"WALL TO WALL" 1-M TOPOGRAPHIC COVERAGE OF THE MARS SCIENCE LABORATORY CANDIDATE LANDING SITES. R.L. Kirk[1], E. Howington-Kraus[1], D. Galuszka[1], B. Redding[1], J. Antonsen[1], K. Coker[1], E. Foster[1], M. Hopkins[1], A. Licht[1], A. Fennema[2], F. Calef[3], S. Nuti[3], T.J. Parker[3], and M.P. Golombek[3]. [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff AZ 86001 (rkirk@usgs.gov), [2] Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721, [3]Jet Propulsion Lab., Pasadena, CA 91109.

Background: The critical importance of topographic and slope data to the process of selecting a safe landing site has been understood since the first soft landers were sent to the Moon and planets, but the quantity and quality of such information that is available has increased dramatically over the last decades. Our involvement in landing site mapping began with the Mars Pathfinder mission, for which we used 40 m/pixel Viking Orbiter images to produce a contour map covering most of the landing uncertainty ellipse with 100 m contour interval [1]. Elevations at most points in the ellipse had to be interpolated from contours on the order of 10 km away, so we also used photoclinometry (shape from shading) [2] to make digital topographic models (DTMs) of small areas with 40 m/post grid spacing. By the time of the Mars Exploration Rovers site selection, both 3 m/pixel Mars Orbiter Camera (MOC) images and software for digital or "softcopy" stereo mapping were available, allowing us to produce stereo DTMs with 10 m/post spacing, supplemented by photoclinometric DTMs at 3 m/post [3]. Because stereo coverage was extremely limited, the strategy adopted was to identify the main terrain types with distinct geomorphic, roughness, and thus hazard characteristics and attempt to produce a DTM of at least one sample of each unit [4]. Mapping in support of the Phoenix mission initially followed the same pattern, but 0.25–0.3 m/pixel images from the Mars Reconnaissance Orbiter High Resolution Imaging Science Experiment (MRO HiRISE) became available late in the process, allowing us to sample key locations with 1 m/post stereo DTMs [5]. Given the limited HiRISE stereo coverage, it was fortunate that the candidate Phoenix sites were relatively uniform in their morphology.

Topographic mapping of candidate sites for MSL began in 2008, after downselection to a total of 6 sites containing a total of 15 target ellipses [6]. Our initial goal was to sample each of the highest priority ellipses with one HiRISE DTM, omitting "safe haven" alternates and two sites in Meridiani Planum, where the terrain was known to be exceptionally smooth [3]. Single DTMs within the Eberswalde, Gale, Holden, Mawrth 2, Mawrth 4, and Nili ellipses were produced at this stage. After downselection to the first four of these sites at the end of 2008 [7], additional stereopairs were requested and we began to produce additional DTMs with the goal of providing near-complete coverage not only of the landing ellipses but also, for sites with science targets outside the landing zone, of areas where the rover might traverse. The effort is nearing completion as this abstract is written, and the final results will be described in our presentation.

Methodology: Our approach to stereomapping with HiRISE images is described in detail in [4] and is summarized in brief here. Stereo coverage is obtained by imaging the same target on two different orbits, with the MRO spacecraft rolled off its normal nadir orientation on one or both orbits to provide convergent viewing, typically at angles of 20–30°. Data obtained by the 10 red-filtered CCD detectors, which provide the widest cross-track field of view, are used for stereo processing. The individual CCD images are radiometrically calibrated and "balanced" in brightness and contrast at the HiRISE Operations Center (HiROC) [8]. The USGS software system ISIS [9] is used to resample and combine the CCD images into a single 20,000-pixel wide image, correcting for the relative offsets and rotations of the CCD segments and optical distortion. This step can also be used to correct image distortions that result from rapid angular motions ("jitter") of the spacecraft. Such motions must first be modeled by tracking common features in the overlaps between adjacent CCDs, a process known as the HiRISE Jitter Adjusted Camera Kernel (HiJACK) pipeline [10]. HiJACK processing is generally used only if the angular motions exceed 2 to 3 pixels (2–3 μRad), the level found to interfere with stereo matching [5]. Before this jitter-correction process became available, it was necessary to request the acquisition of a new HiRISE stereopair in cases where the initial pair exhibited jitter of this magnitude.

Once the CCD images are distortion-corrected and combined in a mosaic, the resulting full-swath image and its trajectory and pointing history are output from ISIS in formats understood by BAE Systems SOCET SET ® software. This commercial stereoanalysis package is then used to control the images, create the DTM by automated image matching, and interactively edit the DTM. Control is based on ~10 ground points in flat areas where elevations are constrained to agree with Mars Orbiter Laser Altimeter (MOLA) data [12], plus a smaller number of points on features that can be identified in both the HiRISE and MOLA data sets and thereby used to constrain the horizontal position as well. Because of the high resolution and signal/noise ratio of HiRISE, the need for DTM editing is minimal and is usually restricted to shadows, smooth featureless areas, and a few of the steepest slopes.

