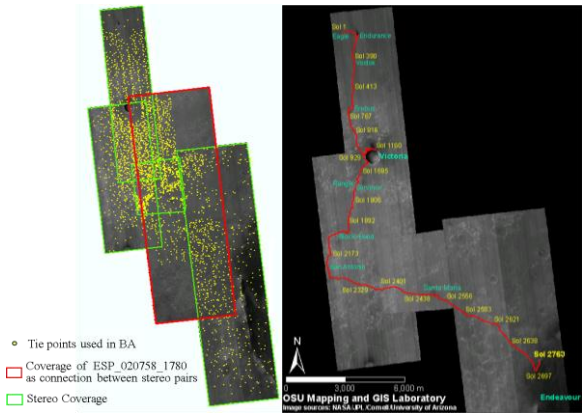
RECENT TOPOGRAPHIC MAPPING OF THE NASA MER 2003 OPPORTUNITY LANDING SITE USING HIRISE AND ROVER IMAGERY. R. Li[1], W. Wang[1], L. Lin[1], W. Gong[1], D. Li[1], R. Wu[1], X. Meng[1], L.H. Matthies[2], and the MER Team. [1]Mapping and GIS Laboratory, CEGE, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210-1275, li.282@osu,edu; [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA.

Introduction: In 2004, the twin rovers of the NASA Mars Exploration Rover (MER) 2003 mission, Spirit and Opportunity, began their exploration of Mars at Gusev Crater (Spirit) and Meridiani Planum (Opportunity) [1]. After over seven years, Opportunity has travelled 33.43 km (as of writing, December 28, 2011). It has just reached Endeavour Crater, its destination since exploring Victoria Crater in August 2008. Spirit, however, became stationary at Troy on Sol 2169 [2] after travelling 6.59 km.

The High Resolution Imaging Science Experiment (HiRISE) carried on the Mars Reconnaissance Orbiter has been acquiring orbital imagery of the Martian surface at an unprecedented resolution of 0.25~0.3 m/pixel since 2006. These high-resolution images, which cover both the Spirit and Opportunity landing sites, present the opportunity for high-precision topographic mapping and to support MER operations [3].

Recent high-precision mapping and localization efforts at the Mapping & GIS Laboratory of The Ohio State University include generation of HiRISE orthoimages for rover localization and topographic mapping of Endeavour Crater to support Opportunity's approach to the crater and search for a "winter haven" at Cape York along the western rim of Endeavour Crater.

HiRISE-based Orthoimage Generation: For Spirit, one stereo pair of HiRISE images was used to generate an orthoimage of the Gusev Crater landing site [4] [5]. However, Opportunity's Meridiani Planum covers a larger area of exploration (due to a much longer traverse than Spirit). Four stereo pairs of HiRISE images were selected to generate the Meridiani Planum orthoimages. In order to achieve accurate global control, exterior-orientation (EO) parameters for these HiRISE images were adjusted through an integrated bundle adjustment (BA) using evenly distributed tie points in the area of overlap (Figure 1a). Since HiRISE is a push-broom sensor, these EO parameters were modeled using a third-order polynomial [3]. Geometric inconsistencies between stereo images were solved by optimizing the polynomial parameters based on the observation equations using tie points and the initial EO parameters from the SPICE kernels. Before the integrated BA, image measurements of common ground features had an average inconsistency of 157.1 pixels with a standard deviation of 92.4 pixels. After the integrated BA, average inconsistency was reduced significantly to 0.6 pixel with a standard deviation of 0.5 pixel (which is equivalent to less than 20 cm on the ground). Detailed statistics on the residuals are listed in Table 1. The Opportunity traverse was then updated (Figure 1b) and archived in the NASA Planetary Data System.



(a) (b)

Figure 1. Generation of HiRISE orthoimage at Meridiani Planum: a) distribution of tie points used in integrated BA, and b) Opportunity traverse (Sol 2802).

Table 1. Residuals of tie points used in integrated BA

	Before BA	After BA
Mean (pixel)	157.1	0.6
Min (pixel)	12.9	0.0
Max (pixel)	608.8	2.7
Std. dev. (pixel)	92.4	0.5
No. of tie points	5594	

3D Topographic Mapping of Endeavour Crater: Prior to arrival at Endeavour Crater on Sol 2681, a set of HiRISE-based 3D topographic products including a digital terrain model (DTM), orthoimage and slope maps of the western rim of Endeavour Crater were produced (Figures 2 and 3).

In order to evaluate the accuracy of the generated DTM, a comparison was conducted using MOLA data obtained over five orbits that was truncated within the range of the DTM. A comparison between MOLA profiles and corresponding DTM vertical profiles was made. The average difference in elevation found along the MOLA tracks is less than 7 m.

