Dielectric properties of clays at MARSIS frequency and Martian temperature. E. Mattei[1], A. Brin[1], B. Cosciotti[1], S.E. Lauro[1], E. Pettinelli[1], G. Caprarelli[2], D.E. Stillman[3], Luca Colantuono[4], Lucia Marinangeli[5], Anna Chiara Tangari[5]. [1]Mathematics and Physics Department, Roma TRE University, Via della Vasca Navale 84, 00146 Rome (Italy), [2]Centre for Astrophysics, Institute for Advanced Engineering and Space Sciences, University of Southern Queensland, Toowomba, Australia, [3]Department of Space Studies, Southwest Research Institute, Boulder, USA, [4]Geo Logica srl, Via Giano della bella 18, 00162 Rome, [5]Dipartimento di Scienze Psicologiche, della Salute e del Territorio, Università degli studi "G. D'Annunzio" Chieti – Pescara, Chieti, Italy (corresponding author: elisabetta.mattei@uniroma3.it).

Introduction: Bright basal reflections detected at Ultimi Scopuli by MARSIS have been interpreted as evidence of wet sediments or briny ponded water. Owing to the low temperature values expected at the base of the SPLD however, the presence of briny water has been questioned, with alternative materials, e.g., clay and clay-rich sediments, proposed as the source of the bright reflections [1, 2].

Clay-rich deposits have been detected on Mars through satellite observations (OMEGA) [3] and (CRISM) [4], as well as by the NASA Spirit and Curiosity rover at the Gusev and Gale craters landing sites (e.g., [5-7]). Martian clay minerals include Fe/Mg smectite, detected in 75% of analyzed sites [8], chlorite (often found in impact crater deposits), Al-bearing phyllosilicates (kaolinite, montmorillonite, beidellite), as well as illite, vermiculite, poorly crystalline or amorphous clays, and ferrihydrite (e.g., [8]). While clay-rich outcrops have not been observed in the terranes surrounding the SPLD, we cannot rule out their presence at the base of the ice.

The dielectric properties values of smectite and other clay materials are a function of frequency, temperature and water content. Experimental data published in the geophysical research literature since the 1950s, imply that these materials are not responsible for the observed strong basal reflections at Martian temperatures and at MARSIS operating frequencies. However, recently published new data suggesting that clays may indeed be highly reflective [2]. This prompted a new set of experimental investigations into the dielectric properties of clays and brines at conditions of temperature and radar frequency specific to the acquisition of MARSIS observations [9].

Here we describe the laboratory set up and methodology we used to perform measurements of the dielectric properties of Martian clay analogs, in a series of controlled experiments reproducing the nominal conditions and utilizing the same sample clay as that described in [2]. Here we report that our results are fully consistent with the well-established dielectric behavior of clay materials: our experimental data indicate that, at the generally accepted range of SPLD basal temperatures, clay sediments, if present, are unlikely to generate bright radar reflections of comparable magnitude to those retrieved from MARSIS observations at Ultimi Scopuli.

Measurement procedure: We analyzed the dielectric behavior of a sample of Texas Montmorillonite Stx-1b (obtained from The Clay Mineral Society). Measurements of dielectric properties were carried out on one oven-dried aliquot of the sample, and on one containing 56% water. The measurements were performed inside a climatic chamber, monitoring the temperature with three Pt (Platinum Temperature) sensors: one inside the sample and the other two inside the chamber. We measured the dielectric properties of the sample in the temperature range 200-290 K, setting a slow cooling/warming cycle (temperature rate 0.04°C/minute), to ensure that the sample inside the cell was in thermal equilibrium during measurements. Data were collected every 5 minutes during freezing and warming cycles.

Figure 1. Measurement device inside the climatic chamber.

