EXPLORING ATHABASCA SUBSURFACE GEOELECTRICAL PROPERTIES USING MARSIS RADAR DATA: HYPOTHESIS ON VOLCANIC OR FLUVIAL ORIGIN OF THE LOCAL MORPHOLOGY

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Introduction: Thermal models of the Martian subsurface suggest that frozen ground may persist to depths ranging from an estimated average of 3 km at the equator to 8 km at the poles, a region known as the cryosphere [1,2]. At greater depths, H_2O may be present as groundwater. Geomorphologic observations of the Martian surface support the hypothesis that a substantial amount of water may reside in the subsurface as both ice and a liquid [3].

In order to constrain the ambiguities regarding the distribution and state of subsurface water, two low-frequency sounding radars, MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) and SHARAD (SHAllow subsurface sounding RADar) are probing the upper crust in an attempt to identify and map potential hydrogeological features that can trace the origin and evolution of the Martian hydrosphere.

In this effort, we explore the dielectric properties of the Martian subsurface in the equatorial area of Athabasca Valles to investigate whether they are consistent with the potential presence of massive ground ice, potentially indicative of a frozen sea. In our approach, we compare the MARSIS radar backscattered echoes over this area to those generated by Finite Difference Time Domain (FDTD) radar simulations based on several plausible geoelectrical scenarios of the subsurface. The models are derived from analysis of the latest available remotes sensing data and the geologic interpretation of Plescia [4] and Murray et al. [5].

Geological Context: The studied area is located at approximately 5°N and 150°E, in the vicinity of Cerberus Planitia, southwest of Athabasca Valles. The site of interest is a part of the youngest major volcanic area on Mars [4].

Recent HRSC images of this area have revealed a surface with a broken, rafted-plate appearance whose origin has given rise to two competing hypotheses:

(1) The first hypothesis assumes a fluvial origin, where the observed morphology of Athabasca is attributed to the discharge and ponding of a large volume of groundwater on the surface. As the water at the surface froze, the resulting pack-ice that would have been susceptible to fracturing and differential movement in response to the continued flow of any surviving liquid water underneath. The subsequent deposition of atmospheric dust and/or volcanic ash may have inhibited the sublimation of ice sufficiently to allow its survival to the present day [5].

(2) The second hypothesis is based on a volcanic origin. A large amount of extruded low viscosity lava may have formed a lava lake. Analogous to the fluvial origin, the cooling and crystallization of magma should have resulted in the formation of a crust that, would have fractured and moved in response to the flow of the still-liquid lava underneath. The resulting rafted-plate morphology was then preserved as the lava lake solidified.

Geoelectrical Context: Our geoelectrical models of Athabasca area are based on the interpretation of data from the TES, HRSC and THEMIS instruments. TES data, acquired over the central peak of a large impact crater in the northern part of Athabasca Valles (9°N, 150°E), indicates that the bedrock is composed of andesitic material [6]. The differences in the two Athabasaca formation hypotheses imply subsurface, compositions with different relative mixtures of ice and basalt. Both models assume a 3-layer structure, with an initial 20-m-thick layer consisting of a mixture of volcanic ash and eolian dust, followed by a 40-m-thick layer that is assmued to be composed of either 80% ice and 20% basaltic ash (our fluvial model) or 80% basaltic dust and 20% ice (our volcanic model) The third and final layer, in both models, is assumed to be a basement of andesite The dielectric properties of these models (at 2 MHz) were derived from lab measurements of analog materials [7,8]

Methodology: For this analysis, we used the MARSIS 5 MHz-band radar data obtained from Mars Express orbit 4092 (Figure 1). In order to eliminate background noise, we applied stacking and average-value removal filters to the echoes. We then calculated the temporal variation in signal losses in dB along the stacked traces of the orbit track. From this analysis we defined the noise level to be nearly at -22 dB (Figure 2 top). Our efforts will focus on understanding whether the propagation losses through the first 250 of the subsurface are linear or exponential between 0 (surface) and -22dB range. The time dependency of the losses will be used to investigate the consistency of the two lithological and geoelectrical models. Finally, we studied the latitudinal variation in the reflection coefficient of a radar trace in order to validate the potential presence of a surface dielectric contrast identified by our previous dielectric model of the Martian surface.

