ROCK HAZARDS IDENTIFIED FROM ORBIT APPROACHING THE VERA RUBIN RIDGE, GALE CRATER. F. J. Calef III[1], A. M. Zastrow[2], M. Hughes[3], V. Fox[4], R. Arvidson[3]. [1]NASA Jet Propulsion Laboratory-California Institute of Technology, fcalef@jpl.nasa.gov. [2]Stony Brook University, [3]Washington University in St Louis, [4]California Institute of Technology.

Introduction: As the Mars Science Laboratory (MSL), aka *Curiosity* rover, approached the Vera Rubin Ridge (VRR) on its way up Mount Sharp (i.e. Aeolis Mons), the strategic traverse crossed over a very dense rock field (Fig. 1). Due to wheel damage collected during the 17+ km traverse from Bradbury Rise to the ridge [1], abundant caution is taken when planning the long-term drive path, so as not to exacerbate current wheel conditions. One approach to delineating a safe rover route combined orbital and in-situ imagery to gain a quantitative assessment of rock hazards along the ~1 km of terrain skirting the northern edge of Vera Rubin Ridge (VRR). This data was used to reassess and plan a new higher fidelity route to "summit" VRR.

To help preserve rover wheels for the duration of the mission, the goal is to avoid as many hazardous rocks as possible. Approaching the VRR, there are many bright, boulder-sized rocks that are flat lying and benign to the rover mobility system; rather, rocks with near-vertical edges are a concern as a wheel would have to 'climb' a sharp edge and risk damage. Dense rock fields incur longer traverse times to avoid all rock hazards, thus extending the time necessary to traverse to high-value science regions.

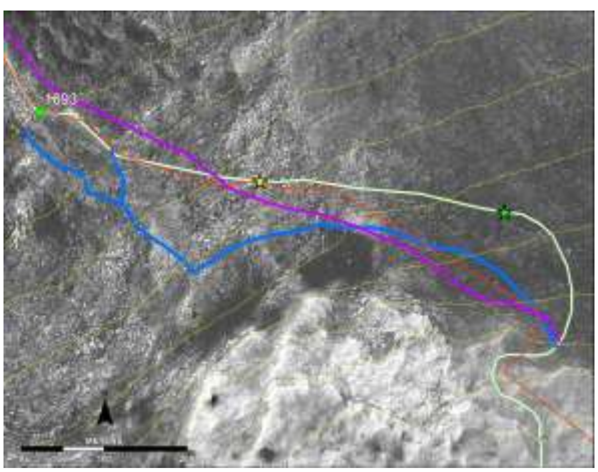

Fig. 1: Overview of the drive approach to VRR (light-toned in the image). Several potential routes are shown.

Methods: For this study, we measured rock size-frequency and identify rocks >30 cm high at their edge to evaluate hazardous driving terrain. HiRISE resolution limits what hazardous rocks we can measure, in terms of density and shadows for height, to about the size of a HiRISE pixel, ~25 cm. The MSL science and engineering teams use an orthophoto mosaic composed of 12 HiRISE orthophotos at 25c m/pixel over a CTX base [2]. Experience comparing this basemap to Navigation Camera (NAVCAM) in-situ oblique mosaics at 1 cm/pixel as well as orthoproducts from said stereo imagery, reveal that rocks in the order of 30-50 centimeters high are identifiable by the shadow that they cast in HiRISE imagery, e.g. the rock Jack Matejevic. We took a blind approach by identifying rocks in HiRISE with purported shadows in areas that we had already driven; one such sol was sol 1677 (Fig. 2). In addition, we measured rock maximum widths in four regions of interest (ROIs) that appeared to represent unique terrains approaching VRR (Fig 3).

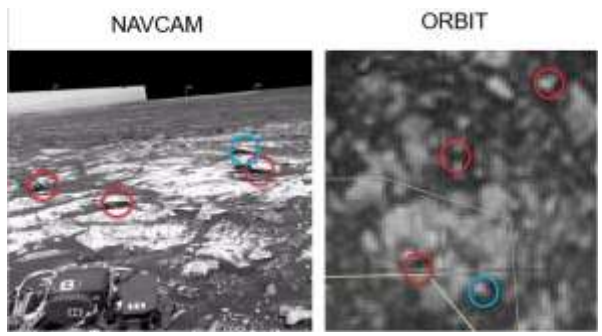

Fig. 2: Hazardous rocks identified in NAVCAM in-situ and HiRISE orbital imagery. Red circles were positive identifications in both datasets, while the blue circle was a "missed" rock hazard seen in NAVCAM, but not HiRISE. Data is from MSL sol 1677.

Fig. 3: Regions of Interest (ROIs) identified in HiRISE imagery for rock size-frequency measurements.

NAVCAM orthophotos were overlaid onto our basemap and insitu oblique mosaics were utilized to measure the accuracy of rock widths measured and hazardous rocks identified in HiRISE. Every rock that cast a shadow along a 100 m corridor of the strategic rover route was circled to approximate the size of the rock. In the four ROIs, we calculated rock size-frequency from maximum rocks widths in HiRISE (Fig. 3) as well as to compare measurements with insitu data. To calculate rock hazard density, the number of hazardous rocks (regardless of diameter) per unit area was generated over a 10 m radius using the "focal density" tool in ArcGIS (v10.5), with an output cell size of 10 m.

