PRELIMINARY ASSESSMENT OF MARS EXPLORATION ROVER LANDING SITE PREDICTIONS. M. Golombek[1], J. Grant[2], T. Parker[1], J. Crisp[1], S. Squyres[3], M. Carr[4], A. Haldemann[1], R. Arvidson[5], B. Ehlmann[5], J. Bell[3], P. Christensen[6], R. Fergason[6], S. Ruff[6], N. Cabrol[7], R. Kirk[8], J. Johnson[8], L. Soderblom[8], C. Weitz[9], M. Malin[10], J. Rice[6], R. Anderson[1] and the Athena Science Team. [1]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109, [2]Smithsonian Institution, Washington, D.C. 20560, [3]Cornell University, Ithaca, NY 14853, [4]U.S. Geological Survey, Menlo Park, CA 94025, [5]Washington University, St. Louis, MO 63130, [7]NASA Ames, Moffett Field, CA 94035, [8]U.S. Geological Survey, Flagstaff, AZ 86001, [9]NASA Headquarters, Washington, DC 20546, [10]Malin Space Science Systems, San Diego, CA 92191.

Introduction: Selection of the Mars Exploration Rover (MER) landing sites took place over a three year period in which engineering constraints were identified, 155 possible sites were downselected to the final two, surface environments and safety considerations were developed, and the potential science return at the sites was considered [1]. Landing sites in Gusev crater and Meridiani Planum were selected because they appeared acceptably safe for MER landing and roving and had strong morphologic and mineralogical indicators of liquid water in their past and thus appeared capable of addressing the science objectives of the MER missions, which are to determine the aqueous, climatic, and geologic history of sites on Mars where conditions may have been favorable to the preservation of evidence of possible pre-biotic or biotic processes. Engineering constraints important to the selection included: latitude (10°N-15°S) for maximum solar power; elevation (<-1.3 km) for sufficient atmosphere to slow the lander; low horizontal winds, shear and turbulence in the last few kilometers to minimize horizontal velocity; low 10-m-scale slopes to reduce airbag spinup and bounce; moderate rock abundance to reduce abrasion or stroke-out of the airbags; and a radar-reflective, load-bearing and trafficable surface safe for landing and roving that is not dominated by fine-grained dust [1]. In selecting the MER landing sites these engineering constraints were addressed via comprehensive evaluation of surface and atmospheric characteristics from existing remote sensing data and models as well as targeted orbital information acquired from Mars Global Surveyor and Mars Odyssey. This evaluation resulted in a number of predictions of the surface characteristics of the sites [1], which are tested in this abstract. Relating remote sensing signatures to surface characteristics at landing sites allows these sites to be used as ground truth for the orbital data, is essential for selecting and validating landing sites for future missions, and is required for correctly interpreting the surfaces and materials globally present on Mars.

General Predictions: General predictions from this evaluation are that both landing sites would be safe for the MER landing system and trafficable by the rovers. At Gusev crater, available data suggested it would look generally similar to the Viking Lander (VL) and Mars Pathfinder (MPF) landing sites, but would be less rocky. At Meridiani Planum, available data suggested a dark, low albedo surface with little dust that would look completely unlike any of the VL or MPF landing sites [1]. Evaluation of the geologic setting of Meridiani suggested a flat to gently rolling plain composed of basaltic sand to gravel with few rocks and sparse outcroppings of a thin bright layer [2]. All of these general predictions appear correct in our evaluation of the landing sites in the first few weeks of the rover missions. In addition, we have compared the specific remote sensing data at the actual landing locations to the general characteristics observed by the rovers. The landers were located on the surface via triangulation to hills and crater rims observable in both orbital/descent and rover images aided by Doppler and two-way tracking of the lander in inertial space and reconstruction of the first impact and bounce history of the lander. In the IAU/IAG 2000 MOLA cartographic frame, Spirit is located at 14.5692°S, 175.4729°E and Opportunity is located at 1.9462°S, 354.4734°E.

Thermal Inertia: Thermal inertia measures the rate at which surface materials change temperature, which can be related to particle size and cohesion [3]. Surfaces dominated by loose dust have low thermal inertia and high albedo, whereas those dominated by rock or duricrust have high thermal inertia. The fine component thermal inertia is the thermal inertia of the surface after the thermal radiance attributable to the rocky component is factored out [4].

The landing location in Gusev crater has a bulk TES thermal inertia of 300-350 J m^{-2} $s^{-0.5}$ K^{-1} or SI units and the landing location in Meridiani Planum has a bulk inertia of ~250 [5, 1]. These thermal inertias suggest the surfaces are dominated by duricrust to cemented soil-like materials or cohesionless sand or granules [6]. These predictions are consistent with the sand and granule dominated surfaces observed at Meridiani and the cemented duricrust soil observed at Gusev. As predicted, the surfaces are competent, load bearing and have posed no special risk to landing or roving. Neither of the sites have thick deposits of fine-grained, non-load-bearing dust, again consistent with the observed thermal inertias.

