INVESTIGATION OF EROS POND PROPERTIES UTILIZING PHASE-RATIO IMAGE ANALYSIS.
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Introduction: The Near Earth Asteroid Rendezvous (NEAR) – Shoemaker mission performed an orbital investigation of the near-Earth asteroid 433 Eros from 2000-2001 [1] returning images with a variety of landforms indicative of widespread coverage by fragmental debris [2, 3]. Among these landforms are exceptionally smooth, flat deposits known as “ponds” [e.g. 3, 4]. Data from the Multi-Spectral Imager (MSI) indicates that ponds are bluer in color than surrounding material, suggesting a fine-grained nature [3]. This interpretation is further supported by descent images suggesting the ponds are smooth down to image scales of 1.2 cm/pixel [3].

Multiple hypotheses for pond formation have been put forth, including electrostatic transport of fine-grained dust [3], granular fluidization and sorting of regolith by seismic shaking [4], erosion of boulders trapped in pre-existing depressions [5], and fluidization of regolith in response to volatile outgassing [6]. Here, we use monochrome image pairs of the ponds to generate phase-ratio images as a means of investigating the surface texture and/or particle sizes of the ponds, and subsequently the pond formation mechanism.

Ponds on Eros:

Formation mechanisms. The hypotheses for pond formation on Eros involve starkly different mechanisms, which should produce different particle size distributions. The electrostatic levitation hypothesis [3] posits the levitation and deposition of the finest fraction of dust into topographic lows, and should result in a uniform deposit with finer grain sizes than the average surrounding regolith.

In contrast, the seismic shaking hypothesis [4] involves shaking and granular fluidized movement of the in situ regolith, such that ponds emplaced by this mechanism have a distribution of particles shifted to larger sizes.

Dombard et al. [2010] [5] proposed a new hypothesis to explain the association between boulders and ponds. They suggested that ponds are formed by the thermal disaggregation of boulder material that is subsequently flattened by seismic shaking. This mechanism would predict the presence of larger particle sizes within large ponds where boulders are present; although small ponds where the boulder has presumably already eroded would be indistinguishable from small ponds formed solely by regolith fluidization and seismic shaking [4].

The final formation hypothesis suggests fluidization of regolith and filling of a depression with finest-fraction grains in response to a release of volatile gases from depth [6, 7, 8]. Similar to the electrostatic levitation hypothesis, this mechanism results in a pond surface dominated by the finest grain fraction. However, there is, as yet, no evidence for the presence of either endogenic or exogenic water to serve as a source for the volatile outgassing [6].

We employ phase-ratio image analysis to explore the properties of Eros ponds, seeking evidence for subtle differences in the particle size distribution.

Phase Ratio Image Analysis:

Method. The reflectance of a surface is a function of the illumination incidence (i), observing (emergence) angle (e), and the phase angle (g), which is the angle between i and e [e.g. 9]. The brightness of a given surface has been observed to change as a function of phase angle, and these changes are related to surface properties such as albedo, surface roughness, particle size, and particle scattering characteristics [e.g. 9]. Phase-ratio image analysis exploits the phase dependent reflectance of the surface to highlight locations where the phase function diverges from the background, e.g., places with a contrasting particle-size distribution [10]. This technique has been used to identify differences in regolith texture in many locations on the Moon using telescopic images [11], Clementine [12] and Lunar Reconnaissance Orbiter Camera images [13, 14, 15, 16, 17], and on Mercury using Mercury Dual Imaging System images [10].

Using the database of 344 Eros Ponds [Roberts, personal communication], we searched for NEAR MSI images of the ponds using the Small Body Mapping Tool (SBMT) [18]. We then selected pairs of images for each pond that have similar incidence angles, but different phase angles. These image pairs were then co-registered and output as an image cube (Fig. 1A, B). A phase-ratio image (Fig. 1C) was generated by dividing the image with the smaller phase angle by the image with the larger phase. In this configuration, lower phase-ratio values correspond to a phase curve with shallower slope, consistent with a smoother surface or finer particles.

Results. We have identified image pairs for 52 ponds with phase angle differences suitable for analysis. We are in the process of generating phase ratio images for these image pairs. Our initial analyses indicate that ponds are distinct and identifiable in
phase ratio images (compare Fig. 1B to 1C). The ponds appear to have slightly lower phase ratio values than the immediate surrounding terrain, indicative of a smoother surface or finer particle sizes. However, we also observe that the pond phase-ratio values are not unique to the pond, and can be observed in other parts of the scene. This might suggest that, although the pond regolith has a finer particle size than the nearby surroundings, it is not an anomalous collection of fine grained material, as might be predicted by the electrostatic levitation hypothesis [3] or the fluidized gas venting hypothesis [6]. Instead, this preliminary observation is most consistent with the granular fluidization and seismic shaking hypothesis [4].

However, we note the large phase angles of the images (~70° - 100°). At these angles, the slope of the phase curve is generally shallow. Therefore, the phase-ratio images may show little contrast, regardless the presence of extreme differences in surface properties.

**Future Work:** Our initial analysis indicates that phase-ratio analysis is a viable method for examining particle sizes and surface textures for ponds on Eros. Thus far, observations are consistent with ponds containing smoother/finer-grained material than the immediate terrain that bounds the ponds.

We are continuing our analysis of pond image pairs to see if our preliminary observations are consistent across a wider variety of pond locations and phase ratio differences. We are also focusing on differences between ponds hosting boulders and non-boulder ponds, as well as equatorial ponds and those at higher latitudes.

**References:**


**Figures:**

Figure 1: A) Two MSI images used to generate a phase ratio image for Pond #35. The images are 135096055F4 and 140257182F4, with phase angles of 75.22° and 81.92°, respectively. B) Red box indicates the location of Pond 37, image 140257182F4, pond diameter ~120 m. C) Phase ratio image of pond 37, red box indicating pond location. Darker tones correspond to lower values of the phase ratio. The image scene in B and C are approximately 1 km in width.