GLOBAL STUDY OF SMALL-SCALE COLOR FEATURES ON 433 EROS, THE EFFECT OF RESIDUAL SCATTERED LIGHT AND IMPLICATIONS FOR PONDED DEPOSIT FORMATION MECHANISMS.

M. A. Riner[1], J. M. Eckart[1], J. G. Digilio[1] and M. S. Robinson[1], [1]Center for Planetary Sciences, Northwestern University, 1850 Campus Dr., Evanston, IL 60208

Introduction: Utilizing all viable MSI color image sequences, we cataloged every resolvable spectral/albedo unit on Eros: high reflectance streaks, dark soils, ponded deposits and average regolith. This complete catalog increases our understanding of regolith processes on Eros and provides additional constraints on understanding the significance of compositional and maturity variations on airless silicate bodies. A new detailed analysis of residual scattered light is presented and used to constrain interpretations of the spectral ratios. The nature of the residual scattered light indicates that we are unable to obtain a pure uncontaminated spectrum of ponded material.

Background: The NEAR Shoemaker spacecraft orbited 433 Eros, a Near Earth Asteroid in 2000-2001. Earth-based telescopic spectra indicated, and the NEAR Infrared Spectrometer (NIS) confirmed, that Eros is composed of mafic silicates, olivine $(Mg,Fe)_2SiO_4$ and pyroxene $(Mg,Fe,Ca)_2Si_2O_6$ [1,2].

Four types of albedo/spectral features have been identified in previous studies (Figure 1). High reflectance streaks are high albedo streaks found on steep slopes. Dark soils are low albedo deposits found in topographic lows and frequently associated with white streaks. Ponded deposits are flat, smooth deposits that infill topographic lows normal to local gravity. Average Eros is typical regolith.

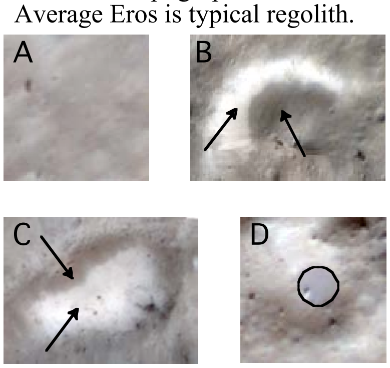

Figure 1 - A: average regolith, B and C: high reflectance streaks with dark soil, D: ponded deposit. (A: from 2001 day 16, 0.78 degrees wide, B: from 2000 day 248, 8.4 degrees wide, C: from 200 day 223, 16.1 degrees wide, D: from 2001 day 16, 0.78 pixels wide.

Methods: All multispectral image sequences of Eros acquired with the NEAR Shoemaker MultiSpectral Imager (MSI) were radiometrically corrected, deblurred [3], photometrically corrected and mosaicked. These images were examined to produce an exhaustive catalog of all color features covered by the MSI multispectral images. There are data for 137 high reflectance streaks, 66 dark soils, 123 average areas, and 66 ponds. Since the resolution of the topography model is coarser than the size of the features studied, we normalize the data for each feature to the average regolith in the same image to reduce photometric errors due to local unresolved topography.

Data: The 950nm/760nm ratio is a proxy for the depth of the 1-micron ferrous iron absorption feature and the 550nm/760nm ratio is a proxy for the visible spectral slope. Dark soils, high reflectance streaks, and average regolith fall on a mixing line (R-value 0.82). Ponds are "bluer" (meaning they higher 550nm/760nm ratios) than white streaks but have similar 1-micron absorption band depths.

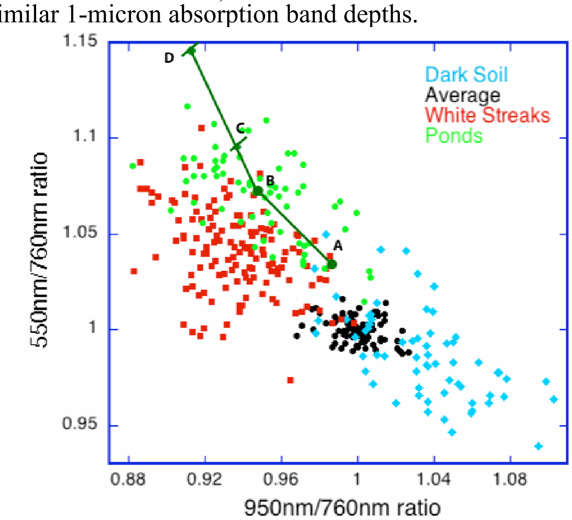

Figure 2 - Color ratio correlation for albedo/spectral features. Each feature has been normalized to average regolith in the same mosaic. The green lines indicate the expected motion of color ratios as a function of degree of scattered light removal. A: measured pond value before deblurring, B: representative pond after deblurring (but with the observed residual scattered light), C and D: minimum and maximum expected change in pond color ratios if residual scattered light were removed.

MSI Scattered Light: During a failed spacecraft maneuver, fuel by-products were deposited on the lens of the multispectral imager (MSI) resulting in wavelength-dependent degradation of the images. A fast Fourier transform based image restoration technique was developed to recover spatial resolution and preserve radiometric accuracy [3]. The efficiency of the restoration varies with wavelength. Figure 2 shows the movement (A to B) of a typical ponded deposit in the color ratio plot after initial restoration.

