MARS EXPLORATION ROVER OPPORTUNITY MOBILITY SIMULATION OF TRAVERSES ON MATIJEVIC HILL, CAPE YORK, MARS. G. L. Coutrot[1], R. E. Arvidson[1], F. Zhou[1], [1]Washington University in St Louis, Rudolph Hall room 110, 1 Brookings Drive, St Louis, MO, 63130

Introduction: The Opportunity rover's traverses on the in-board or eastern side of Cape York, an isolated portion of rim of Endeavour crater, have largely been on densely packed soil or bedrock sparsely covered with soil. Slopes traversed have approached 15 degrees where significant wheel slip going uphill and skid going downhill were expected. Slip is defined as 100*(1-actual_distance/commanded_distance). If the actual drive distance is shorter than commanded slip is positive, whereas if the actual distance is longer than commanded slip is negative and is called skid.

We simulate selected drives on the Matijevic Hill portion of Cape York (Fig. 1) with ARTEMIS (Adams-based Rover Terramechanics and Mobility Interaction Simulator, a dynamic computer-based model for rover drives over realistic terrains (1)). The intent is to understand how Opportunity responded on these tilted surfaces as a look-ahead to planning more difficult drives expected at Solander Point (25 degree slopes) and also Curiosity's drives on relatively steep slopes on Mount Sharp.

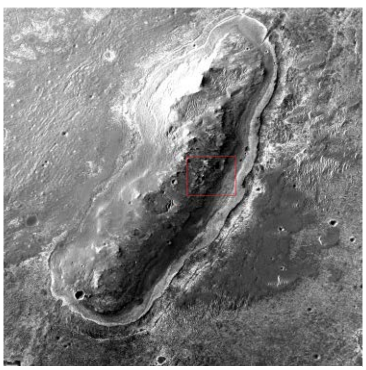

Figure 1: Cape York and the Matijevic Hill (red square) area. HiRISE Frame ESP_018701_1775

ARTEMIS model at Matijevic Hill: Elevation data for the simulations were derived from HiRISE stereo observations, complemented by Navcam and Pancam-based elevation maps. Soil mechanical properties were assigned to map cells based on examination of image data and characterization of the extent of bedrock as opposed to soil exposures. Mechanical properties were estimated based on previous drives (2) and tests in the JPL Mars Yard and various terrains in the Mojave Desert (1). A "walk about" was conducted by Opportunity on Matijevic Hill because CRISM data indicated the presence of smectite clay minerals in particular locations (3). We will simulate all of these drives and we report here initial traverse simulations on the bench bordering the in-board side of Cape York (Figs. 2-3).

The simulated drives: Drives were commanded in flight a blind mode in which the rover drove to a way point while periodically conducting rover-based 3D slip checks using visual odometry. This included stopping and checking orientation and assumed distance traveled based on the assumption of no slip. Ackerman arcs were commanded to reorient the vehicle to get to the way point. We simulated these commands and motions, varying mechanical properties of the soil and bedrock surfaces to match the actual path and slip or skid patterns observed. The focus of the initial work was the drive conducted on sol 3051 (Figs. 2-3). The slope of the terrain for this drive was 9 deg toward the SE.

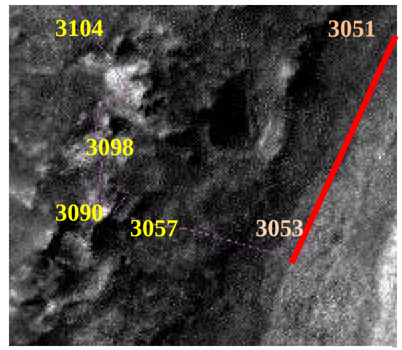

Figure 2: initial sols of the Walkabout (purple) and the traverse simulated (red)

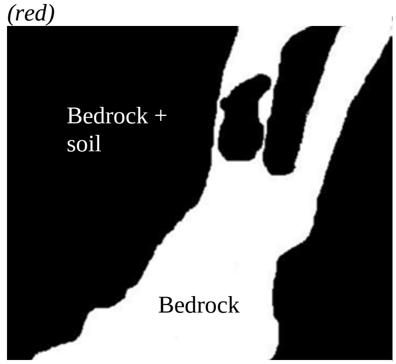

Figure 3: Bedrock-soil region (black) and bedrock region (white) for region covered in Fig. 2