Albedo, Dustiness: Spirit landed in the lowest albedo portion of the Gusev landing ellipse characterized by dark dust devil tracks. As a result, the surface observed by the rover is substantially less dusty than inferred in the rest of the ellipse. The average TES albedo [5] of the Gusev ellipse is ~0.23 and bright areas have albedos as high as 0.26. The low albedo portion of the ellipse in the dust devil track region that Spirit landed has a much lower albedo of ~0.19, which is lower than the VL and MPF landing sites. The surface observed by Spirit is characterized by a deeper red soil surface with many dark granules, pebbles and small rocks as a lag and much less obvious bright atmospheric dust coating the rocks and soil surfaces, which is consistent with the lower albedo. This correlation of albedo is consistent with the low dust index for this portion of the ellipse [7].

The average albedo of the Meridiani landing site is ~0.15 and thus it represents the first landing in a characteristically low albedo portion of Mars [3]. Opportunity landed in an area of the ellipse with even lower albedo (~0.11) and descent images indicate that the 20 m diameter crater where Opportunity is located is even darker than the outside plains. The dust index of this part of the ellipse is among the lowest on Mars [7]. The dark granule rich and bright-dust-free surface observed in the crater is consistent with its low albedo. The bright rim of the crater observed in the orbital and descent images is consistent with bright outcrops and brighter red soil surfaces that Opportunity has observed near the crater rim.

Rock Abundance: Average rock abundance at the Meridiani ellipse is ~5% as estimated from thermal differencing of the Viking IRTM (Infrared Thermal Mapper) [4]. Rock abundance at the Gusev ellipse is higher (~7%) and similar to the global mode of ~8%. Opportunity landed at a location near the border of 1% and 6% rock abundance pixels [4], suggesting a rock abundance of a few %. Spirit is in a 7% rock abundance pixel (1° bins) and is not in a dense boulder field identified in MOC images [8]. These estimates suggested a low to moderate rock abundance at Gusev and very few rocks at Meridiani, both of which are benign for driving the rover, which has been confirmed on the surface.

Preliminary rock counts within 10 m of Spirit suggest ~5% of the surface is covered by rocks, which is within the ±5% uncertainty of the IRTM estimate [4], although the abundance of rocks appears to vary by perhaps a factor of two in the far field. The largest rock within 10 m is only ~0.3 m diameter and there are substantially more pebbles <0.04 m diameter than at the VL or MPF landing sites (consistent with less bright dust and drift material at the site). The size-frequency distribution of rocks generally follows the exponential model distribution based on the VL and MPF landing sites for 5% rock abundance [8]. The area covered by rocks >0.1 m diameter is about half of the total, suggesting an insufficient number of rocks large enough at this spot to account for the IRTM estimate. If this count is representative of the broader area estimated by the IRTM, then the fine component thermal inertia is likely higher than has been estimated, which is consistent with the cemented soil layer or duricrust observed by Spirit.

There are no rocks greater than several cm size within 6 m of the Opportunity lander. The IRTM rock abundance estimate at this site is likely due to the outcrop, which appears to cover roughly 5% of the area within the ~20 m diameter crater. Larger dark rocks exist around the rim of the crater and in the plain visible outside the crater and there are small bright outcrops in the plain as well that likely contribute to the IRTM rock abundance estimate. In general, the area covered by outcrops and large dark rocks appears broadly consistent with the IRTM estimate of a few % at Meridiani.

Slopes: Slopes were evaluated at three length scales important for landing: 1 km, 100 m and ≤10 m. At all three scales Meridiani Planum is the smoothest, flattest place ever investigated or landed on, which is consistent with the incredibly flat plain viewed by Opportunity outside the crater. Gusev also appears smoother than VL1 and MPF at all three scales [1, 9, 10], which is consistent with the relatively flat plain seen by Spirit.

Radar: Radar reflectivity values of 0.04 and 0.05 indicated surfaces with loosely constrained, but reasonable bulk densities of ~1500 and ~1200 kg/m^3 at Meridiani and Gusev, respectively, that pose no special problem to landing or roving [6] and are similar to the range of bulk densities of soils that were successfully landed on and roved over by Mars Pathfinder [11]. These conditions have been confirmed by the successful landing and roving at the two sites.

The RMS slope or roughness derived from the radar data indicated a smoother surface at Meridiani than at MPF (X-band RMS 1.4° versus 4.5°) and a smoother surface at Gusev than at VL1 (S-band RMS 1.7° versus 6°) [1]. Interpretation of the radar data predicted that Meridiani Planum would be much less rocky and smoother than the VL 2 site, and that Gusev would have a combination of roughness at decimeter scales similar to or greater than VL 1 and MPF sites, but will be smoother at meter-scales. These predictions appear generally consistent with the generally smooth flat surfaces with moderate and few rocks observed by Opportunity and Spirit, respectfully.

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