MARSIS FLASH MODE SUBSURFACE RADAR SOUNDING OF MERIDIANI PLANUM, MARS: IMPLICATIONS FOR THE PROPERTIES OF THE PLAINS DEPOSITS.

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Introduction: The Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) onboard the European Space Agency's Mars Express spacecraft has been returning data since June 2005 [1]. The MARSIS sounder has to date successfully probed three major units on Mars, the polar layered deposits (PLD) [2] the Medusae Fossae Formation (MFF) [3], and the Hematite-Bearing Plains (HBP) and Etched Plains (EP) deposits of Meridiani Planum [4] (Fig. 1). The radar sounder data clearly delineate the subsurface interface between PLD and MFF materials and the underlying terrain. The PLD at the south and north poles are known to be ice-rich deposits. The MFF deposits occur along the dichotomy boundary and may be composed of volcanic ash, eolian sediments, or an ice-rich material analogous to the PLD. The HBP-EP of Meridiani are deposits of basaltic sand containing hydrated sulfates and hematitic concretions [5−11], and depositional and alteration settings likely included aqueous environments [10−12]. Here, we continue our study of subsurface radar sounder echoes in Meridiani Planum [4] found in MARSIS flash-mode data.

The MARSIS Radar Sounder: 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. Its free-space range resolution is ~150 m and the cross-track and along-track footprint sizes range from 10 to 30 km and 5 to 10 km, respectively [1].

MARSIS has a number of "normal" operating modes for subsurface sounding [13]. The most commonly used mode is designated as SS3, consisting of 2 frequency bands and 3 Doppler filters collected on the dipole antenna channel [13]. In this mode, significant onboard processing is performed that includes pre-summing and conversion of digitized radar echoes from four-byte reals to one-byte integers. In the SS3 and other like modes, onboard processing can be skipped and raw data can be downlinked on a restricted basis.

Another mode of the instrument allows for the collection of raw data to be stored in onboard flash memory. In the flash mode (FM) the sounder collects 2 frequency bands of data in relatively long or short along-track segments. The along-track distance covered in FM, as with SS3 mode, varies with spacecraft altitude; normal FM tracks are typically ~100 to 250 km in length. The normal FM radargrams are corrected for both spacecraft tracking and altitude. The disadvantage of "normal" mode is that the time it takes to move and process frames in flash memory results in gaps in coverage and the radargram resembles a picket fence (Fig. 2). The super-frame FM provides continuous coverage at the expense of along-track distance, typically <100 km (Fig. 3).

MARSIS Flash Tracks: Radargrams for normal FM orbits obtained in 2007 (04927) and 2008 (06118), covering the HBP-EP deposits ~300 km east of the Opportunity landing site, show subsurface echoes offset in time-delay from the surface return (Fig. 2). A super-frame FM orbit obtained in 2016 (15520) also shows relatively deep subsurface echoes located ~300 km east of the Opportunity landing site (Fig. 3): the subsurface echo in super-frame orbit 15520 extends across much of the ~80 km length of the radargram. The maximum offsets in time-delay from the surface return is comparable to those in the normal FM orbits to the west (Fig. 2).

Implications for the HBP-EP Deposits: MARSIS FM observations provide additional data for evaluating the electrical properties of the HBP-EP deposits. The bulk real dielectric constant ε' can be determined if the thickness of the HBP-EP deposits are known. One interpretation is that the subsurface echoes are nadir reflections from the interface between the HBP-EP deposits and the underlying cratered terrain. Estimates of the maximum thickness of the HBP-EP deposits are ~600 to 900 m [5, 9]. Estimates of the thickness based on the elevation difference of nearby cratered terrain is ~800 to >1000 m in the area of SS3 and FM subsurface reflectors. Assuming $\varepsilon'=3$, the observed maximum time delays in orbit 15520 corresponds to a thickness of ~860 m (Fig. 3), in good agreement with the thickness of ~860±60 m estimated from SS3 reflectors [4]. The maximum depths in FM orbits 04927 and 06118 (Fig. 2), however, exceed 1 km for $\varepsilon'=3$. A real dielectric constant of 3 is consistent with either a low bulk density over much of the thickness of the deposit, or a very high fraction of water ice in the HBP-EP deposits (analogous to conclusions reached for the MFF [3]). If the local maximum thickness of the HBP-EP deposits is nearer to 600 m [6], then larger values of ε' (~6) are

likely. Another interpretation prompted by the real uncertainty in the local thickness of HBP-EP deposits is that subsurface reflectors are from a more shallow-depth interbed or interface. If this is the case, larger values of ε′ (≥6) consistent with a dry geologic medium are possible. The basaltic sand composition of the HBP-EP is consistent with a high porosity and a low bulk density. The real dielectric constant as a function of rock density is approximated by $\varepsilon'=1.96^{d}$, where d is the density [14]. A value of ε′=3 corresponds to a density of ~1.6 g/cm^3, at the low end of reasonable values for typical sandstones. We thus cannot yet firmly distinguish among these three possible explanations for the MARSIS results: (1) a large proportion of ice, (2) a low bulk density, or (3) a reflecting interface more shallow than the inferred base of the deposit.

