SHARAD SOUNDING AND SURFACE ROUGHNESS OF ONCE AND FUTURE MARS LANDING SITES.

N. E. Putzig[1], B. A. Campbell[2], R. J. Phillips[1], and M. T. Mellon[1]. [1]Southwest Research Institute, Boulder, CO. [2]Smithsonian Institution, Washington, DC. Email contact: nathaniel@putzig.com.

Introduction: To search for subsurface interfaces and characterize surface roughness, the Shallow Radar (SHARAD) instrument on the Mars Reconnaissance Orbiter is observing past, present, and proposed future Martian landing sites. Orbital and landed imagery and altimetry data show that most sites are located atop layered sequences that extend over tens to hundreds of kilometers and are hundreds of meters thick. With resolution of 0.3–6 km horizontally and 5–10 m vertically below the surface, SHARAD is capable of identifying subsurface interfaces at those scales, provided sufficient dielectric contrast between layers. In addition, analysis of the amplitude and time-delay characteristics of SHARAD echoes provides a measure of roughness on scales of meters to tens of meters.

Previous Work: The SHARAD Team first made note of low-power apparent subsurface returns at the Mars Phoenix landing site in 2008 [1]. Subsequently, similar shallow returns were identified across the northern plains [2] and the southern highlands [3], suggesting wide-spread detections of the base of ground ice. However, further analysis has revealed that most of these far-ranging returns occur at delay times that correspond to those expected for sidelobes of the surface return. While the returns do have about twice the expected power of the sidelobes, the close correspondence in delay time casts great doubt on any subsurface interpretation.

Unpublished examinations of SHARAD data taken over Meridiani Planum revealed some of the highest-power surface returns on the planet, but no evidence of returns from subsurface interfaces, despite the several-hundred-meters stack of layers seen in great detail by orbital imagery and by the still-going Mars Exploration Rover (MER) *Opportunity.* Preliminary evaluations of SHARAD observations were also conducted for the prospective landing sites of the Mars Science Laboratory (MSL) *Curiosity*, now on its way to Gale Crater [4]. That work yielded tentative evidence of subsurface returns only at Gale Crater and qualitative roughness information gleaned from surface power, with sites ranked from smoothest to roughest as Gale, Holden Crater, Eberswalde Crater, and Mawrth Vallis. All four were found to be substantially rougher than the *Opportunity* site by this measure.

All of this earlier work employed a range of different SHARAD data products and the analyses were complicated by the differing sets of evolving approaches to focusing-parameter choices and corrections of ionospheric distortion.

SHARAD Data Processing: SHARAD transmits 85-μs chirped pulses, swept linearly from 15 to 25 MHz and recorded for 135 μs at an interval of 37.5 ns. A range resolution of 15 m in vacuum is recovered upon correlation of the received signal with the chirp waveform. Coherent gain and along-track resolution are improved by focused synthetic-aperture processing. For this work, we use an autofocus technique to correct phase distortions caused by the Martian ionosphere [5] and a consistent set of processing parameters (an aperture of 12 s, a multi-look frequency window of 0.2 Hz, and Hann weighting for sidelobe suppression).

Our roughness parameter is obtained from 2.3-km along-track averages of the ratio of total to peak power in the first 19 range bins (713 ns) beginning with the surface return. This corresponds to radar echoes from the surface between nadir and 1.5° incidence, and may include power from subsurface returns due to layers or volume scattering within the uppermost 30–60 m [6].

Methods: We produce radargrams (i.e., 2-D power images of along-track distance vs. delay time) for each SHARAD observation of the regions surrounding the landing sites for Mars Phoenix, MER *Opportunity* (Meridiani Planum), MER *Spirit* (Gusev Crater), Viking Lander 1, Viking Lander 2, and Mars Pathfinder, and for the proposed MSL *Curiosity* landing sites at Gale Crater, Holden Crater, Eberswalde Crater, and Mawrth Vallis. For each site, we import the radargrams into a project within the SeisWare™ seismic-data interpretation software to facilitate data co-registration and the delineation and mapping of surface and possible subsurface returns. We extract profiles along each SHARAD ground track from the 128-ppd gridded elevation map of Mars Orbiter Laser Altimeter data to help distinguish nadir and off-nadir surface returns and to align the radargrams in delay time (offsets occur due to variable delays introduced by the ionosphere).

We also calculate roughness parameter from each SHARAD observations at the 10 sites. To assess both regional and local roughness, we are producing maps of each site at two scales, for 3°×3° regions at 50 ppd and for 40×40-km local areas at 200 ppd. The latter scale includes the 20-km *Curiosity* landing ellipse and surrounding areas that may be accessible to the rover.

Results: Only two of the ten landing sites examined show evidence of late returns that could be from discrete subsurface interfaces. All sites provide returns that are useful in assessing roughness according to the method described above. Data are sparse at the Viking and Pathfinder sites, which were not explicitly targeted, and the roughness parameter is not yet available for the most recent observations at all of the sites.

Potential subsurface returns at Phoenix and Gale. In contrast to the other late returns identified in the northern plains [2] and southern highlands [3], the shallow returns at Phoenix (e.g., Fig. 1) do not closely parallel the surface return, they often occur at delay times greater than those of the first two sidelobes, and their power relative to the surface return (with a modal value of -9 dB) is much higher than that expected for the first and second sidelobes (-20 dB and -34 dB, respectively). These characteristics lend strong support to a subsurface interpretation for these returns, which occur at depths of ~15–40 m in a grid of 80 SHARAD observations over a 2900-km^2 area around the landing site. Possible sources of the returns include boundaries in the concentration of subsurface volatiles and either depositional or erosional surfaces between geologic units of impact, sedimentary, or volcanic origin [7].