Results: In the 4 ROIs, 4100 rock widths were recorded. Comparing to insitu measurements, orbital values were mostly underestimates (2:1) with < 6% median difference for meter-scale rocks. Cumulative size-frequency distributions reveal ROI 1 and 3 to be similar over all widths, while ROI 2 and 4 are the most different at rock widths 1-2 m (Fig. 4).

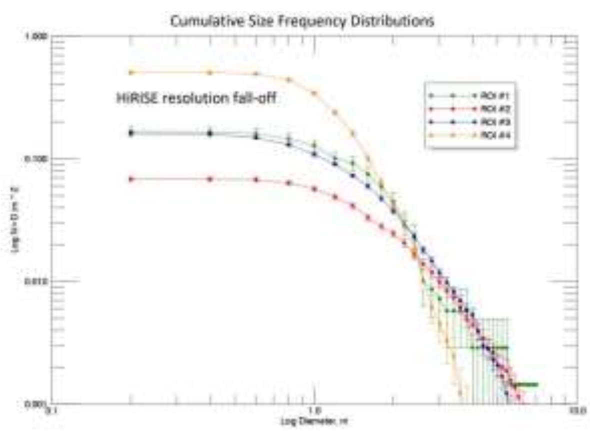

Fig. 4: Rock width (diameter) cumulative size-frequency distributions at the four ROIs.

Over the whole VRR approach, we identified 2117 hazardous rocks in our basemap. Using the rock centroids to calculate rock hazard density, we identified three distinct regions along the strategic route (Fig. 5). ROI 1-2, consists of in-place outcrop and flat-lying slabs with some sub-meter diameter heaved blocks with low hazard density. ROI 3 rocks were more 'jumbled', sub-meter in diameter, heaved blocks, with high hazard density. ROI 4 consisted of large, although more dispersed, sub-meter diameter blocks with a few centimeters of sand cover interspersed.

ROI 3 contained the most rock hazards, causing new routes to be proposed and an alternate route was taken closer to the VRR, skirting the densest areas. Looking back at previous drive locations, we assembled a qualitative guide to what the terrain would look like based on comparisons in HiRISE imagery to previous positions (Fig. 6).

Discussion/Conclusion: Both meter-scale rock width (quantitative) and sub-meter rock height (qualitative) can be measured in HiRISE imagery with sufficient accuracy for strategic traverse planning. These measurements allow precise assessments of future drive hazards to formulate strategic path planning at the meter-scale.

References: [1] Perkins, *Science*, doi:10.1126/science.aal0947. [2] MSL basemap at USGS Annex: https://astrogeology.usgs.gov/search/map/Mars/MarsScienceLaboratory/Mosaics/MSL_Gale_Orthophoto_Mosaic_10m_v3.

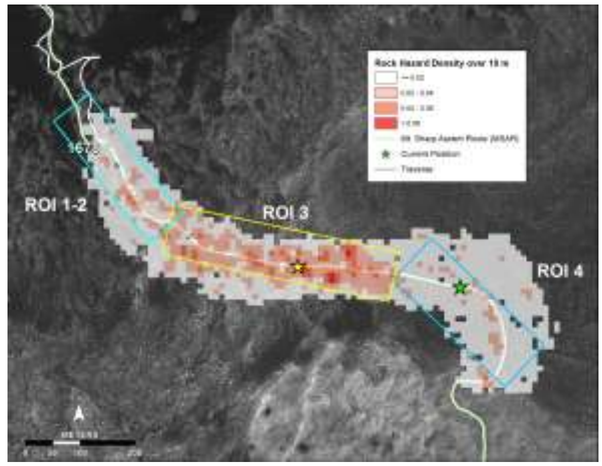

Fig. 5: Rock hazard density along the MSL strategic route to the VRR.

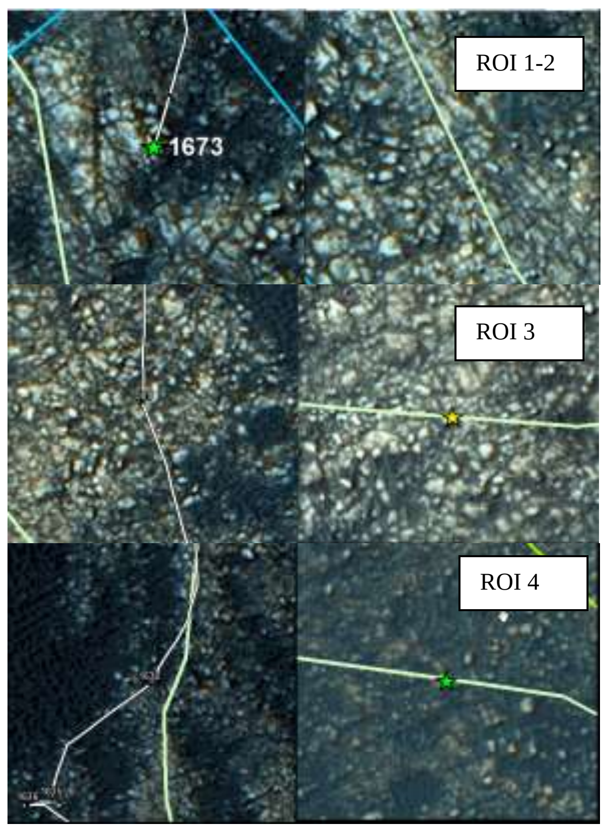

Fig. 6: Qualitative comparison of rock density along the VRR in HiRISE imagery. Previously visited terrain on the left and ROI on the right, at the same scale.