SELECTION OF THE FINAL FOUR LANDING SITES FOR THE MARS EXPLORATION ROVERS. M. Golombek[1], J. Grant[2], T. Parker[1], D. Kass[1], J. Crisp[1], S. Squyres[3], M. Carr[4], M. Adler[1], R. Zurek[1], A. Haldemann[1], R. Arvidson[5], and C. Weitz[6], [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, [6]NASA Headquarters, Washington, DC 20546.

Introduction: Engineering constraints developed for the Mars Exploration Rovers (MER), their translation into ~185 potential landing sites and their down-selection to 6 high priority science sites have been described [1, 2]. These 6 sites (Meridiani-previously referred to as Hematite, Gusev, Isidis, Melas, Eos, and Athabasca) were evaluated in detail as to their science potential and safety, relative to specific engineering constraints, at the 3rd MER Landing Site Workshop held March 26-28, 2002 in Pasadena, CA. This abstract describes: (1) the evaluation of these 6 sites, (2) the removal and reprioritization of sites following this workshop, (3) the identification of a low-wind site in Elysium, (4) the final 4 sites being considered for landing the 2 MER and (5) their evaluation at the 4th MER Landing Site Workshop held January 8-10, 2003 in Pasadena, CA [3].

3rd Workshop Results: Evaluation of the 6 high priority landing sites indicated serious engineering/safety concerns at three of them (Melas, Eos, and Athabasca). Engineering sensitivity studies identified 3 dominant concerns for the MER landing system: (1) horizontal winds and wind shear at a few kilometers altitude, while the spacecraft is on the parachute, which could impart horizontal velocity to the lander, (2) surface slopes at the scale of the airbags, which is equivalent to adding a horizontal velocity to the lander, and (3) rocks at the surface that could rip the outer airbag layers or stress the interior bladders, which must cushioned from the lander during impact. Models of horizontal winds and wind shear at the two sites within Valles Marineris (Melas and Eos) appear to be near the limit of the capabilities of the landing system and were removed from further consideration. Slopes at these sites were also too dangerous. Preliminary engineering analyses suggest that the landing system may be able to accommodate slightly non-optimal conditions for 1 or 2, but not all 3 of these dominant engineering concerns. High radar backscatter at the Athabasca site suggested a rough untrafficable surface. As a result, Athabasca was demoted to a backup site and later removed from further consideration. Isidis was promoted from a backup to a prime site, and a search was made for an additional safe low-wind site.

Meridiani, Gusev, and Isidis show evidence for surface processes involving water and appear 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. Thermal Emission Spectrometer results indicate coarse-grained hematite distributed across a basaltic surface at the Meridiani site, suggesting precipitation from liquid water or a hydrothermal deposit [4]. Gusev has been interpreted as a crater lake with interior sediments deposited in standing water [5]. Isidis Planitia may contain a sampling of ancient Noachian rocks shed off the highlands, which may record an early warm and wet environment as suggested by the abundant valley networks [6]. Evaluation of science criteria at the 3rd workshop place Meridiani and Gusev as the highest priority science sites.

Search for Low Wind Site: The search for a safe, low-wind site involved identifying atmospherically quiet regions in 2 global circulation models (GCM) for the season and time of arrival [7, 8]. Because low winds were the prime consideration, latitudinal (15°S to 10°N) and elevation (<-1.3 km) constraints were relaxed from those originally considered [1] to include areas up to 15°N and areas up to 0 km elevation. Four potential areas were investigated: east of the existing Meridiani site, southeast of Isidis, Elysium and the area south and east of Viking Lander 1 (VL1). The area south and east of VL1 was found to be a region of strong storm tracks and so was omitted from further consideration. Regional mesoscale wind models were evaluated for each region [9]. A handful of prospective sites were identified in each area and evaluated in terms of science potential and safety. The sites east of Meridiani are likely too cold (i.e., low thermal inertia) and too close to the existing site (thereby reducing data return) and the areas southeast of Isidis had low science appeal. The sites with the highest science interest were in the highland/lowland boundary in Elysium Planitia (EP78B2 ellipse is 155 km by 16 km oriented at an azimuth of 94° at 11.91°N, 236.10°W and EP80B2 ellipse is 165 km by 15 km oriented at an azimuth of 95° at 14.50°N, 244.63°W in MDIM2 coordinates).