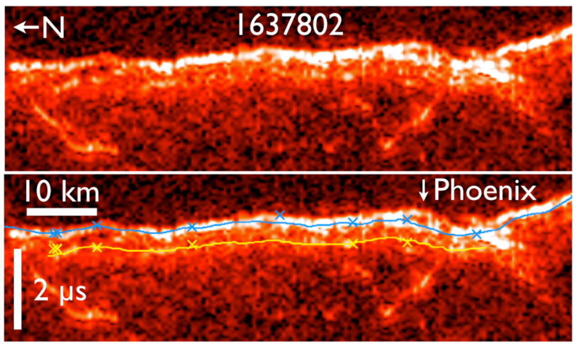

Figure 1. Segment of a radargram for a SHARAD observation near the Phoenix landing site. Delay times are registered to the MOLA-derived surface at nadir (blue line in lower panel). Yellow line indicates the putative subsurface return. Symbols (×) show where the nadir surface and putative subsurface returns occur on crossing SHARAD observations.

In the northern floor region of Gale Crater, we find returns that are sub-parallel to the surface and occur between 0.5 and 2.7 μs after the surface return on 16 adjacent radargrams (e.g., Fig. 2). The returns are relatively weak and may originate from different subsurface strata (depths vary from 31 to 165 m, assuming a permittivity of 6). Possible sources of the returns include (a) the interface between the unit mapped as "Hummocky Plains" of purported fluvial origin and one or more highly fractured, layered "basal units" and (b) interfaces within or below these basal units [8]. Citing numerous geologic studies, Anderson and Bell [7] list a broad range of possible infilling and modification processes (fluvial and aeolian activity, lacustrine and pyroclastic deposition, lava flows, and mass wasting) that may have affected Gale Crater, and these provide an ample supply of potential sources of permittivity contrasts at depth.

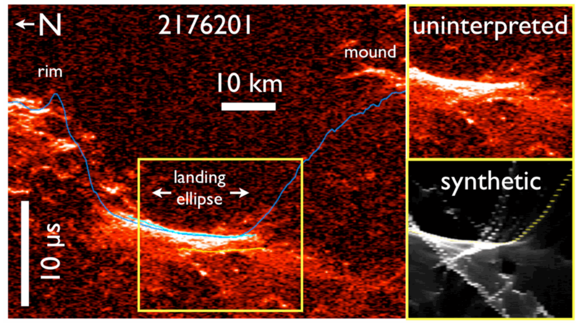

Figure 2. Segment of a radargram for a SHARAD observation crossing the *Curiosity* landing ellipse. Delay times are registered to the MOLA-derived surface at nadir (blue line in left panel). Yellow line in left panel indicates putative subsurface returns. Synthetic produced from a MOLA map helps identify surface returns from nadir and off-nadir features.

Surface roughness at the landing sites. Preliminary histograms of SHARAD-derived, meter- to tens-of-meter-scale roughness at each landing site for the local mapping case are presented in Fig. 3. The Meridiani Planum site is substantially smoother than all of the other sites, a result that is consistent with other orbital data sets and landed observations. Our results show that the proposed landing sites for the *Curiosity* rover are as rough or rougher than all of the previous landing sites, generally consistent with the earlier assessment based on just the surface-return power [4].

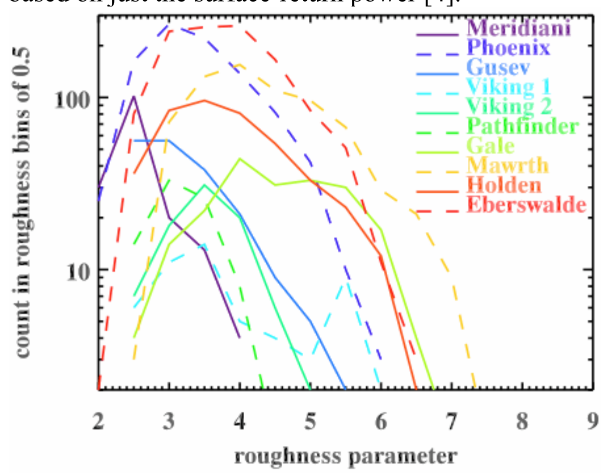

Figure 3. Histograms of SHARAD-derived roughness parameter mapped at 200 pixels/degree in 40×40-km regions at each landing site.

References: [1] Safaeinili et al. (2008) *AGU Fall Mtg.*, Abstract #P23B-06. [2] Putzig et al. (2009) *LPS XL*, Abstract 2477. [3] Putzig et al. (2009) *AGU Fall Mtg.*, Abstract #P13B-1280. [4] Putzig et al. (2010) *AGU Fall Mtg.*, Abstract #P34A-04. [5] Campbell B. A. et al. (2011) *IEEE GRSL, 8*, 939–942. [6] Campbell B. A. and Putzig N. E. (2011) *LPS XLII*, Abstract #1489. [7] Heet et al. (2009) *JGR 114*, E00E04. [8] Anderson R. B. and Bell III J. F., *Mars 5*, 76–128.