References: [1] Picardi G. et al. (2005) *Science*, 310, 1925-1928. [2] Plaut J.J. et al. (2007) *Science*, 316, 92-95. [3] Watters T.R. et al, (2007) *Science*, 318, 1125-1128. [4] Watters, T.R. et al. (2014) *LPSC 45*, #2521. [5] Christensen, P. R., et al. (2000) *JGR*, 105, 9623– 9642. [6] Hynek, B.M. et al. (2002) *JGR*, 107, 5088, doi:10.1029/2002JE001891. [7] Arvidson, R.E. et al. (2003) *JGR*, 108, 8073, doi:10.1029/2002JE001982. [8] Gendrin, A. et al. (2005) *Science*, 307, 1587–1591. [9] Arvidson, R.E. (2005) *Science*, 307, 1591– 1594. [10] Griffes J.L. (2007) *JGR*, 112, E08S09, doi:10.1029/2006JE002811. [11] Squyres, S.W. et al. (2004) *Science*, 306, 1698–1703. [12] Andrews-Hanna J. C. et al. (2007) *Nature*, 446, 163-166. [13] Jordan R. et al. (2009) *PSS*, 57, 1975-1986. [14] Ulaby F.T. et al. (1988) Univ. of Michigan, Ann Arbor.

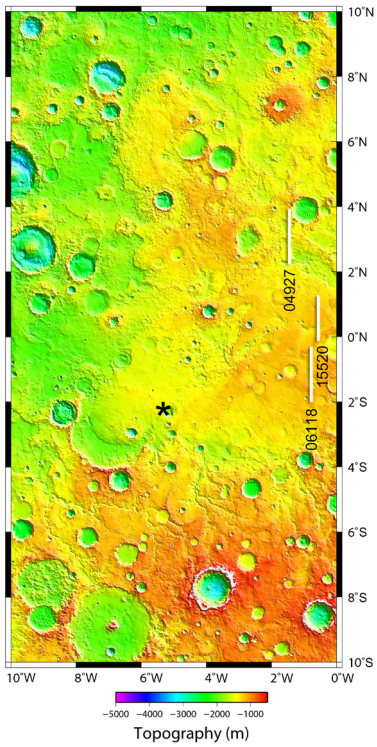

Figure 1. Mars Orbiter Laser Altimeter (MOLA) color-coded shaded relief of the Meridiani Planum region. The approximate locations of MARSIS orbit tracks 04927, 06118, and 15520 are indicated by white lines. The location of the Opportunity Rover is shown (*).

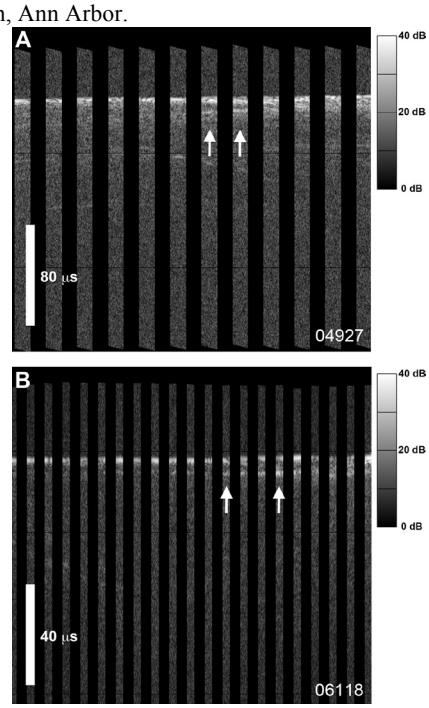

Figure 2. Radargrams showing MARSIS normal FM data for orbits 04927 (A) and 06118 (B) where echoes are plotted in time-delay versus position along the orbit. The subsurface echoes (white arrows) are offset in time-delay from the surface echo and are interpreted to be nadir reflections from the interface between the HBP-EP deposits and the cratered terrain or a more shallow interbed.

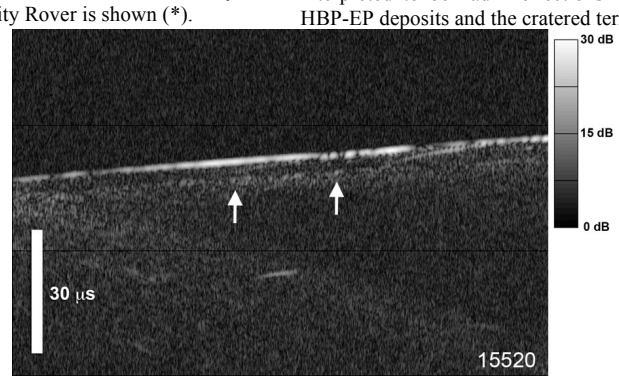

Figure 3. Radargram showing MARSIS super-frame FM data for orbit 15520 where echoes are plotted in time-delay versus position along the orbit. The subsurface echoes (white arrows) are offset in time-delay from the surface echo.