GEOMORPHIC/GEOLOGIC MAPPING, LOCALIZATION, AND TRAVERSE PLANNING AT THE OPPORTUNITY LANDING SITE, MARS.

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Introduction: The Opportunity rover is the current record-holder for long-distance traverse on another planet, by a margin of more than 10 kilometers over the next contender. This has enabled Opportunity to investigate and contextualize the geomorphology and geology of the materials and sites visited to a degree that could not have been anticipated early in the mission. Geomorphic mapping of the landing site is being conducted using a combination of the project's planning tool, "maestro", and GIS mapping software. The experience gained by the science and engineering teams will be invaluable for planning and conducting future mobile explorer missions to Mars and other planetary bodies.

Rover Localization: In order to maximize the quality of science results obtained by Opportunity, its elevation and location with respect to the Mars Control Network needs to be accurately determined. Both MER rover vehicles record wheel rotations and accelerometer data to aid in determining their locations from one site to the next, and science team member Li [1] adjusts these derived locations via photogrammetry of navcam and pancam images. The precision of these results is limited by propagation of errors due to factors such as wheel slippage, and so the rover's location must be checked and updated periodically by comparing very high-resolution orbiter images of the vicinity around the rover with ground panoramas taken by the on-board science and navigation cameras.

No derived location is better than the base map on which it is determined, however, so it is important that it be accurately referenced to the global control network. We start with the global gridded MOLA topography map as a base and register regional image mosaics from Odyssey and MRO – from the 100 m/pixel THEMIS IR images, to the 25 cm/pixel scale of individual HiRISE frames. Georeferencing intermediate-scale image mosaics to the MOLA global map allows us to minimize the introduction of errors from georeferencing high-resolution data to features that are incompletely resolved by MOLA. Our ability to locate the MER rovers in the HiRISE images using this approach is accurate to about a half meter (two HiRISE pixels), and their absolute locations with respect to the Mars control net is likely comparable to the 100 m scale of a THEMIS IR pixel.

For MER, we use overhead projections of panoramas taken by the Navigation cameras and georeference these to the HiRISE orbital view of the site, using GIS mapping software. These data are used in combination with the HiRISE image data to compile traverse maps that we update with new location panoramas as the rover proceeds along the route.

Geomorphic/Geologic Mapping:

Stratigraphy: Grotzinger et al. [2] characterized the sedimentology and stratigraphy of the Meridiani Planum materials exposed at Burns Cliff in Endurance. When Opportunity reached Erebus, the team was able to investigate the stratigraphy at the Payson outcrop [3]. The most recent vertical exposure studied in detail with Opportunity is the wall of Victoria, as exposed in the many spurs, or "capes" extending into the crater, with those at Cape Verde having been visited by the rover while in Duck Bay [4]. The exposures at Endurance and Victoria indicated that much of the upper 10-20 meters of the Meridiani Planum sulfate deposits appear to be eolian in origin, though the outcrops at Eagle and Payson included water-formed ripples within the deposits.

Topography: One of the persistent challenges to the science team continues to be the placement of the results of the observations at the above four crater sites into stratigraphic context with one another and with the regional geology. The rover climbed in elevation by about 30 meters from the plains around Eagle to the raised rim of Victoria. But the surface exposures, in particular those traversed between Eagle and Erebus, are interrupted by overlying sand and ripple bedforms. Also, on much of the rover's path, stopping points investigated with panoramas have been separated typically by tens of meters or mor. This makes it difficult to correlate one outcrop exposure with the next. Since the path has been on very gentle slopes, it isn't even certain that driving up slope equates to driving up-section. The situation will start to improve within the next 2 kilometers, however, as Opportunity begins a descent down an 80m slope toward Endeavour crater, much of it containing broad outcrop exposures. These exposures exhibit subtle "festoon" banding that may be exposed edges of sub-horizontal bedding on this slope, or onlaps of material onto pre-existing topography.

Plains morphologies: Opportunity has demonstrated the usefulness of acquiring ground images at scales only 1 or 2 orders of magnitude higher than the base orbiter data and placing the features studied in detail into something approaching a regional context. Features that can be readily identified at both ground and orbiter scales, that are relevant to the imaging and other science instruments on board the rover are craters, eolian bedforms, outcrop exposures (particularly where a change can be identified from orbit), and "gravel piles". Craters have been very useful in beginning the compilation of a method for dating lightly cratered surfaces to estimate the rates at which the eolian bedforms move, and the residence times of meteorites on the surface by examining the degradation of individual craters at very fine detail and correlating those observations with those from orbit of the region [5,6]. Gravel piles are localized concentrations of material too coarse to be moved by martian winds, and yet appearing to be remnants of relatively thick deposits (< 1m), not lags over finer material. Their origin and preservation in isolated patches is as yet unknown, so future visits to these features, identified along the path ahead, are planned.