To simulate the MARSIS signal in the shallow subsurface of Athabasca Valles, we used the FDTD technique [9] that solves Maxwell's equations in discrete steps of time and space [10]. The depth of the simulation space is 250 m. This simulation space is divided into elementary cells of 2×2×2 m. The emitted signal is a plane wave (polarized in Ex) with maximum amplitude of 1 V/m at the surface level. The emitted waveform is a modulated Gaussian with a frequency band of 1-5 MHz. We used this approach to simulate radar wave propagation through our two geoelectrical models. Simulation results yield the magnitude of the backscattered electric field as function of the wave propagation time. In order to compare this result with the MARSIS 5-MHz radar data, we applied an inverse Fourier transform to the simulation output that allowed us to simulate the same frequency. Then, to maintain consistency with how the MARSIS data is processed, we calculated the signal losses in dB for the propagation time (Figure 2, middle and bottom)

Results: We focused our study on the analysis of MARSIS data obtained between 4.5°N and 8.5°N, where the surface roughness as inferred from the observed topography is very low. Here, we are interested in the geographical variation of the surface reflection coefficient, whose value is used to perform comparative studies of the variation in the average dielectric properties of the shallow subsurface (i.e. skin depth). From the slope of the observed MARSIS signal losses, we observed average subsurface losses of -0.11dB/m for the 4092 orbit (between 4.5°N and 8.5°N).

A comparison of the backscattered radar echo of the two FDTD simulations (one ice-rich, the other predominantly basaltic) indicates that the slope of the loss function generated by the ice-rich (fluvial) model is less steep than that generated by the predominantly basaltic (volcanic) model where the loss-function slope is high – characteristic of the significant signal attenuation typical of terrestrial basalts.

The signal attenuation of the ice-rich model was observed to be -0.05dB/m. These low losses reflect the high electrical resistivity of pure ice. The attenuation of the basaltic model is -0.09dB/m. The attenuation difference between the two geoelectrical models clearly reflects their differing compositions and demonstrates how higher ice concentrations in the subsurface can considerably reduce signal losses.

Preliminary conclusion: The observed attenuation of the MARSIS radar signal power is higher than the highest observed in our simulations by 0.02dB/m. This result seems most consistent with a subsurface composition, in the southwest region of Athabasca (5.0°N, 149,17°E), similar to our volcanic model. Although we cannot rule out the presence of a large ice component (consistent with a frozen sea) in this area, it does not appear consistent with our analysis of subsurface losses inferred from the MARSIS data.

Through the analysis of additional MARSIS and SHARAD sounding data, supplemented by compositional data from the OMEGA (Mars Express) and CRISM (MRO) spectrometers, we hope to improve our ability to test the fluvial and volcanic hypotheses for the origin of the pack-ice-like morphology of Athabasca Valles

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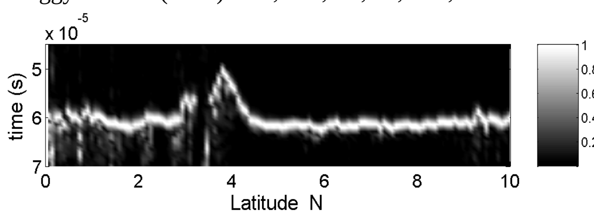

Fig.1, Normalized amplitude radargram for the 5 MHz-band MARSIS data from for orbit 4092.

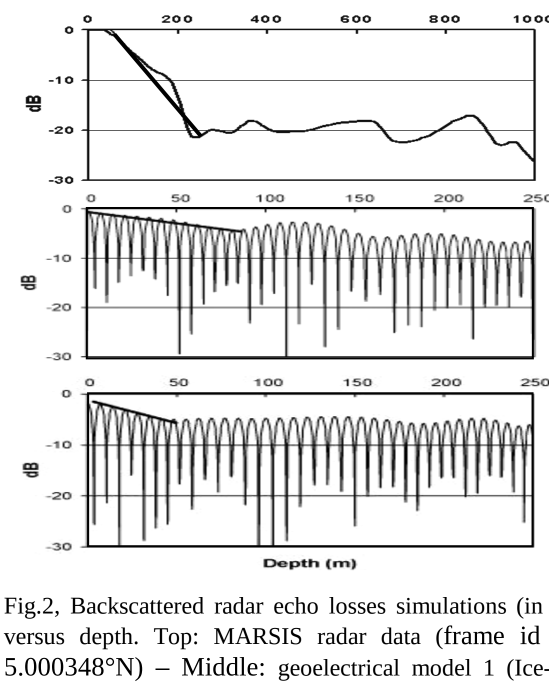

Fig.2, Backscattered radar echo losses simulations (in dB) versus depth. Top: MARSIS radar data (frame id 20, 5.000348°N) – Middle: geoelectrical model 1 (Ice-rich model) – Bottom: geoelectrical model 2 (Ice-poor model).The black line slope is the slope of the loss-functions for each model.