MARSIS subsurface radar sounding of the Medusae Fossae Formation, Mars.

Thomas R. Watters[1], Bruce A. Campbell[1], Lynn M. Carter[1], Carl J. Leuschen[2], Jeffrey J. Plaut[3], Giovanni Picardi[4], Ali Safaeinili[3], Stephen M. Clifford[5], William M. Farrell[6], Anton B. Ivanov[3], Roger J. Phillips[7], Ellen R. Stofan[8] and the MARSIS Science Team, [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, D.C. 20560 (watterst@si.edu); [2]Center for Remote Sensing of Ice Sheets, The University of Kansas, Lawrence, Kansas 66045; [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; [4]Infocom Department, "La Sapienza" University of Rome, 00184 Rome, Italy; [5]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058; [6]NASA/Goddard Space Flight Center, Greenbelt MD 20771; [7]Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130; [8]Proxemy Research, Laytonsville, MD 20882.

Introduction: The Medusae Fossae Formation (MFF) occurs along the dichotomy boundary as a series of discontinuous units extending from Amazonis to Elysium Planitiae (~140°E to 220°E) [1, 2]. They are among the youngest surficial deposits on Mars, unconformably overlying ancient Noachian heavily cratered highlands and young Amazonian lowlands [1-4]. Origins proposed for the MFF deposits include volcanic ash deposits [1, 2, 5, 6], aeolian deposits [1, 7], or deposits analogous to polar layered and circumpolar deposits formed as a consequence of either polar wandering [8] or during periods of high obliquity [9]. The predicted volatile (i.e., water ice) content from these models of the deposits varies from ice-rich (polar layered deposit-like materials) to largely ice-free (volcanic ash or aeolian deposits). Sounding data from the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) instrument are being used to analyze the MFF deposits.

MARSIS: The MARSIS instrument is a multi-frequency synthetic aperture orbital sounding radar that operates in four frequency bands between 1.3 and 5.5 MHz in its subsurface modes. The free-space range resolution is ~150 m and the cross-track and the along-track footprint range in size from 10 to 30 km and 5 to 10 km, respectively [10]. The time delay of the peak surface return is corrected to agree with the corresponding MOLA topographic profile along the orbit track to compensate for the high variability in the ionospheric phase distortion. This allows direct comparison of MARSIS radargrams (time-delay renderings of the sounding data) with MOLA-derived surface clutter models.

Subsurface Detections in Western Units of MFF: Initial observations of MFF units in Amazonis Planitia by MARSIS showed detection of possible subsurface interfaces [11]. Four adjacent MARSIS orbits obtained in April, 2006 (2875, 2886, 2896, 2907) cover western units of the MFF northeast of the dichotomy boundary in Elysium Planitia. These units comprise a series of undulating hills with a maximum relief of ~900 m relative to the adjacent lowlands. Radargrams for the MARSIS orbits show subsurface echoes offset in time-delay from the surface return where the orbits pass over the MFF (Figure 1). The echoes are interpreted to be nadir reflections from the interface between the MFF materials and the underlying plains material. Prominent subsurface echoes in orbit 2896 are spatial correlated with the hill-forming MFF material (Figure 1a). The subsurface echoes associated with the northernmost hill in the MFF unit (informally named North Hill) generally parallel the surface return except near the margins of the hill where the subsurface and surface echoes converge (Figure 1a). This relationship is also found in the subsurface echo associated with the broader adjacent hill to the south (informally named Middle Hill). The same spatial correlation of subsurface echoes with the hills is observed in orbit 2907 (Figure 1b), located approximately 50 km west of orbit 2896. Orbits 2885 and 2874 cross over the eastern flanks of North Hill and Middle Hill to the east of orbit 2896. Subsurface echoes in both orbits converge with surface return at the margins of the MFF units.

Implications for MFF Composition: We are analyzing the MFF MARSIS echoes using the simplest possible two-layer scattering model (Figure 2). Our initial assumption is that the roughness and dielectric properties of the plains and the subsurface interface below the MFF are very similar. The properties of the upper surface of the MFF are not so important, except as a dielectric interface with transmission losses.

Ignoring the "absolute" brightness of any given area, we may compare the relative echo strength of the nearby plains and the MFF subsurface reflector as a function of six parameters: the real dielectric constant of the MFF and plains, the imaginary dielectric constant of the MFF, the roughness or "C-factor" [12] of the two interfaces, and the thickness of the MFF mantling material. The thickness is constrained by MOLA data, but the remaining five terms are less well understood.

The real dielectric constant of dry geologic materials, including cold ice, is typically 3-8, with a strong dependence on density. In the two-layer model, the real dielectric terms dictate the transmission loss at the top of the MFF and the reflectivity contrast between the plains and the overlying mantle. The imaginary component, often expressed as a loss tangent, tanδ, modulates the bulk loss properties within a layer and is dependent upon density and the rock/powder composition. The roughness term, which is linearly related to the nadir backscatter strength, is often taken to be the inverse square of the rms slope (radians) at wavelength or larger scales [12].