Elysium Site Selection: Both Elysium ellipses were targeted for the acquisition of new Mars Orbiter Camera (MOC) and Thermal Emission Imaging System (THEMIS) images and safety and science potential were evaluated. Rock abundance estimates from thermal differencing techniques show an average of 5% at EP78B2 and 9% at EP80B2, but other bulk thermophysical properties are similar [12]. EP78B2 also appears smoother than EP80B2 in: Mars Orbiter Laser Altimeter (MOLA) estimates of 1.2 km scale adirectional and bi-directional slopes, 100 m scale MOLA pulse spread [11], extrapolations of the 100 m relief from Hurst exponent fits to the Allen variation at longer baselines [12], and 6 MOC images and 4 THEMIS images per ellipse that had been acquired. High resolution mesoscale wind models [9] for the 2 sites show slightly lower horizontal winds are expected at EP78B2 (similar to Meridiani) than EP80B2 (similar to Gusev), with similar estimates of wind shear and turbulence (both sites are comparable to Meridiani, but slightly more turbulent). EP78B2 is also slightly farther south so solar power should be greater. Science evaluation showed no strong preference of one site over the other. Both sites appear to be on reworked highlands material. EP80B2 has greater relief, but less thermophysical variation in THEMIS thermal images with more dust and sand dunes in the lows. On the basis of these evaluations, EP78B2 was selected as one of the final 4 ellipses and EP80B2 was eliminated at a meeting of the Mars Landing Site Steering Committee and the THEMIS team at Arizona State University in August 26-27, 2002.

Science and Safety: Further discussion and evaluation of these four landing sites took place at the 4th MER Landing Site Workshop. The Elysium site is located on a Hesperian-age surface transitional between the highlands and lowlands and may preserve reworked Noachian highlands. Comparison of the thermophysical properties of Elysium with the Viking and Pathfinder landing sites indicates that the Elysium ellipse has comparable thermal inertia, fine component thermal inertia and albedo to the Viking sites [10] and so will likely be as dusty as these sites, but with fewer rocks.

The 4th Workshop focused on the identification of testable hypotheses at the 4 sites, the definition of the observations that can be made by MER to test the hypotheses and the measurements that can be made by the Athena payload to carry out these investigations. Results show that measurements by the Athena payload should be able distinguish most of the competing hypotheses for the origin of the sites by observing rock textures and fabrics as well as rock mineralogy and chemistry. The results of the 3rd and 4th workshops indicate that the Meridiani and Gusev sites most directly address MER scientific objective because they have strong mineralogical and geomorphological indicators of liquid water in their past. Isidis and Elysium may also address these scientific objectives if Noachian rocks are preserved at the sites either formed in a warmer and wetter past or were deposited by liquid water.

Evaluation of the dominant three safety criteria (slopes, rocks and winds) indicates that Meridiani is probably the safest of the sites, followed by Elysium, Gusev and Isidis. Specifically, horizontal winds and wind shear are lowest at Meridiani and Elysium and higher at Gusev and Isidis. Rock abundance is lowest at Meridiani and Elysium, slightly higher at Gusev and higher still at Isidis [2]. Slopes at the scale of the airbags are in order of increasing slopes: Meridiani, Elysium, Isidis and Gusev [13].

Plans: Winds, slopes and rocks will be incorporated in a sophisticated Monte Carlo simulation of entry, descent and landing by the project engineers to determine the relative safety of the 4 sites. The results of this simulation and the science potential of each site will form the basis of the MER project recommendation of the two landing sites. A full peer review of this process and recommendation will occur in March 2003, followed by selection of the final 2 landing sites by NASA Headquarters in April 2003. These two sites will be targeted in the first trajectory correction maneuvers about a month after launch, which will occur in late May and June 2003.

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