartile range	0.69	3.86	6.87
Water ice (ε_r = 3.1)	92.32%	28.86%	35.67%
Siliciclastic (εr = 9.7)	7.68%	71.14%	64.33%

Figure 2: Distribution of dielectric constant values for the three areas of study and statistical summary, including estimated volume fractions of an hypothetical mixture of water ice and siliciclastic materials with shergottitic composition.