Traverse Planning: This mapping technique has proven invaluable in planning science observations and activities and traverses for the MER rovers. For example, when Opportunity encountered Purgatory Dune, we were able to suggest a route that would minimize the chances of encountering similar large ripples by examining MOC images (prior to HiRISE) and THEMIS derived thermal inertia maps produced by Robin Furgeson and made available to the MER project. Once HiRISE images became available after the Victoria Campaign, we were able to use them to suggest 3 potential routes through or around the worst of the large ripple fields en route to Endeavour Crater (yellow area, figure 1). Many of our most productive science targets since Victoria Crater have been identified well in advance in the HiRISE images, which has expedited their investigations once they were reached by the rover.

References: [1] Li R. et al. (2006) *JGR*, *112*, E02S90. [2] Grotzinger, J. P. et al. (2005) *EPSL*, *240*, 11-72. [3] Metz, J. M. et al. (2009) *J Sed Res*. 79, 247-264. [4] Edgar L. A. et al. (2010) *LPS XVI*. [5] Golombek M. P. et al. (2010) *LPS XVI*. [6] Chappelow J. E. and M. P. Golombek (2010) *LPS XVI*.

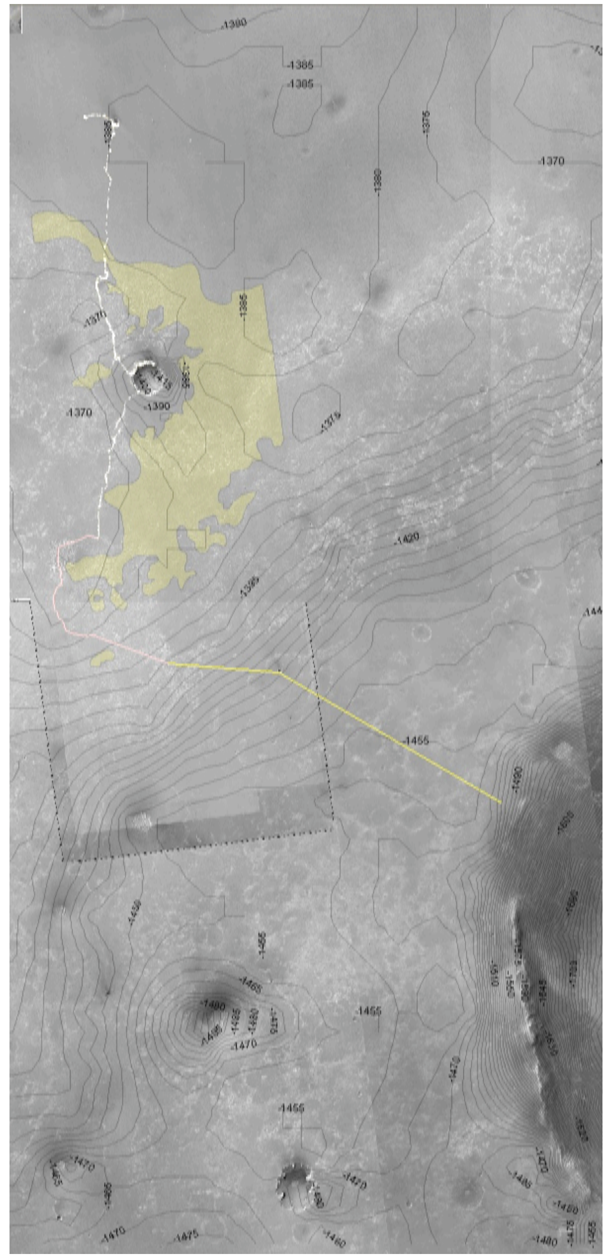

Figure 1: Planning map mosaic compiled of CTX and HiRISE images in Photoshop for mapping version of maestro software, showing Opportunity traverse from Eagle Crater through Sol 2088. Original file rendered at 25cm/pixel. MOLA topography contoured at 5m interval. Note that elevation change on traverse to date is about 30 meters (excluding crater ingresses). Pink path indicates route being considered to avoid large ripple fields (yellow) and allow shortest route to Endeavour Crater (lower right).