MER EARLY TRAVERSE MAPPING: MOC VS HIRISE LOCALIZATION.

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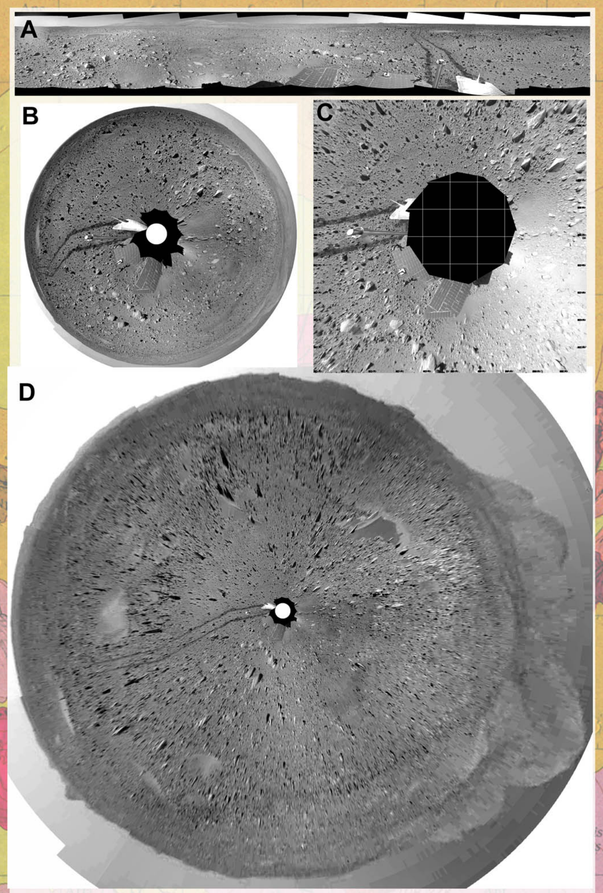

Fig. 1: Spirit sol 144 Navcam panorama (A), polar version (B), vertical map (C) and circular reprojection used in this study (D)

Introduction: The Mars Exploration Rovers Spirit and Opportunity landed on Mars in January 2004 and operated for seven and nine Earth years respectively (Opportunity is still functioning productively). Site certification and traverse planning were originally based on Mars Global Surveyor MOC images with resolutions as good as 1.5 m/pixel. Mars Reconnaissance Orbiter arrived at Mars in 2006 and obtained its first images of the rovers on 3 October (Opportunity) and 22 November (Spirit).

Since then all traverse planning has made use of HiRISE images with resolutions of about 25 cm/pixel. Now it is possible to revisit the early mission localization results for both rovers and to assess their accuracy. Results suggest that both rovers were typically located within about 15 to 20 m of their true positions but errors of as much as 50 m occur. Comparisons with the PDS Mosaic Viewer map in the Analyst's Notebook show errors usually smaller than 10 m but occasionally up to 45 m.

Method. The data used for this study are the contemporary route maps released through the MER website at JPL, a new set of route maps compiled by the author on HiRISE bases, and surface panoramas (360 degrees where possible, partial if full data were not obtained), most of which are available through PDS. The panoramas were converted to a polar format and modified from a simple polar projection by enlarging the radial scale as a function of elevation, giving in effect a map of the site extending out to the horizon (Figure 1).

The inner part of the projection approximates a map, the outer part is vertically exaggerated, making distant features more recognizable than a standard polar projection. Features in these circular projections were matched to HiRISE images to identify rover locations to within about 1 m (estimated by comparing with later MER route mapping by Tim Parker of JPL, also posted on the MER site). The new set of route maps was compiled by locating each end of drive location and adding the route itself between stops from images of the tracks in panoramas and in HiRISE images where visible. The JPL route map and the new route map were compared by overlaying the two, aligned by matching the larger terrain features. Also the more recent maps available through the NASA PDS Analysts Notebook Mosaic Viewer were registered and superimposed for an additional comparison.

Spirit traverse. The first image of Spirit from HiRISE was taken on Spirit sol 1026 while it was at Low Ridge Haven just after the second winter. Earlier route planning was based on MOC images during the long trek from the landing site to the Columbia Hills and at West Spur, Husband Hill and Home Plate. Direct comparisons of locations (Figure 2) show that the mapped traverse was usually close to the actual traverse (typically within 10 m), but that location errors along the route were larger, rising to 40 m in places (Figure 3). HiRISE images of tracks confirm the comparisons. Particularly bad locations include sols 122, 123 and sols 143-154. Sources of error include high sun angles in some MOC images (varying with season), limited azimuthal coverage of surface panoramas and relatively featureless terrain in some areas.

