DETERMINING SURFACE ROUGHNESS AND ADDITIONAL TERRAIN PROPERTIES: USING OPPORTUNITY MARS ROVER RESULTS TO INTERPRET ORBITAL DATA FOR EXTENDED MAPPING. A. Shaw[1], R. E. Arvidson[1], M. J. Wolff [2], F. P. Seelos[3], S. M. Wiseman[4], and S. Cull[5], [1]Washington University in St. Louis, [2]Space Science Institute, [3]Johns Hopkins University Applied Physics Laboratory, [4]Brown University, [5]Bryn Mawr College. **Correspondence:** ashaw@levee.wustl.edu.

Introduction: The objective of this work is to determine surface properties from orbital data. The Opportunity Mars Exploration Rover traverse (Fig. 1) is an ideal location to observe the interplay between surface properties and orbital observations because there are ground truth images for a percentage of each orbital image, and this information can be used to make conclusions over the expanse of the orbital coverage. From this technique, we are able to derive maps of mm- to cm-scale surface roughness (Fig. 2). Surface roughness on this spatial scale is dominated by the abundance and burial depth of hematitic spherules (Fig. 3) in our study area (Fig. 1).

Technique: The bulk of this effort was spent analyzing Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) spectrophotometry (i.e. information on how radiance varies with illumination geometry, viewing geometry and wavelength).

Determining the degree to which the phase function of a surface is anisotropic (i.e. how backward or forward scattering the surface is) becomes especially useful for determining the boundaries between surface units for regions that appear to be relatively spectrally homogenous from orbit, which is true for the majority of our study area. It is possible to determine how the scattering of light varies with phase angle (the angle between the incident and scattered rays of light) because CRISM gimbals, which means that it alters its viewing angle to track a target patch of ground as it flies over, allowing us to measure scattering from many different directions. This yields a "phase cube" (two spatial dimensions, and the third dimension is phase angle coverage) at each wavelength. Each pixel in this phase cube is iteratively fitted [1] to a model that includes contributions from both the atmosphere and the surface, and surface parameters are adjusted until the model I/F matches the observed CRISM I/F.

For the surface model, we use a simplified version of the Hapke model (Fig. 4) in order to minimize the number of parameters being varied; this results in well-constrained fits over most of the study area. This version of the Hapke model is basically a radiative transfer model with a modification for multiple scattering; it is used in conjunction with the one-term Henyey-Greenstein phase function. Inputs at each iteration include the radiance at the surface and the illumination and viewing geometry, and the parameters we fit for are the single scattering albedo (*w*; indicator of surface reflectivity, normalized so that it's independent of illumination and viewing geometry) and the asymmetry parameter (*b*; describes the degree to which the phase function is anisotropic). Note that the simplified version of the Hapke model does not have surface roughness as a separate parameter, therefore the effects of surface roughness are included in and end up dominating the expression of *b*, allowing us to make maps of surface roughness.

Results: We created maps of *w* and *b* (Fig. 2 gives an example) for the study area; this was done for several wavelengths and then these maps were formatted into spectral cubes and *w*-spectra and *b*-spectra (Fig. 5) were extracted for several regions of interest that span the study area.

From inspection of the *b*-maps and comparison to rover-based results [3,4; Fig. 3, 5], it is apparent that *b* can be used as a proxy for mm- to cm-scale surface roughness. In this region, surface roughness is present on multiple scales: there are mm- to cm-sized spherules as well as meter-scale ripples. The roughness pattern indicated by *b*-maps is dominated by the spherules rather than the ripples, this is probably at least partially due to the observational setup and its relation to ripple orientation. Ripples in this region trend north-south, and CRISM's flight path is south to north, so all the phase information is in that direction.

In the map in Fig. 2, large wind deposit regions (e.g. degraded craters, wind streaks) appear smooth (low backscatter) because dust and sand have filled in the crevices and gaps, lessening mm- to cm-scale roughness. In Fig. 5, note that the most distinct region, in terms of scattering behavior, is located on Victoria crater's ejecta apron. The majority of the apron appears more backscattering than the surroundings; this is due to a shadowing effect created by many spherules which have weathered out of the ejecta blocks. We also note scattering properties derived using CRISM data are similar in value and spectral trend to those derived using the rover's Panoramic Camera, but the single scattering albedo viewed from orbit is higher because of the larger pixel size resulting in some bright bedrock being included in most pixels, whereas the near-surface results [3, blue curve shown in Fig. 5] are from a soil end-member. *b* is lower in the orbital results due to incorporating roughness into this parameter. Fig. 5 also shows the surface becomes more backscattering with increasing wavelength.

References:
[1] Markwardt, C.B. (2008) "Non-Linear Least Squares Fitting in IDL with MPFIT," *Astronomical Data Analysis Software and Systems XVIII*, p. 251-254, Quebec. [2] Hapke, B. (1993), *Theory of Reflectance and Emittance Spectroscopy*, 455 pp., Cambridge Univ. Press, NY. [3] Johnson et al. (2006), *JGR*, *111*, E12S16. [4] Geissler et al. (2008), *JGR 113*.

*0's left out of CRISM frame IDs.