Data Products: The main products generated for each stereopair are a DTM at 1 m/post, and orthorectified (i.e., projected onto the DTM to remove parallax distortions) versions of each image at 1 m/pixel (to match the DTM) and 0.25 m/pixel (the approximate scale of the source imagery). To facilitate the MSL landing site analysis, products are delivered to the project upon completion as ISIS "cube" files and GeoTIFFs, in Equirectangular projection with planetocentric latitude type, center latitude 0°, scaling based on the equatorial radius of Mars, and heights expressed as radii. DTMs and orthoimages are subsequently archived along with other HiRISE DTMs in NASA Planetary Data System (PDS) format and with slightly different cartographic parameters as described in [13]. Supplementary products for MSL include maps of adirectional (downhill) slope computed from the DTM over 1x1, 2x2, and 5x5 m squares [3]; page-sized "layout" figures showing the image and color shaded relief DTM with scale, graticule, and annotation; and color-coded slope maps downsampled to 10 m/pixel.

As the set of DTMs for each landing site is completed, we are also producing a DTM mosaic that covers the entire uncertainty ellipse, traverse areas, and environs. Because the individual DTMs were produced over a period of years, each was controlled to the MOLA coordinate system individually. Production of the DTM mosaics includes steps that, although less rigorous, can improve the positional accuracy and especially the consistency between overlapping stereomodels. Horizontal errors are reduced by incorporating the DTM segments into a landing site GIS model developed at JPL [14]. In this model an intermediate resolution MOLA-controlled Mars Express HRSC DTM and orthoimage (DA4 product) [15] are used to improve registration of low emission angle 6 m/pixel CTX images [16] by measuring tiepoints and carrying out a "rubber sheet" transformation. The HiRISE DTMs and orthoimages are then registered to the CTX images by a similar process. Vertical errors are reduced by returning the data once again to ISIS and using the program "equalizer" to determine and apply vertical offsets to the HiRISE DTMs, first minimizing the mismatches between overlapping segments and then adjusting a mosaic of the segments to agree on average with the MOLA and HRSC DTMs. The end result is to reference all data sets to the

MOLA base, which provides a well-understood conversion from inertial apace in which the spacecraft are flown into cartographic space on the surface of Mars [4].

Topographic and Slope Results: Topographic coverage of the final four MSL landing site candidates consists of 25 HiRISE stereopairs, listed in Table 1,which summarizes slope properties (slope analyses for four DTMs are still pending) and, for comparison, the corresponding statistics from three past Mars landing sites. Not listed are 3 pairs at these sites that were rejected for excessive jitter or poor image quality and later replaced, as well as the two completed DTMs of the eliminated sites Mawrth 4 and Nili Fossae.

From the table it is clear that 1) DTM coverage of the landing ellipses is substantial (68–95% with >75% at all sites when the last 4 DTMs are complete); 2) slopes within a given ellipse are relatively consistent from DTM to DTM; 3) overall, slopes in the candidate ellipses range from comparable to those at the MER Spirit site (Gusev cratered plains, excluding Columbia Hills [5]) at Holden to about twice as great for Gale, but slopes in excess of 25°, which would begin to present a landing hazard [14] occur over <1% of the roughest site; and 4) slopes in some of the traverse areas outside the ellipses are substantially greater. This is, of course, why these science targets are designated as "go to" traverse destinations rather than being included in the landing ellipse as at the Mawrth 2 site.

Quality Assessment: In addition to supporting the MSL mission, the large collection of overlapping DTMs described here offers a unique opportunity to assess the quality of our HiRISE products. The following investigations are just beginning now that DTM collection is nearing completion:

- By looking at the tiepoint offsets between HiRISE and HRSC products, we can assess the horizontal accuracy with which we can control a single HiRISE image.
- By looking at the vertical offsets introduced by equalizer, we can similarly assess vertical control accuracy.
- By comparing independent, overlapping DTMs we can assess the vertical precision of HiRISE stereomodels.
- By comparing HiRISE DTMs to the HRSC DTM, we can assess the vertical precision and true horizontal resolution of the latter.

