

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

R. E. Arvidson<sup>1</sup>, S. W. Squyres<sup>2</sup>, R. Gellert<sup>3</sup>, D. W. Mittlefehldt<sup>4</sup>, and the Athena Science Team, <sup>1</sup>Earth and Planetary Sciences, Washington University in Saint Louis, Saint Louis, MO, 63130, [arvidson@wunder.wustl.edu](mailto:arvidson@wunder.wustl.edu), <sup>2</sup>Cornell University, Ithaca, NY, <sup>3</sup>University of Guelph, Ontario, Canada, <sup>4</sup>NASA Johnson Space Center, Houston, TX.

**Introduction:** The Mars Exploration Rover Opportunity is beginning its 11<sup>th</sup> year of exploration and as of sol 3535 (1/3/14 UTC) has traversed 38,729 m (based on wheel turns) across the plains of Meridiani and the rim of the ~22 km wide Noachian Endeavour Crater. Opportunity has investigated ancient sulfate-rich sandstones (Burns formation) that dominate the plains and formed in ancient playa and dune environments [1], characterized impact breccias (Shoemaker formation) and their aqueous alteration on Endeavour's Cape York rim segment [2], and investigated extensive aqueous alteration of rocks on Cape York's Matijevec Hill that stratigraphically underlie Shoemaker formation and predate the Endeavour-forming event [3]. In this abstract results from Opportunity's recent exploration of Endeavour's rim are covered, focusing on comparing what was found on Matijevec Hill with observations acquired on Murray Ridge, where Opportunity will spend its sixth winter at Cook Haven (Fig. 1).

**From Cape York to Murray Ridge:** Endeavour Crater is older than Burns formation rocks that cover much of Meridiani Planum. Age relationships are evident from extensive embayment relations between Burns formation materials and Endeavour's rim segments (Figs. 1-3). After completing extensive measurements of Burns formation rocks Opportunity was directed to traverse toward and onto Cape York, an isolated Endeavour rim segment, and investigated in detail rocks from this ancient crater, focusing on the nature and history of aqueous alteration [2,3].

The rover completed its measurement campaign on Cape York on Matijevec Hill on sol 3309 (5/13/2013 UTC) (Fig. 2) and began a set of traverses across Botany Bay to Solander Point and Murray Ridge, another Endeavour rim segment. After exploring the small rim segments Sutherland Point and Nobbys Head, and the benches that surround them, Opportunity was directed to the eastern side of Murray Ridge. The rover focused on additional measurements of the bench materials at this location and then traversed counter-clockwise toward the western exposures of rim rocks on Murray Ridge (Fig. 3). Opportunity was guided to specific outcrops (Moreton Island, Figs. 3-4) by use of CRISM along-track oversampled hyperspectral observations that showed the presence of a 2.2  $\mu\text{m}$  Al-OH absorption feature, consistent with the presence of an

Al-rich smectite such as montmorillonite [4]. Opportunity then traversed to Cook Haven to spend its sixth winter season. This area exposes relatively bright, recessive outcrops with northerly slopes of 15° or more that are required for enough solar power over the winter season (southern hemisphere winter solstice occurs on 2/14/14 UTC) to conduct in-situ measurement campaigns with small "bumps" between campaign sites.

**Matijevec Hill and Murray Ridge Rocks:** During its exploration of the eastern side of Cape York Opportunity was directed to turn west onto Matijevec Hill in an area where CRISM oversampled data indicated the presence of Fe<sup>+3</sup> smectites [3]. Opportunity showed that this mineral signature is associated with dark veneers partially covering finely layered rocks, subsequently named the Matijevec formation (Fig. 5). The veneers and associated Fe<sup>+3</sup> smectites are interpreted to have formed as surface varnishes or bedding plane deposits in the presence of relatively minor amounts of water. Additional measurements by Opportunity uncovered evidence for more extensive aqueous leaching and formation of Al-rich smectites within boxwork fractures in the Matijevec formation rocks [3] (Fig. 5). Further, Opportunity showed that narrow fractures in both the Matijevec formation and overlying breccias are filled with Ca-sulfate veins, again indicative of aqueous activity. The combined orbital and rover-based observations showed that aqueous alteration was an ongoing process before and after formation of Endeavour.

Imaging and in-situ measurement campaigns using Opportunity's Pancam, Microscopic Imager, and Alpha Particle X-Ray Spectrometer have been conducted on several rim outcrops on the western side of Murray Ridge (Fig. 3). Because of the need to get to Cook Haven before the winter solstice, and the rough nature of the outcrops, grinding into the rock surfaces with the Rock Abrasion Tool was not done as part of the measurement campaigns. Removal of dust, sand, and coatings has proven to be important in revealing intrinsic rock compositions (e.g., see Fig. 5). On the other hand, imaging data do clearly show that the Murray Ridge rim outcrops are impact breccias, with Moreton Island exhibiting a higher matrix to clast areal proportion as compared to most other Endeavour breccia outcrops. Murray Ridge rocks examined thus far are quite distinct texturally and compositionally from Matijevec formation rocks. They are similar to Shoemaker formation breccias measured on Cape York

(particularly at Greeley Winter Haven), but with subtle compositional differences, e.g., higher Fe/Si, Mn/Si, and Ca/Si ratios (Fig. 5). The lack of a compositional trend toward an Al-rich smectite for Moreton Island rocks suggests that the formation of the smectite was done with a low water/rock ratio and was basically an isochemical process. Imaging and in-situ data acquisition campaigns at Cook Haven have just begun and the bright, recessive outcrops have yet to be measured. They may be outcrops of Matijevec formation or matrix-rich breccias.