**Thermal inertia map courtesy of M. T. Mellon.

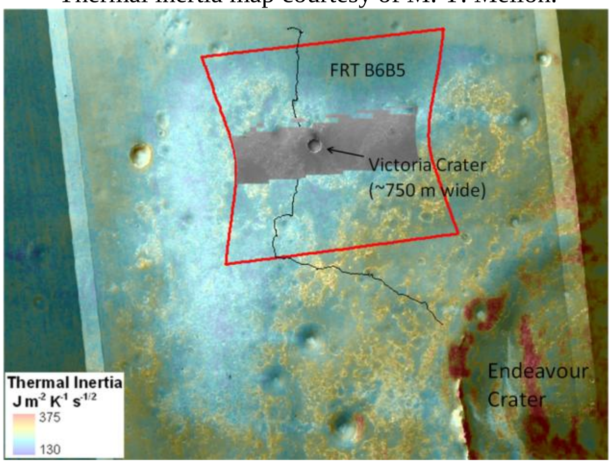

Figure 1. CTX mosaic with THEMIS thermal inertia, FRTB6B5* central scan footprint (red line) and Opportunity traverses (black line) overlain. Grayscale region shows where all ten off-nadir frames overlap with the central scan.**

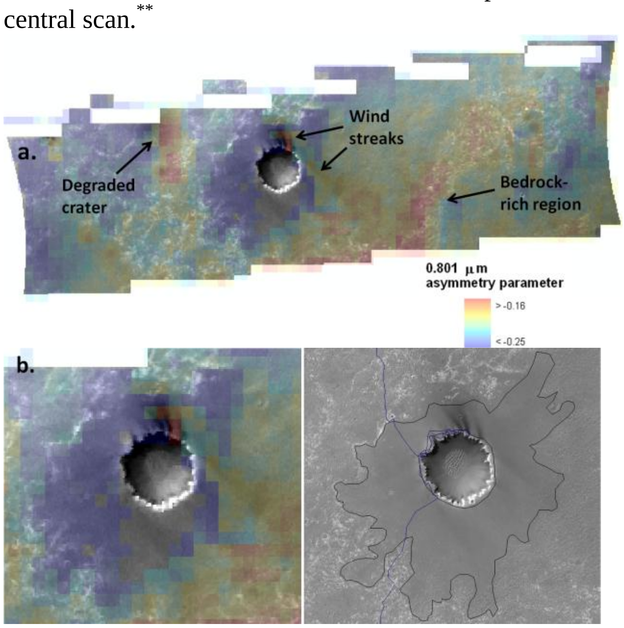

Fig. 2. a. Example of parameter map. Cooler colors indicate greater small-scale surface roughness. Background is CRISM I/F at 0.801 μm. Artifacts due to topography and other high-χ^2 pixels are removed.

b. (left) Zoom-in on Victoria crater & ejecta apron. (right) HiRISE image of Victoria with outlined apron.

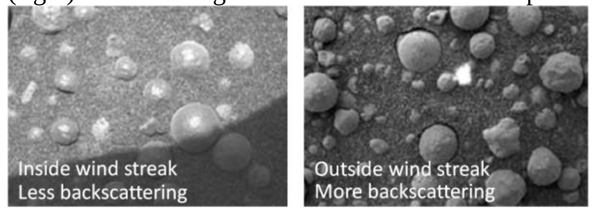

Fig. 3. Modified from [4].

$$rf = \left(\frac{w}{4}\right)\left(\frac{\mu_0}{\mu_0+\mu}\right)\left[(p(g)+H(\mu_0)H(\mu)-1\right]$$

$$p(g) = \frac{(1-b^2)}{\left[1+b^2+2b\cos(g)\right]^{3/2}}$$

$$H(\mu) \sim \frac{1+2\mu}{1+2\sqrt{1-w}\,\mu}$$

Fig. 4. Hapke equation for radiance factor (rf) and 1-term Henyey-Greenstein phase function, p(g). g=phase angle, w=single scattering albedo, H=multiple scattering function, μ_0=cos(incidence angle), μ=cos(emergence angle), b=asymmetry parameter [2].

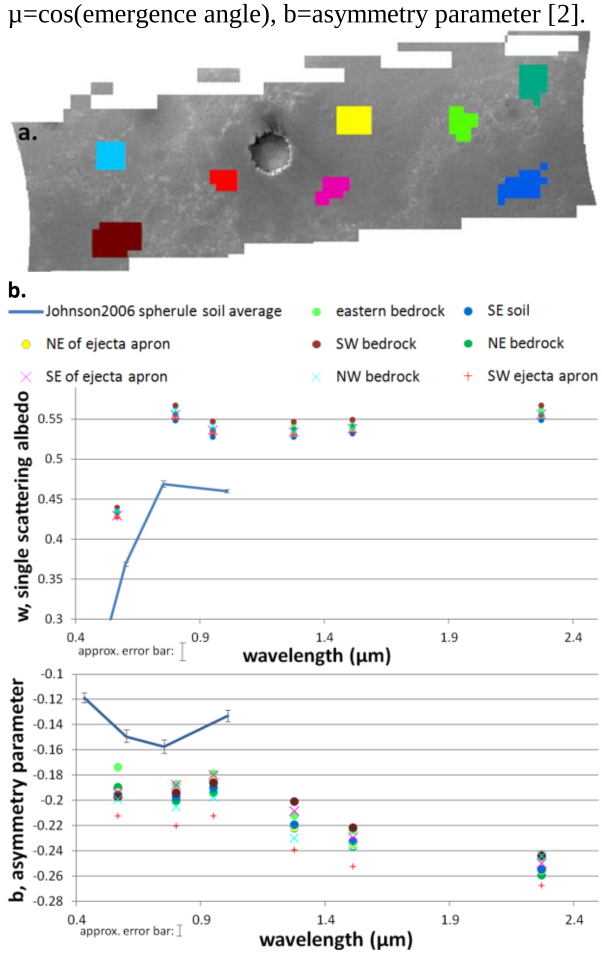

Fig. 5. a. Regions from which spectra were taken. **b.** *w*- and *b*-spectra. See text for comments. Blue curves are near-surface results from [3].