SURFACE CHARACTERISTICS AND TRAVERSABILITY OF THE GALE CRATER MARS SCIENCE LABORATORY LANDING SITE. M. P. Golombek[1], P. Bellutta[1], F. J. Calef[1], R. L. Fergason[2], R. H. Hoover[1], A. Huertas[1], D. Kipp[1], R. L Kirk[2], T. J Parker[1], Y. Sun[1], H. L Sladek[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109. [2]U.S. Geological Survey, Flagstaff, AZ 86001.

Introduction: Previous landing sites on Mars have been related favorably to their signatures in remotely sensed data from orbit and from the Earth [1]. Comparisons of the rock abundance, types and coverage of soils (and their physical properties), thermal inertia, albedo, and topographic slope determined by landers and rovers all agree with orbital remote sensing estimates and show that the surface characteristics of landing sites important for safely landing spacecraft can be accurately predicted with available remote sensing data. Because the quality and quantity of orbital remote sensing information used to characterize the surface of the landing sites has drastically improved in the modern era of Mars exploration, the fidelity of the predictions from orbit has also improved. In this abstract, comparison of remote sensing data of Gale crater with the existing six landing sites on Mars is used to predict the likely surface characteristics at the Mars Science Laboratory (MSL) landing site [2].

Thermal Inertia and Albedo: The MSL Gale landing ellipse (25 by 20 km) is located on cratered plains just to the northwest of the central crater mound. The bulk thermal inertia of the Gale ellipse (365 $Jm^{-2}K^{-1}s^{-1/2}$) is comparable to the Mars Pathfinder (MPF) landing site, suggesting a surface dominated by indurated or cemented surface materials [2]. The albedo (0.24) and dust cover index [3] of the site are comparable to Viking Lander 1 (VL1) suggesting a moderately dusty surface. The identification of sulfates and clays in the lower part of the Gale mound (the area of greatest science interest), however, suggests this area is relatively dust free.

THEMIS thermal inertia maps of the Gale landing site show that surfaces vary from <240 $Jm^{-2}K^{-1}s^{-1/2}$, corresponding to poorly consolidated eolian bed forms, to 555 $Jm^{-2}K^{-1}s^{-1/2}$ indicating well-indurated material [4]. The majority of the ellipse has a moderate thermal inertia (300-400 $Jm^{-2}K^{-1}s^{-1/2}$), which appears to be an indurated or cemented surface. Thermal inertia at this scale agrees with materials observed in high-resolution images.

Rock Abundance: Low resolution thermal differencing suggests about 10% rock abundance at the Gale crater landing site [5]. Rocks and rock size-frequency distributions were measured using software that segments shadows cast in HiRISE images (0.3 m/pixel), fits ellipses to shadows and cylinders to the rocks and accurately determined the size-frequency distribution of rocks >1.5 m diameter as was done for the Phoenix landing site [6]. To eliminate detections of large shadowed escarpments, which skewed the cumulative size-frequency curves, the total number of rocks 2.25-1.5 m diameter was found to follow model size-frequency distributions and was used to determine the best fit model cumulative area covered by rocks in 450 m square bins. Maps of the cumulative fractional area covered by rocks across the Gale landing site show a somewhat rocky surface with broad tracks with 5-10% area covered by rocks (particularly in the southern part of the ellipse), with a mean of 5.8±1.4% and a maximum of 17%.

About 0.05% of the surface is covered by boulders >1.5 m diameter as measured in high-resolution images, which when extrapolated along Mars rock size-frequency models to derive the area covered by rocks >0.1 m diameter, suggest an equivalent rock abundance of ~6%. Bulk rock abundances of <8% indicate the probability of encountering 1 rock higher than 0.55 m (corresponding to a 1.1 m diameter rock) under the area of the rover during touchdown is <0.5% and thus meet the engineering criterion for safe landing.

Slopes and Relief: Relief at ~900 m spacing along individual MOLA tracks was compared to the engineering constraint of <100-130 m relief to ensure proper control authority and fuel consumption during powered descent [2]. The Gale ellipse is relatively smooth at this scale, with most surfaces showing relief of <40 m and a mean of 18.5 m. It also has small areas that exceed 80 m (8 out of 770 measurements).

For comparison to other landing sites, the 1.2 km bi-directional slope along MOLA tracks was also calculated. Gale is substantially rougher at this length scale (1.23±1.05°) than previous landing sites. The MOLA pulse width and the relief at 100 m, extrapolated from that 0.3 to 1.2 km using the Allen deviation and Hurst exponent, assuming self-affine statistics, were also determined [2]. The MOLA pulse spread is a measure of the RMS relief within the ~75 m diameter laser spot after removal of regional slopes. Using slope corrected data [7], Gale is rougher than previous sites (~2 m), although the standard deviations are large so most ranges overlap. The extrapolated RMS roughness at ~100 m length scale in Gale (2.3°) is slightly smoother than the relatively rough Spirit (3.3°) and MPF (2.9°) landing sites.