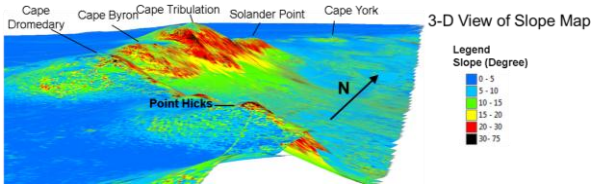


Figure 2. 3D slope map of the western rim of Endeavour Crater.

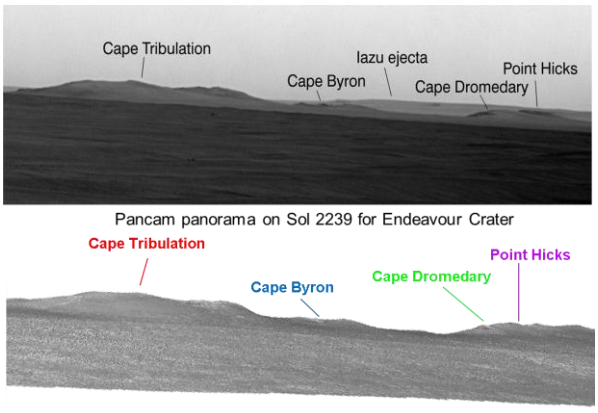


Figure 3. Pancam panorama on Sol 2239 (top) and 3D perspective view (bottom) looking toward the western rim of Endeavour Crater from HiRISE-derived DTM.

Finding a "Winter Haven" at Cape York: Due to higher atmospheric opacity and dustier solar arrays than experienced in previous years, for the first time Opportunity required a "winter haven" site with sufficiently steep north-facing (NF) slopes (ideally fifteen degrees) to provide sufficient solar energy for the rover to survive the harsh Martian winter.

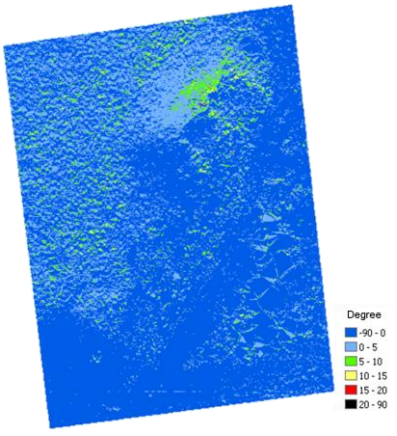
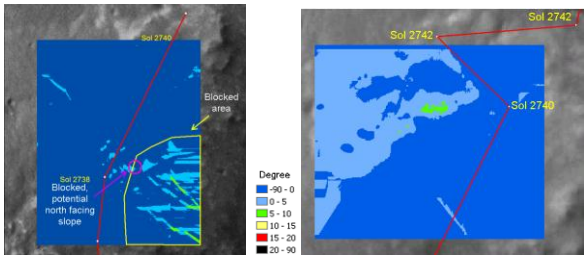


Figure 4. HiRISE-derived north-facing slope map at Cape York.

NF slope map were generated based on a HiRISE-derived DTM (Figure 4) and a number of rover-image-derived DTMs in support of the search for an overwintering location at Cape York by the MER science and engineering teams. Several potential sites observed on HiRISE-derived NF slope maps (3-m slope window) and 3D anaglyph stereo images were further evaluated through analysis of rover-image-based NF slope maps (1.5-m slope window). For example, "Shoemaker Ridge" on the southern part of Cape York was identified as a potential site according to these two sources. However, it was later confirmed using ground images from the rover that no areas with slope of ten to fifteen degrees existed (Figure 5). At the northern end of Cape York, however, two locations, "Turkey Haven" and "Greeley Haven", were found to have the required NF slopes (Figure 6). Up to Sol 2817, Opportunity had completed a traverse of over 800 m across Cape York and continued her investigation at Greeley Haven.



(a) (b)

Figure 5. Two maps of north-facing slopes along Shoemaker Ridge generated using ground images.

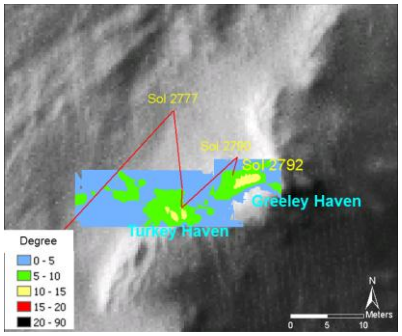


Figure 6. Map of favorable north-facing slopes at "Turkey Haven" and "Greeley Haven".

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References: [1] Squyres S. W. et al. (2003) *JGR*, *108*(E12), 8062. [2] Arvidson R. E. et al. (2010) *JGR*, *115*, E00F03. [3] McEwen A. S. et al. (2007) *JGR*, *112*, E05S02. [4] Li R. et al. (2011) *JGR*, *116*, E00F16. [5] Hwangbo J. (2010) Ph.D. dissertation. The Ohio State University, Columbus, OH.