**Beyond the Sixth Winter Campaign:** CRISM oversampled data show an extensive outcrop with a 2.2  $\mu\text{m}$  Al-OH absorption on the western side of Murray Ridge ~600 m from the south of Cook Haven [4]. In addition, the original CRISM-based Fe-Mg mixed smectite discovery location as detailed in [5] is located ~2 km to the south. Both locations are prime targets for Opportunity once the sixth winter campaign is finished and solar power allows traversing to the south.

**References:** [1] Squyres, S. W. and A. Knoll, *Earth Planet. Sci. Lett.* **240**, 1 (2005). [2] Squyres, S. W., et al., *Science* **336**, 570 (2012). [3] Arvidson, R. E., et al., *Science*, in press. [4] Fox, V., et al., LPSC, these abstracts. [5] Wray, J. J., et al., *Geophys. Res. Lett.* **36**, L21201 (2009).

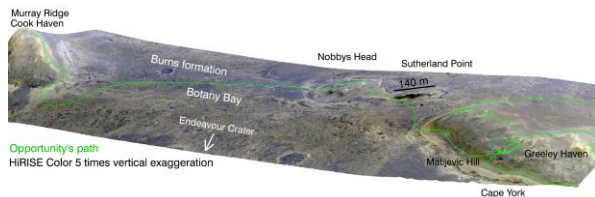


Fig. 1 – HiRISE false color perspective view of Cape York, Botany Bay, and Murray Ridge, showing Opportunity's traverses and key landmarks. Traverses provided by Ohio State University.

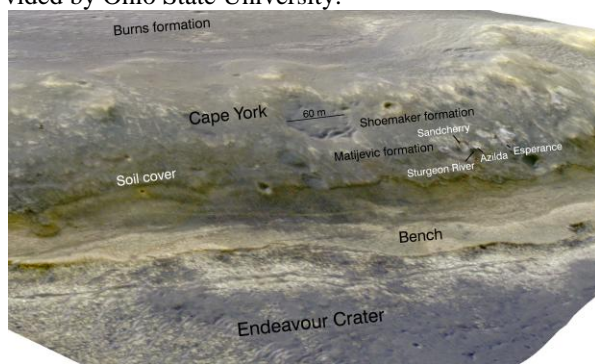


Fig. 2 – HiRISE false color perspective view of the eastern side of Cape York showing locations of key measurements for Matijevec formation rocks. The Sandcherry targets were dark veneers covering finely-layered outcrops (Azilda), the Espérance targets are in a boxwork fracture and shows a high degree of aque-

ous alteration, and Sturgeon River targets have spherules interpreted to be enriched in iron oxides.

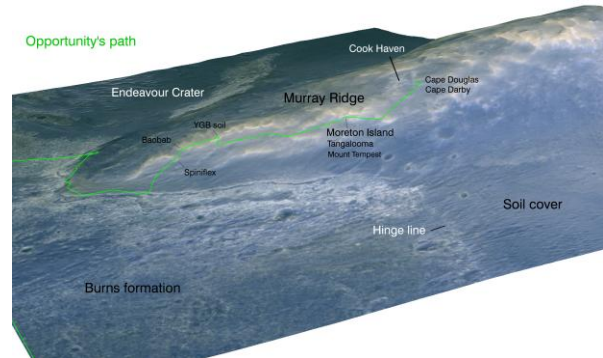


Fig. 3 – HiRISE false color perspective view of the eastern side of Murray Ridge showing locations of key measurements. CRISM data show the presence of Al-smectites at Moreton Island [4].

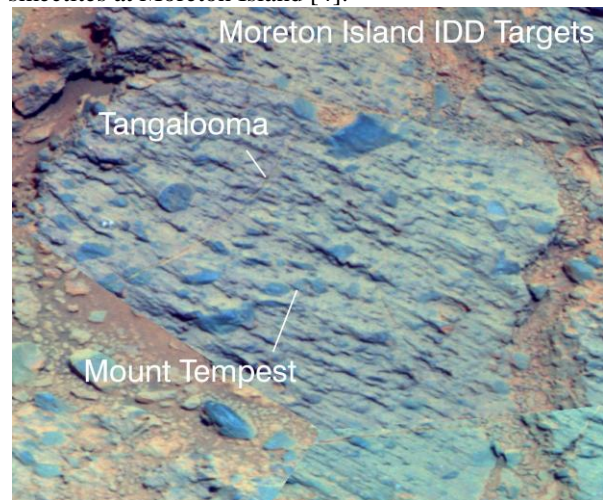


Fig. 4 – Pancam false color mosaic of the two in-situ targets at Moreton Island. Tangalooma is matrix dominated whereas Mount Tempest is an embedded rock clast. Frame covers ~30 cm in width.

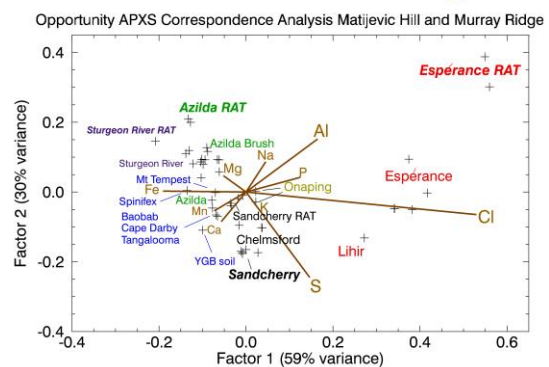


Fig. 5 – Correspondence analysis plot for rim rocks at Matijevec Hill and Murray Ridge (blue). APXS oxide data were normalized to  $\text{SiO}_2$  concentrations to avoid artifacts. Murray Ridge rocks are subtly different than Matijevec Hill rocks.