Nearly complete stereo coverage of the Gale ellipse by 0.3 m/pixel HiRISE images has yielded digital topographic models (DTMs) with 1 m elevation postings [8]. RMS slopes at 5 m length scale for Gale (5°) are similar to the roughest of the existing landing sites – the cratered plains at VL1 and MPF. Slopes >30° at which stability at landing becomes a concern are limited to <0.1% of the ellipse. The maximum relief within 1 km of each posting was also compared to the 100-130 m engineering constraint and results are consistent with the MOLA results and indicate a very low probability of exceeding the fuel allocation for safe landing.

Potential inescapable hazards, such as fresh craters or mesas in which the rover might land safely inside or on top of, but could not traverse out of, were also evaluated using slope maps from the DTMs and surface materials identified in HiRISE images. These parameters were compared to the drive capabilities of the rover (traverse up unconsolidated slopes <15° or outcrop slopes <30°). Four craters comprising ~0.2% of the ellipse area have walls steep enough to be considered inescapable if the rover were unfortunate enough to land within them. Six mesas that cover ~0.1% of the ellipse have slopes that are <45° (the rover stability limit) so all should be escapable [2].

Traversability: Slopes within the landing ellipse cratered plains rarely exceed 15° so there are few mobility concerns within the landing ellipse. A field of fresh, dark sand dunes extends from the southeastern to southern part of the landing ellipse. Slopes on many of the dunes exceeds the 15° limit for traversing in unconsolidated sand. Nevertheless about 6 low slope paths (many of which are sand free) exist through the dunes so that traversing from the ellipse to the mound should be possible [2].

At Gale crater, the key stratigraphic clay and sulfate layers are accessible via multiple traversable paths in the lowermost and low slope part of the central mound (Figure 1). Access to sulfates higher in the section would require driving into steep sided canyons with a number of potential choke points having slopes up to 30°, whose traversability cannot be positively known with available data. The fact that about 6 possible traversable pathways have been found suggests that an additional 5 km (straight line distance) of traverse into the mound can be accomplished, before the ubiquitous slopes in the upper unit make driving impossible.

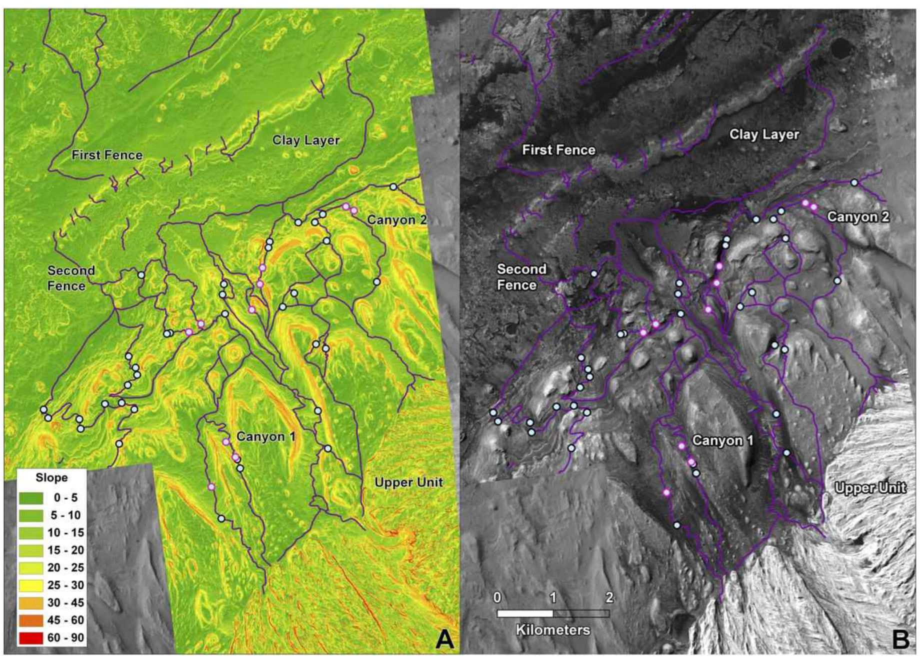

Figure 1. One meter slope map (A) and corresponding HiRISE image (B) showing traversable paths ≥10 m wide (in purple) through high science priority clay and over- and under-lying sulfate deposits south of the Gale crater ellipse. Between 10 and 20 paths have been identified through the "first fence," so access to the clay layer is also possible. The mixed sulfate and clay layer above the clay layer begins above a "second fence" of steep slopes, which also has multiple traversable paths (5-10) through it. About 6 paths extend higher into the sufates, until ubiquitous steep slopes in the upper unit would stop the rover. Choke points where the traverse path must go through a narrow canyon are shown as dots (blue where the slope approaches the rover limit for the observed material, pink where the traverse path is between 5-10 m wide).

References:

[1] Golombek M. et al. (2008) Ch. 21, The Martian Surface, J. Bell ed., Cambridge U. Press. [2] Golombek et al. (2012) Selection of the Mars Science Laboratory Landing Site *SSR* in review. [3] Ruff S. & P. Christensen (2002) *JGR 107*, E12. [4] Fergason R. et al. (2012) THEMIS thermal inertia of the MSL landing sites, *SSR* in review. [5] Christensen P. (1986) *Icarus 68*, 217-238. [6] Golombek M. et al. (2008) *JGR 113*, E00A09. [7] Neumann G. (2003) *GRL 30*, 1561-1565. [8] Kirk R. (2011) *42nd LPSC*, abs. #2407.