Opportunity traverse. The first image of Opportunity from HiRISE was taken on Opportunity sol 957 while it was at Cape Verde on the edge of Victoria crater. Before that time route planning was based on MOC images during the drive from the landing site to Endurance, to Erebus and finally to Victoria. Opportunity maps at JPL are inferior to Spirit's, with less detail and infrequent sol labels.

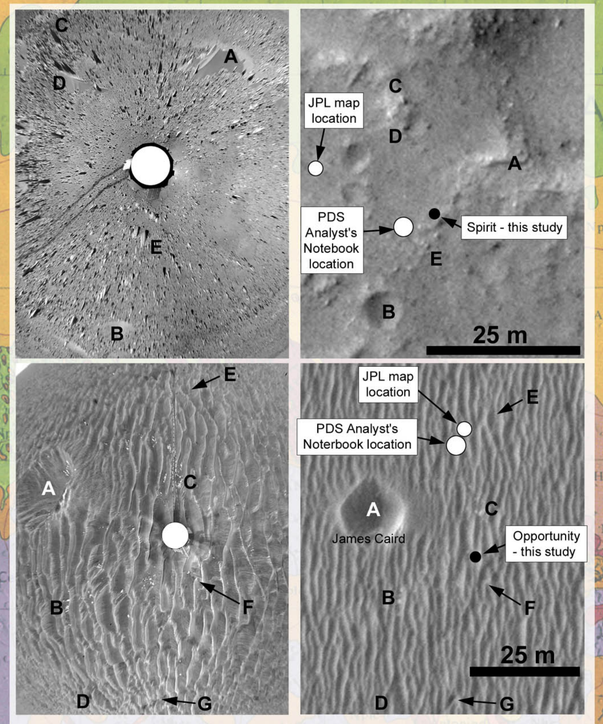

Figure 2. Localization. Top: Spirit circular panorama from sol 144 and HiRISE image PSP_001777_1650. Common features establish the location (allow for small rotation of panorama). Sites from JPL, PDS and this study are compared. JPL error is on the order of 20 m. Bottom: Opportunity circular panorama from sol 408 and HiRISE image PSP_001414_1780. Common features establish the location, and sites from JPL, PDS and this study are compared. Both errors are on the order of 25 m.

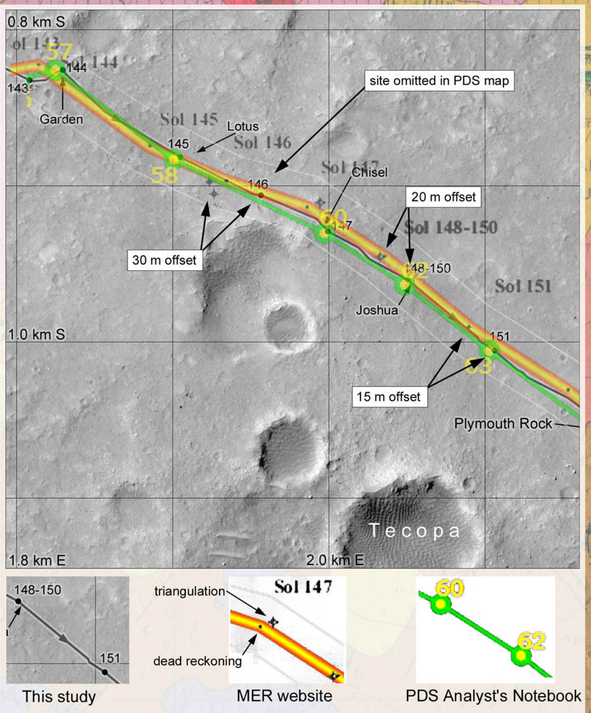

Figure 3. Spirit route map, sols 143-151. Background is a map from this study with HiRISE base, traverse, sol markers and feature names. The grid interval is 100 m. Yellow: the map from the MER website at JPL. Green: Map from the PDS Analyst's Notebook labelled with site numbers. Alignment is based on landscape features. The three traverses lie mostly within 10 m of each other but sites can be offset up to 30 m along the route.