The dielectric properties were measured by a two-port Vector Network Analyzer (Agilent ES5071C) connected by two cables to a coaxial-cage line filled with the clay sample. The cell consisted of a stainless-steel cage with a central conductor and eight equally spaced rods arranged in a cylindrical pattern, housed in a plexiglass box. We computed the complex dielectric permittivity and complex magnetic permeability of the sample clay in the frequency range 1MHz - 1GHz, from the reflection Γ and transmission Ψ coefficients through the coaxial line, applying the Nicolson-Ross-Weir algorithm [10, 11]. Such parameters were computed combining the following equations:

$$\sqrt{\frac{\varepsilon}{\mu}}F_g = \frac{1-\Gamma}{1+\Gamma} \quad (1)$$

$$\sqrt{\varepsilon\mu}l = \frac{jc}{2\pi f}\ln(\Psi) \quad (2)$$

where ε and μ are the complex relative dielectric permittivity and magnetic permeability, respectively, F_g is a geometrical factor accounting for the impedance mismatch between the coaxial cables and the coaxial-cage line in air, $l = 5\ cm$ is the length of the coaxial-cage line, c is the velocity of the light in a vacuum, Γ and Ψ are the reflection and transmission coefficient, respectively. Details can be found in [12].
Finally, we calculated the apparent permittivity as follows:

$$\varepsilon_a = \varepsilon_1 \frac{\varepsilon_1 + |\varepsilon_2| + \sqrt{\varepsilon_1^2 + |\varepsilon_2|^2 - 2\varepsilon_1\varepsilon_2'}}{\varepsilon_1 + |\varepsilon_2| - \sqrt{\varepsilon_1^2 + |\varepsilon_2|^2 - 2\varepsilon_1\varepsilon_2'}} \quad (3)$$

This is a real quantity that accounts for both polarization and conductive processes, and fully describes the dielectric properties of a material. Use of this quantity makes it possible to compare laboratory results with the values of apparent permittivity retrieved from MARSIS data [9].

Results:
The cooling and warming trends were similar, indicating that thermal equilibrium was attained for all measurements (Fig. 2). During the cooling experiment, the apparent permittivity dropped dramatically at about 273 K, and then decreased gently, reaching a value of 9 at 230 K, and approximately 4 at 200 K. In [2], they reported a value of apparent permittivity of 39 at 230 K, markedly different from the value we measured at that temperature. We did obtain the same value of permittivity, but at the much higher temperature of 273 K (Fig. 2). To investigate the reasons for this difference, we carried out a fast cooling and warming cycle test (2°C/minute) of the sensor performance, measuring the temperatures inside and outside the cell. We found that the apparent permittivity of 39 was measured at 208 K if the external temperature sensor was considered and at 255 K if the temperature inside the sample was considered. None of these values are correct, as at such fast cooling/warming rate the sample is never in thermal equilibrium and the external sensor does not measure the real temperature of the sample.

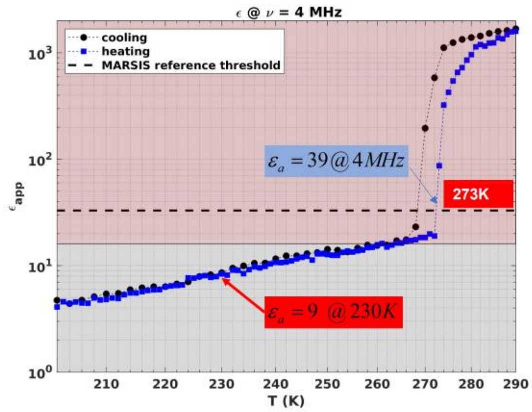

Figure 2. Apparent permittivity plot during cooling (black dots) and warming (blue dots) cycles. At 230 K the apparent permittivity is 9. The value of 39 [2] is reached just below 273 K.

Our experiment suggests that to perform reliable measurements the thermal equilibrium should be reached (slow cooling rate), and the temperature should be measured inside the sample. Moreover, the apparent permittivity value of 9 at 230 K and 4 at 200 K confirm other data reported in the literature. These values do not support the hypothesis that the bright reflections obtained by MARSIS at Ultimi Scopuli are generated by clay-rich materials.

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