Preliminary analysis of the MARSIS data yields a locus of possible solutions for the loss properties of the MFF material, dependent upon the MFF-plains real dielectric contrast. The observed delay between the surface and subsurface echoes is consistent with a MFF real dielectric constant of ~2.8. If we hold the mantling material at a real dielectric constant of 2.8 (typical of the lunar regolith fine component), then a value of 6 for the plains real dielectric constant yields an "effective" loss tangent of 0.0015. Higher values for the plains permittivity, which seem unlikely, would lead to greater loss tangents. Just slightly higher real dielectric values for the MFF material (e.g., 3.0) lead to arbitrarily low loss tangent estimates.

Loss tangents on the order of 10^{-3} could be interpreted to indicate a component of even lower-loss material (such as ice), but these values are also consistent with some dry lunar rocks [13]. Given our uncertainty in the true roughness of the buried substrate, and the sensitivity of the tanδ estimate to minor changes in the real permittivity values, the composition of the MFF material can not be uniquely constrained. An ice-rich composition cannot be ruled out at this stage. Nevertheless, MARSIS' detection of the buried boundary between the MFF materials and the substrate indicate that the MFF have unusual electrical properties for the low latitudes of Mars.

References: [1] Scott D.H. and Tanaka K.L. (1986) *USGS Misc. Invest. Ser. Map, I-1802-A*. [2] Greeley R. and Guest J.E. (1987) *USGS Misc. Invest. Ser. Map, I-1802-B*. [3] Bradley, B.A. et al, (2002) *JGR*, 107, 10.1029/2001JE001537. [4] Lanagan, P.D. et al. (2001) GRL, 28, 2365-2367. [5] Zimbelman J.R. et al. (1999) *LPSC* 30, #1652. [6] Scott D.H. and Tanaka K.L. (1992) *JGR*, 87, 1179-1190. [7] Carr, M.H. (1996) *Endeavour*, 20, 56-60. [8] Schultz P.H. and Lutz A.B. (1988) *Icarus*, 73, 91-141. Head J.W. and Kreslavsky M. (2004) *LPSC* 35, #1635. [10] Picardi G. et al. (2005) *Science*, 310, 1925-1928. [11] Ivanov et al. (2006) *LPSC* 37, #1946 [12] Hagfors, T. (1964) *JGR*, 69, 3779-3784. [13] Carrier W.D. et al. (1991) Lunar Sourcebook, Cambridge Univ. Press.

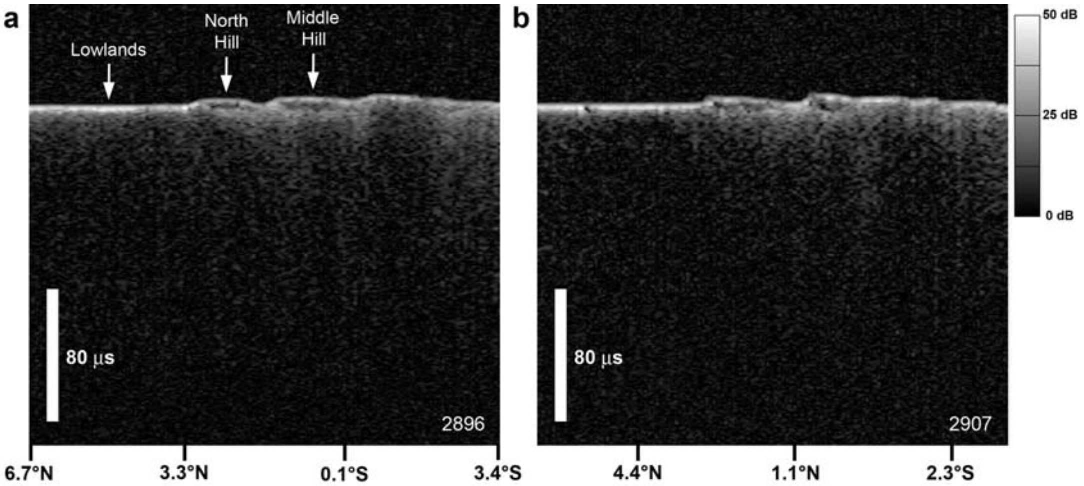

Figure 1. Radargrams showing MARSIS data for orbit 2896 (a) and 2907 (b) where echoes are plotted in time-delay versus position along the orbit. The subsurface echoes are offset in time-delay from the surface echo and are interpreted to be nadir reflections from the interface between the MFF material and the lowland plains material. The peak surface return is corrected to agree with the MOLA topography along the orbit track.

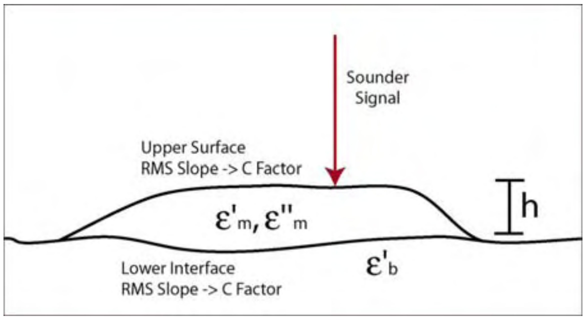

Figure 2. Schematic showing the two-layer inferface model. Model parameters are the *C* factor which is approximately the inverse square of the rms slope roughness of the upper and lower interfaces, the real ε'_m and imaginary ε''_m dielectric constant of the mantling material, the real dielectric constant of the basal layer ε'_b, and the time-delay which is related to the thickness *h* by the dielectric constant of the medium.