SUMMING UP THE “BRINE BELOW THE SPLD” DEBATE.

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Introduction: The MARSIS radar sounder has detected strong radar returns from the basal ice in the region of Ultimi Scopuli (81°S, 193°E), within the South Polar Layered Deposits (SPLD) [1-2]. Here, we summarize our most recent papers [3-7]. We conclude that most recent detailed papers continue to suggest the presence of brines at the base of Ultimi Scopuli.

Radar Background: Radar waves are reflected at sharp interfaces with differing electrical or magnetic properties. The magnitude of the reflected energy increases with the magnitude of the contrast in electrical and magnetic properties at an interface. MARSIS reflectivity data cannot separately compute the real (ε') and imaginary (ε'') parts of the complex permittivity, but only the apparent permittivity (ε_a) [3], which is a single quantity that accounts for both ε' and ε''.

Frequency Dependence of the Basal Reflection: MARSIS simultaneously collects radar data at 3 and 4 MHz or 4 and 5 MHz. Remarkably, basal reflections in the Ultimi Scopuli region both within and surrounding the high-reflectivity zone show that data collected at the higher-frequency bands of MARSIS record lower echo power when compared to the lower-frequency bands. Such frequency dependence was used by *Orosei et al.* [4] and *Lalich et al.* [8] to investigate various thicknesses and compositions of thin layers at the basal interface. While these simulations show that constructive interference can create enhanced echo power similar to that measured, no single composition or geometry was able to replicate the observed frequency dependence.

However, the observed frequency dependence of the echoes within and outside of the high-reflectivity zone can be associated with attenuation caused by dust within the SPLD overburden. We then accounted for the enhanced loss of high-frequency bands to estimate that the dust content within the SPLD in the Ultimi Scopuli region to be between 5–12% (1st to 3rd quartile values; Fig. 1) [3]. The new radar attenuation estimate of dust content is similar to those previously estimated for the SPLD by radar 10% [9], by gravity data ~15% [10], by elastic loading 14-28% [11], and by elastic loading constrained by radar data of 9-18% [12]. Additionally, if the attenuation rate is extrapolated to SHARAD (Shallow RADar) frequencies of 15-25 MHz, then the reflected energy would be below the nominal noise floor of SHARAD [4]. However, highly-rolled SHARAD measurements may be able to reduce the noise floor, allowing SHARAD its first view of this anomalous target.

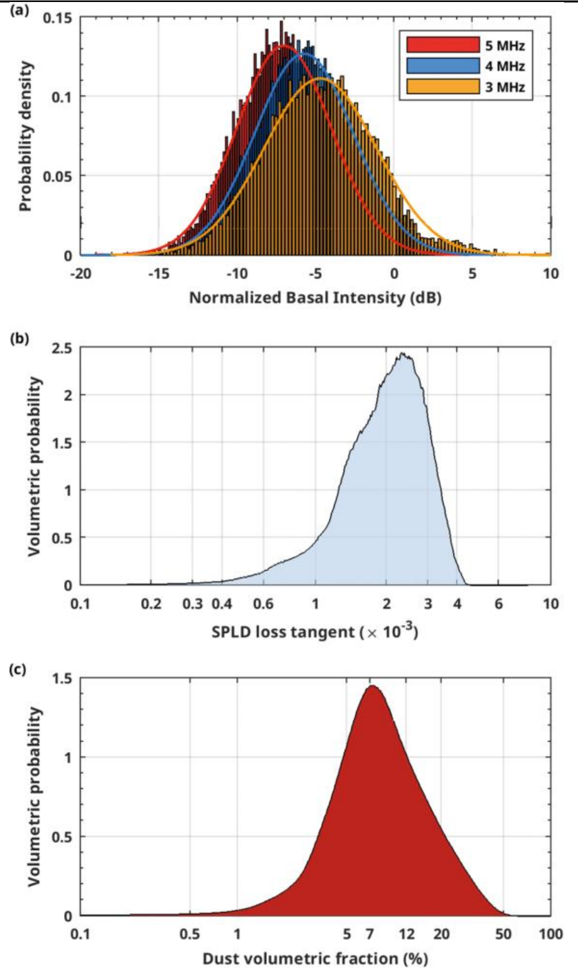

Fig. 1. Analysis of MARSIS data collected outside the bright areas. **(a)** Normalized basal power distributions at three frequencies measured over two-way travel times from 13-25 μs. **(b)** Volumetric probability of the estimated SPLD loss tangent. **(c)** Dust volumetric probability from which the range 5-12%.

