

## RECENT RESULTS FROM THE OPPORTUNITY ROVER'S EXPLORATION OF ENDEAVOUR CRATER, MARS.

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**Introduction:** The Mars Exploration Rover Opportunity is beginning its 14<sup>th</sup> year of exploration and as of sol 4603 (3 Jan. 2017) has traversed ~43.7 km across the plains of Meridiani and the rim of the ~22 km wide Noachian Endeavour Crater. In this abstract recent results from Opportunity's exploration of Endeavour's rim are covered, focusing on results from Marathon Valley and points south, i.e., initial results from the 10<sup>th</sup> Extended Mission (Fig. 1).

**Aqueous Alteration:** As part of the EM-10 objectives Opportunity was commanded to leave Marathon Valley after finishing characterization of smectite-bearing outcrops [1], fractures with evidence of leaching to produce pebbles enriched in Al and Si [2], and a soil-filled fracture with multiple sulfate-bearing phases [3], and headed downhill to Spirit Mound (Fig. 1). Spirit Mound was a candidate for exposures of pre-Endeavour Matijevic formation outcrops similar to those found on Cape York. On Cape York these rocks were found to contain ferric smectites based on CRISM data [4], together with significant leaching toward an Al-rich smectite composition in a fracture zone, where enhanced fluid flow was likely [4,5]. Limited areal and stratigraphic exposures of Matijevic formation outcrops on Cape York precluded an understanding of its depositional environment. Thus one key objective for EM-10 was to search for and characterize more extensive exposures of these rocks.

In fact, Spirit Mound exposes Shoemaker formation impact breccias, but with an interesting twist. A relatively bright linear portion of the outcrop (Fig. 2), with its Gasconade targets, was found to be enhanced in Ca and S, and is interpreted to be yet another type of fracture-controlled of aqueous alteration (Fig. 3). This discovery adds to the growing understanding of the complex aqueous alteration history of Endeavour's rim, as evidenced by smectite-bearing outcrops on Cape York and Marathon Valley [1,4,5], Ca-sulfate veins found on Cape York, Murray Ridge, and Cape Tribulation [4,6,7], Mg and other sulfate-bearing minerals excavated from a soil-filled fracture by Opportunity's wheels in Marathon Valley [3], the presence of Mn oxides as a coating over Mg and Fe-bearing sulfate minerals on the excavated Pinnacle and Stuart Island rocks in Cook Haven [8], and hematite enrichments in fracture zones [9]. The enhanced Mg and S contents of Marathon Valley and Spirit of Saint Louis Crater outcrops, relative

to previous Shoemaker formation outcrop measurements, together with Ge-enrichments found around Spirit of Saint Louis Crater (upper portion of Marathon Valley), also indicate aqueous alteration [2].

**Mobility in Challenging Terrains:** After finishing work on Spirit Mound Opportunity was commanded to traverse uphill to the southwest, with an intent of examining grooved terrain in Willamette Valley to compare to similar grooves (possibly fluvial in origin) found in the lower portion of Marathon Valley (Fig. 1). Steep slopes and boulder fields led to tactical changes to traverses relative to the strategic EM-10 route. One of the EM-10 objectives is to evaluate Opportunity-class rover mobility capabilities in challenging terrains, including steep slopes covered with bedrock rubble and soil. Two traverses are exemplary of the difficulties. One occurred at the base of Beacon Rock when the rover was traversing uphill (20 to 22° slope) on soil-covered terrain with strewn rocks (Fig. 4). High wheel currents led to an automatic drive cessation and slip was found to exceed 80% as a consequence of the front wheels excavating into crusty soil. High slip was also encountered while the rover tried to ascend 30 to 35° slopes on Knudsen Ridge in Marathon Valley. The combination of the rover mobility capabilities and terrain placed the vehicle in highly nonlinear portions of the slip-skid-tilt regime (Fig. 5). In both cases downhill drives led to skid, demonstrating that gravity is the key to extricating the rover from mobility-challenging situations.

**What's Ahead?:** A key EM-10 objective is to reach the entrance to an ancient gully found on Cape Byron (Fig. 6) and to descend into the gully toward Endeavour crater. Observations of gully geomorphology and sedimentary deposits are expected to allow testing among dry flow, debris flow, and fluvial mechanisms of formation. Once within Endeavour traverses will be focused on examining the benches and sulfate-bearing outcrops adjacent to the eastern outcrops on Cape Byron (Fig. 6). The intent is to understand the environment of deposition of Burns formation rocks within the crater, together with the detailed stratigraphy that can be inferred from the bench exposures. For example, are Matijevic formation rocks exposed? Are Grasberg formation rocks exposed and are the contacts evident to further characterize the stratigraphic relationships posed by [7].