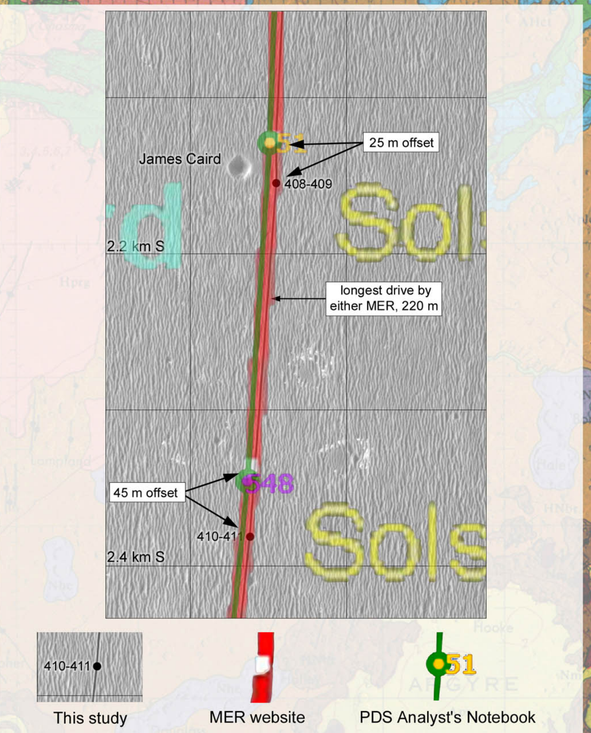

Figure 4. Opportunity route map, sols 408-411. Background is a map from this study with HiRISE base, traverse, sol markers and feature names. The grid interval is 100 m. Red: the map from the MER website at JPL. Green: Map from the PDS Analyst's Notebook labelled with site numbers. Alignment is based on landscape features. The three traverses lie mostly within 10 m of each other but sites can be offset up to 45 m along the route.

Traverse accuracy was similar to Spirit's (typically within 10 m), but location errors along the traverse were larger, rising to 50 m in places. Particularly bad locations include sols 410-413. MOC images of Meridiani show fewer features than those at Gusev but route accuracy was maintained as the 'crater-hopping' design of the traverse allowed frequent location checks. Again the rover tracks seen in HiRISE images as far back as the rim of Endurance crater help confirm the true locations.

The PDS maps are usually better than the early JPL mission maps, but the route is often simplified and some stops are omitted altogether. Errors on the order of 10 m are common, probably related to registration of raw position data with the HiRISE image base, but errors on the order of 50 m can occur, for example at Opportunity sols 410-413.

Comments. Full Navcam panoramas are invaluable for accurate location and route mapping. Monoscopic or 2x downsampled images would be acceptable if downlink is limited. Rearward imaging of tracks along the route is desirable for route reconstruction. This comparison pointed out the lack of an official, detailed rover route map with an accurate traverse, labelled with stops, dates and feature and target names, which is highly desirable after the mission for accurate location of observations. Mission cartographic products should be part of the PDS Analysts Notebook submission.

The maps used in this study (Figures 3, 4) and others shown in Figure 5 are being prepared for a future publication which will summarize and illustrate MER and MSL rover activities.

Acknowledgements: I thank the rover engineering and science teams for their spectacular missions, and NASA's Planetary Data System for superb access to data and planning materials, especially through the Analyst's Notebook, which is invaluable. It can only be hoped that future missions including non-NASA missions will be equally forthcoming (ExoMars - I'm talking about you!)

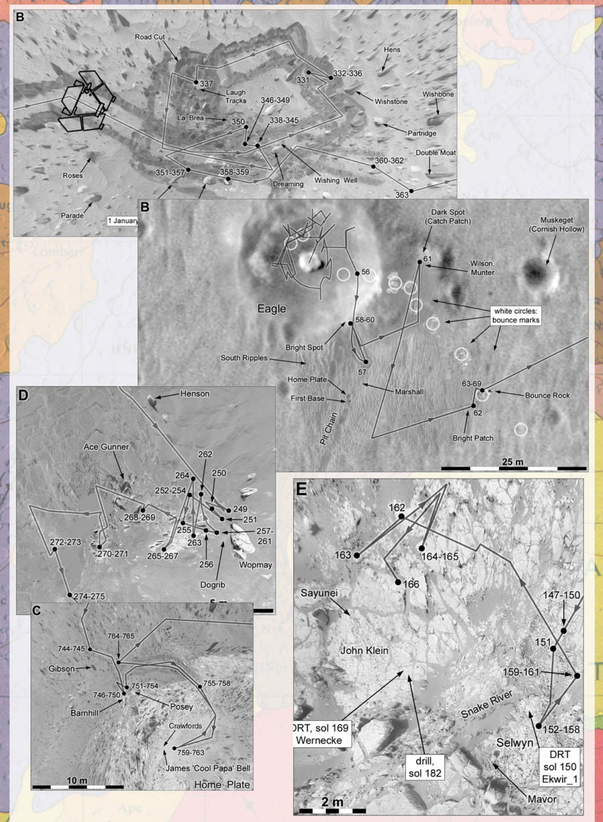

Figure 5. Samples of route mapping from the forthcoming *International Atlas of Mars Exploration*, v. 2., now in preparation for release in 2015. From top: Spirit at Wishstone; Opportunity at Eagle crater, Opportunity at Wopmay, Curiosity at John Klein and Spirit at Barnhill.