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Table 1. HiRISE Stereo Coverage and 5-m Roughness Statistics of the Final 4 MSL Landing Site Candidates

Site/DTM	Image 1	Image 2	Fraction of Ellipse	RMS Slope	98th %ile Slope	99th %ile Slope	Slopes > 15°	Slopes > 20°	Slopes > 25°
Eberswalde Total			**84%**	**7.03**	**21.3**	**24.9**	**5.93%**	**2.45%**	**0.94%**
Eberswalde W	PSP_010052_1560	PSP_010553_1560	17%	8.29	23.1	26.9	7.49%	3.31%	1.38%
Eberswalde WC	PSP_010474_1560	PSP_007481_1560	26%	6.19	23.3	27.3	7.30%	3.28%	1.43%
Eberswalde C	ESP_019190_1560	ESP_019335_1560							
Eberswalde EC	ESP_011331_1560	ESP_011265_1560	21%	6.17	17.5	20.9	3.23%	1.15%	0.38%
Eberswalde E	ESP_016065_1560	ESP_016210_1560	19%	7.75	20.1	22.9	5.69%	1.99%	0.50%
Eberswalde T1	*ESP_019757_1560*	*ESP_020034_1560*							
Eberswalde T2	*ESP_020390_1555*	*ESP_020324_1555*							
Mawrth 2 Total			**95%**	**6.00**	**15.5**	**18.1**	**2.15%**	**0.57%**	**0.15%**
Mawrth 2 W	PSP_010816_2040	PSP_010882_2040	16%	5.72	14.9	17.7	1.88%	0.51%	0.13%
Mawrth 2 WC	PSP_008469_2040	PSP_008825_2040	25%	5.81	14.7	17.1	1.74%	0.42%	0.10%
Mawrth 2 C	PSP_005964_2045	ESP_011884_2045	22%	6.27	16.1	18.9	2.53%	0.71%	0.20%
Mawrth 2 SC	ESP_015985_2040	ESP_016262_2040	8%	5.65	14.5	16.9	1.63%	0.40%	0.10%
Mawrth 2	PSP_006676_2045	PSP_007612_2045	23%	6.25	16.3	18.9	2.60%	0.72%	0.20%
Gale Total			**75%**	**5.01**	**12.5**	**15.6**	**1.13%**	**0.46%**	**0.21%**
Gale W	PSP_009650_1755	PSP_009716_1755	17%	4.00	9.9	11.9	0.37%	0.06%	0.00%
Gale WC	ESP_018854_1755	ESP_018920_1755	3%	4.91	12.0	14.4	0.84%	0.23%	0.07%
Gale C	PSP_010573_1755	PSP_010639_1755	21%	4.21	10.3	12.1	0.29%	0.04%	0.01%
Gale	PSP_009505_1755	PSP_009571_1755	23%	4.96	11.9	14.1	0.73%	0.22%	0.09%
Gale E	ESP_011562_1755	ESP_011417_1755	10%	7.66	22.5	27.0	5.42%	2.74%	1.39%
Gale T1	*PSP_009149_1750*	*PSP_009249_1750*		*17.16*	*41.3*	*44.9*	*33.48%*	*22.15%*	*14.85%*
Holden Total			**68%**	**4.33**	**10.5**	**12.8**	**0.57%**	**0.19%**	**0.05%**
Holden	PSP_007191_1535	PSP_007903_1535	9%	4.38	10.1	11.9	0.26%	0.05%	0.01%
Holden SW	ESP_019823_1530	ESP_019889_1530	7%	5.92	16.3	21.1	2.34%	1.22%	0.38%
Holden C	PSP_010540_1535	PSP_010685_1535	17%	4.63	10.1	11.5	0.17%	0.01%	0.00%
Holden T2	ESP_019322_1530	ESP_019045_1530	11%	3.97	10.0	11.4	0.31%	0.08%	0.01%
Holden E	ESP_015999_1535	ESP_016276_1535	25%	3.70	10.5	13.1	0.58%	0.14%	0.03%
Holden EE	ESP_019612_1535	ESP_019678_1535							
Holden SW	*ESP_019823_1530*	*ESP_019889_1530*		*6.74*	*17.9*	*20.8*	*3.73%*	*1.22%*	*0.32%*
Holden T2	*ESP_019322_1530*	*ESP_019045_1530*		*6.22*	*17.7*	*21.1*	*3.41%*	*1.21%*	*0.49%*
Holden T1	*PSP_002088_1530*	*PSP_002154_1530*		*6.45*	*17.7*	*21.1*	*3.41%*	*1.21%*	*0.49%*
Spirit	**PSP_001513_1655**	**PSP_001777_1650**		**3.73**	**10.1**	**12.1**	**0.36%**	**0.05%**	**0.01%**
Opportunity	**PSP_001414_1780**	**PSP_001612_1780**		**3.27**	**8.1**	**9.5**	**0.06%**	**0.00%**	**0.00%**
Phoenix	**PSP_008591_2485**	**PSP_008644_2485**		**1.85**	**4.1**	**4.5**	**0.00%**	**0.00%**	**0.00%**

DTM designations W, WC, stand for west, west-center, etc. Initial DTM in some sites was not given a designation of this type. T1, T2 stand for traverse area DTMs 1, 2. Results for traverse areas are italicized and are not included in computation of total landing ellipse statistics.