Profiles across the bright asteroid limb into space from calibrated and deblurred images show measurable residual scattered light. A representative limb profile is computed from the median of seven limb profiles normalized to the first pixel (the first pixel off the limb in space). Approximate point spread functions (PSF) representing the residual scattered light in 550nm, 760nm and 950nm bands are computed by rotating the median profile for each filter (Figure 3). Values are set to zero at an empirically determined distance from the center for each filter (the point at which we assumed noise dominates over signal). We modeled the effect of residual scattered light with the wavelength dependent residual PSFs with an idealized image and found that bright features will become redder, and dark features bluer if the residual scattered light were removed.

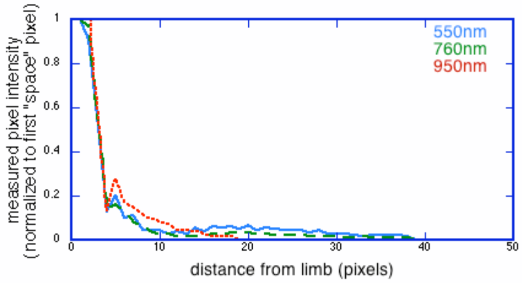

Figure 3 – Composite profile of median pixel intensity values in space moving away from the bright asteroid limb. If the deblurring process was 100% efficient there would be no energy in space, thus the residual can serve as a measure of error in the derived spectral parameters.

Using the limb profile derived PSF we modeled relative changes in pond reflectance at 550nm, 760nm, and 950nm that would produce a typical pond to determine the direction of the change. We constrained the magnitude of the change based on a ratio of energy seen just off the limb of the asteroid before and after deblurring. The minimum and maximum values of the magnitude of the motion in the ratio plot (Fig. 2) are shown in Table 1 as percentages relative to the magnitude of the original ratio change after initial deblurring.

Wavelength	Minimum	Maximum
550	33%	100%
760	10%	33%
950	10%	33%

Table 1 - Bounds on the magnitude of motion (Fig. 2) along A-C (minimum) and A-D (maximum) expected if a residual scattered light correction were applied, reported as a percentage of the motion from the original correction A-B (Fig 2).

Discussion: Dark soils, average regolith and high reflectance streaks fall on a mixing line consistent with varying concentrations of mature materials. Removing the residual scattered light would further separate the spectral ratios thus increasing separation along the mixing line. The positions of the ponded deposits on the spectral plot are not entirely consistent with this maturity mixing line hypothesis [4,5]. Ponded deposits appear to be a spectral end member in their own right, suggesting differences in grain size or composition in addition to or instead of maturity.

Maturity describes the degree of alteration due to surface exposure, including comminution, impact melt glass production (including agglutinates), vapor deposited coatings and reduction of ferrous iron to iron metal [ref]. Increasing maturity causes a decrease in the 1-micron absorption band and a decrease redness. Here, composition effects are considered as variations from a four component composition model - pyroxene, olivine, plagioclase (small amounts) and chondritic iron (iron metal native to the asteroid, not produced by space weathering). Olivine and pyroxene have deeper 1-micron absorption bands and redder continuum slopes than plagioclase and chondritic iron. An decrease in chondritic iron (or plagioclase) is equivalent to increasing olivine and pyroxene. Comminution of mafic silicate minerals below ~50 microns results in decreasing redness [6]. For transparent or weakly absorbing minerals decreasing grain size decreases absorption and we expect the depth of the 1-micron band to decrease [6]. Thus ponds could be spectrally distinct because of some combination of decreasing grain size; depletion of chondritic iron, or maturity but the spectral characteristics of ponds cannot be explained by any of these alone.

Conclusions: The increased separation along the mixing line (i.e. an effective increase in spectral contrast) that would result from a complete correction of scattered light does not alter the previously proposed hypothesis [4,5] that high reflectance soils, average materials, and dark soils represent a range of maturation states, and not compositional units.

The ponded deposits do not fall on the maturity mixing line. The color ratios of ponded deposits are consistent with ponded material being less mature and composed of smaller grain sizes (<<50microns), or being depleted in native iron metal (or enriched in olivine and pyroxene) or some combination of these two possibilities. After accounting for residual scattered light, the spectral signature of ponded material is still consistent with formation by electrostatic levitation [4,5,7] but does not rule out formation by seismic shaking [4,5,8].

We are unable to obtain a pure uncontaminated spectrum of ponded material because the largest deposit (in terms of pixel diameter) is smaller than the residual scattered light footprint. The residual scattered light tends to suppress the true spectral contrast of the ponded material with its surroundings. Accounting for residual scattered light will further separate the ponds from the maturity mixing line demanding an additional alteration mechanism.

References: [1] Murchie S.L. and Pieters C.M. (1996) *JGR 101* (**E1**) 2201-2214. [2] McFadden L.A. et al. (2001) *Meteoritic & Planet. Sci. 36* (**12**) 1711-1726. [3] Li H. et al. (2002) *Icarus 155* (**1**) 244-252. [4] Robinson M.S. et al. (2001) *Nature 413* (**6854**) 396-400. [5] Robinson M.S. et al. (2002) *Meteoritics & Planet. Sci.,37* (**12**) 1651-1684. [6] Adams J.B. and Felice L.A. (1967) *JGR 72* 5705-5715. [7] Cheng A.F. et al. (2002) *Meteoritics & Planet. Sci.,37* (**8**) 1095-1105. [8] Colwell J.E. et al. (2005) *Icarus 175* (**1**) 159-169.