Basal Temperatures of Ultimi Scopuli: The anomalous reflector is under ~1.5 km of ice. Temperatures estimated at this location are heavily dependent on the heat flow and thermal conductivity of the SPLD. Published [13] basal temperatures of ~171-176 K, calculated assuming a heat flow range of 14-25 mW/m^2, are likely underestimated. Using geologically consistent thermal conductivity values for the SPLD, *Lauro et al.* [3] calculated a basal temperature of 193 K, a mere ~4 K below the calcium perchlorate eutectic temperature. With further refinement of the models of internal structure of the SPLD, perchlorate eutectic temperatures are likely within reach.

Hypothesized Basal Reflecting Material: The observed attenuation [3] is greater than was previously recognized [1-2]. Thus, the observed median ε_a within the high-reflectivity region is 40 (median) with values ranging from 20-120 (1^{st} to 3^{rd} quartile values) [3]. Outside this high-reflectivity region the basal reflection yield an ε_a of 10 (median) with values ranging from 7-12 (1^{st} to 3^{rd} quartile values) [3]. The range of ε_a values outside the high-reflectivity region are consistent with dry volcanic rock with a density range of ~2,960-3,780 kg/m^3. However, the high ε_a values of the highly-reflective region significantly limit the possible materials that could cause such a reflection. Below we discuss three categories of materials that have been hypothesized to produce the high reflectivity.

Dry Minerals: Previous measurements of hematite and jarosite have shown low electrical conductivity of dry samples [3,9], contradicting the suggestions made by *Bierson et al.* [14]. However, grey hematite is a Martian mineral with an unusually high permittivity [5,19]. Here, we update our previous discussion [5] assuming the updated ε_a values of the highly-reflective region [3]. Overall, the grey hematite concentration needed to obtain an ε_a of the 1^{st} quartile and median values range from 16.4–31.9 vol% and 40.5–50.9 vol%, respectively. To obtain the ε_a 3^{rd} quartile value, the grey hematite concentration must be ~93 vol%. All the modeled grey hematite concentrations are greater than the maximum concentration (15%) of gray hematite that has been spectroscopically observed on the surface [17]. Thus, the grey hematite concentration would have to be significantly more concentrated than any other observed location on Mars.

Clay with Adsorbed Water: *Smith et al.* [18] suggested that the dielectric relaxation of clay with adsorbed water at the base of the SPLD could produce a material with a high ε_a at predicted basal temperatures. Our papers [6-7] document our measurements and others in the literature made on clay with adsorbed water as a function of temperature that contradict the finding of *Smith et al.* [18].

Brine Mixtures: Salts, when mixed with H_2O form a mixture of phases (anhydrous salt, hydrated salts, brines, and ice) that depend on the parameters of the salt (type and concentration) and the environment (temperature and pressure). At temperatures above the eutectic temperature (~197 K for calcium perchlorate), brines form and drastically increase ε_a. Liquid brine has a high ε' of ~80 and is highly conductive thus increasing ε''. Such values of 100 vol% of brine would produce reflections that are much greater than the measured ε_a. Thus, a brine mixture with regolith or ice is needed to match the median ε_a of 40.

To estimate the amount of calcium perchlorate mass concentration needed to fit the new observed ε_a, we fit a power law to our laboratory measurements for salt-H_2O mixtures and salt-H_2O mixed with 60 vol% sand [4]. We found that the calcium perchlorate mass concentration that fit the 1^{st} quartile, median, and 3^{rd} quartile are 3.7, 5.0, 8.0%, respectively, for the salt-H_2O mixtures. The calcium perchlorate mass concentration that fit the 1^{st} quartile, median, and 3^{rd} quartile are 18.6, 27.4, 50.7%, respectively, for the salt-H_2O mixed with 60% sand.

Surface Expression: Analysis of the surface above the bright reflector using infrared data and high-resolution images did not find evidence for surface modification linked to postulated lake locations [19]. However, more recently *Arnold et al.* [20] described an anomaly in the surface topography similar to those found above terrestrial subglacial lakes of comparable size. A similar finding suggesting subsurface brines attributed to this anomalous surface topography was reported shortly afterwards by *Sulcanese et al.* [21].

Summary: After considering all possible alternatives, brines remain the most likely candidates as the source of MARSIS bright basal reflections, albeit their mode of occurrence and origin need to be further explored and discussed. Future work will focus on refinement of the thermal properties of the SPLD, the local and planetary processes responsible for the formation and persistence of brines, and search for other possible locations of brines under the SPLD.

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