Results: The 3D slip data reported by Opportunity was dominated by skid in both the drive and downhill directions, with a magnitude of 5%. Our initial runs reproduced the skid but with a mean of 10%, with excursions up to 20%. We thus adjusted the parameters which affect the shear stress, since it is directly related to slip values, to better match actual results. The shear deformation modulus k_x was adjusted since this influences shear stress between the wheels and the soil or bedrock. τ_x is the main source of driving traction and is given by the following equation:

$$\tau = \tau_{max}(1 - e^{-\frac{j_x}{k_x}})$$

Where τ_{max} is the maximum shear resistance on a Mohr-Coulomb failure criterion, j_x is the shear displacement. τ_{max} is calculated by:

$$\tau_{max} = (c + \sigma \cdot \tan\phi)$$

where σ is normal stress, c is cohesion and ϕ is internal friction angle. These two last parameters are fixed in our simulations according to previous studies (2).

We took half of the initial k_x value of 10 mm along the same path and it decreased skid to a mean of 5% with excursions up to 10%.

We then modified the normal stress (and thus the shear stress) by changing k_ϕ, the Reece's pressure-sinkage friction modulus from 800 to 1600. The new value produced skids typically of 0 to 2%, with excursions up to 5% (Fig. 4), which is in agreement with actual data. Further the skid direction is in agreement with flight data.

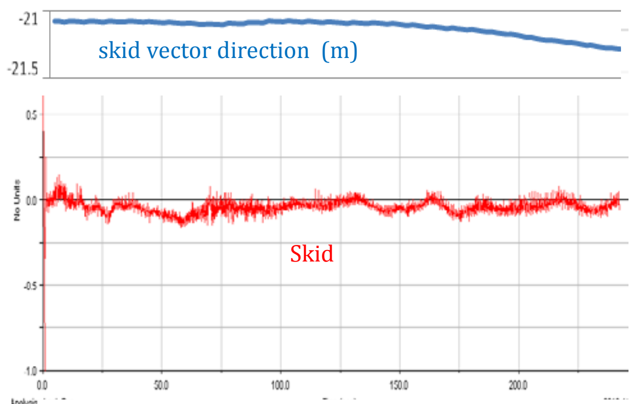

Figure 4: topography and skid results after changing kx to 5mm and k_φ to 1600

Solander Point and Mount Sharp: There is a strong interest to finish work at Cape York and head across Botany Bay to Solander Point (Fig. 5).This Endeavour rim segment has extensive outcrop on its northern side and provides slopes of up to 25 deg for parking for winter survival. On the other hand these steep slopes will lead to drives with significant slip uphill and skid across topographic contours and downhill. The work we will do in simulating drives for the Matijevic Hill walk-about will provide a basis for understanding how to accomplish these difficult drives and reach targets for both remote sensing and in-situ observations.

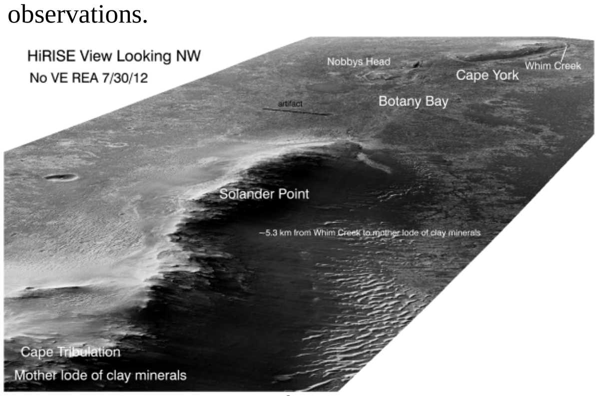

Figure 5: Perspective view of Cape York, Botany Bay and Solander Point, where Opportunity will be roving during the next few months. The area around Solander point has steep slopes that will lead to significant slip and skid. .

Further, the work on the walk-about will provide a basis for modeling Curiosity's drives on Mount Sharp, where steep slopes with extensive bedrock exposures are also expected.

References: [1] Zhou F. et al. (2013) , J. Field Robotics, submitted; [2] Arvidson, R., et al., (2011), J. Geophys. Res, 116. [3] Arvidson et al., (2013) these abstracts