**References:** [1] Fox, V. et al. (2016) *GRL* doi:10.1002/2016GL069108. [2] Mittlefehldt, D. et al. (2016) *GSA Abs* doi:10.1130/abs/2016AM-283470. [3] Arvidson, R. E. et al. (2017) *LPSC* these abstracts. [4]

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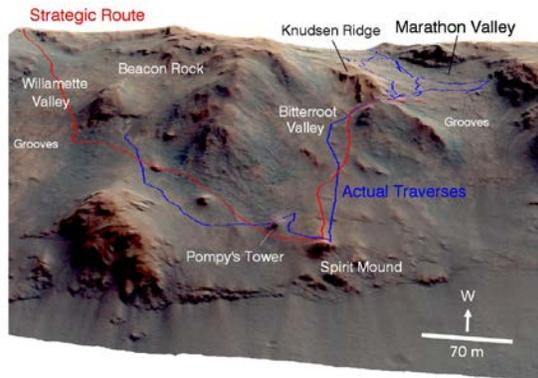


Fig. 1 HiRISE-based perspective view (2 times vertical exaggeration) showing Opportunity's EM-10 strategic traverse plan and actual traverses through sol 4603.



Fig. 2 Opportunity conducted a series of in-situ measurements on the Gasconade targets within a fracture zone on the side of Spirit Mound.

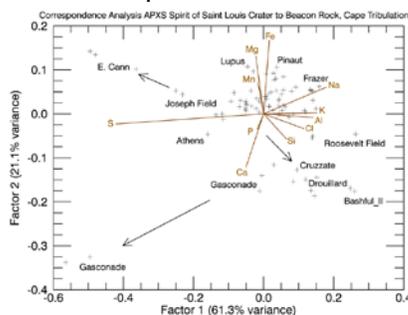


Fig. 3 Correspondence Analysis plot showing Ca, S enrichments for the Gasconade targets, Mg and S enrichments for the scuffed, soil-filled fracture in Marathon Valley (E Cann and Joseph Field), and Si, Al

enrichments for selected targets, including red pebbles in fractures. Lupus, Pinaut, and Frazer represent outlier bedrock targets.

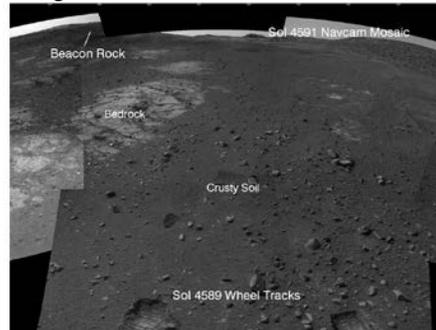


Fig. 4. Portion of a Navcam mosaic showing tracks produced on sol 4589 in crusty soil when Opportunity's drive was automatically stopped because of high wheel currents associated with an uphill drive and front wheel sinkage.

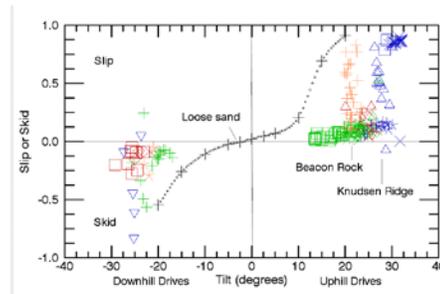


Fig. 5. Slip-skid-tilt relationships are plotted for drives over loose sand collected during Earth testing, together with data within Marathon Valley (green and blue symbols), slip during the sol 4589 drive, and skid during the sol 4591 downhill drive (red symbols).

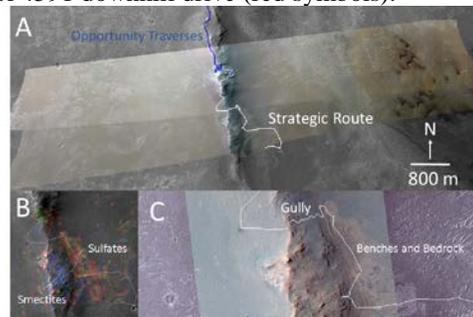


Fig. 6 A. HiRISE-based mosaic overlain with two CRISM scenes showing Opportunity's traverses through sol 4603 and the EM-10 strategic route. B. CRISM-based smectite and sulfate parameter maps. C. Merged RGB HiRISE view showing the gully, benches, and bedrock strategic traverse plan.