NOT ALL PONDS ARE FLAT: A STEREOPHOTOCLINOMETRIC ANALYSIS OF EROS TOPOGRAPHY. James H. Roberts[1], Olivier S. Barnouin[1], Louise M. Prockter[1], Eliezer G. Kahn[1], Robert W. Gaskell[2], [1]*Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 (James.Roberts@jhuapl.edu)*, [2]*Planetary Science Institute, Altadena, CA, 91001.*

Introduction: Asteroid 433 Eros possesses over 300 "ponds". These flat, smooth deposits typically lie at the bottoms of craters or other topographic lows. They are usually easy to distinguish from the surrounding terrain (see e.g., Figure 1), and are often slightly bluer in color [1,2]. When emplaced on a local slope, the ponds are commonly located downslope of the geometric center of the depression in which they lie, and their surfaces appear to lie on a geopotential [2]. The pond deposits appear to be composed of fine material relative to the surrounding terrain. These ponds are largely concentrated near the equator at the ends of the long-axis of the asteroid [1].

Several mechanisms have been proposed for the origins of ponds. The first is that the ponds are the result of the accumulation of the finest components of regolith by electrostatic levitation [1], transported to and trapped within a bounding depression [3]. A second hypothesis is that the pond material originates from regolith surrounding local depressions. These materials are then transported to and sequestered in the bottoms of depressions by seismic shaking caused by impacts elsewhere on Eros [2]. The third hypothesis is that many of the ponds could be the result of disaggregating boulders commonly observed in their midst, broken up either by micrometeorites or thermal cracking [4]. In both the first and third cases, subsequent seismic shaking is anticipated [1,4] in order to distribute the pond material onto an equipotential.

Here, we further investigate the topography of ponds on Eros using a new shape model derived from sterophotoclinometric analysis (SPC) [5], in order to evaluate the various hypotheses for the formation and emplacement of pond material.

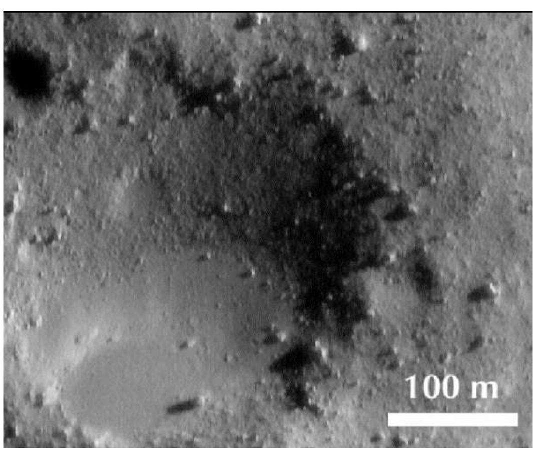

Figure 1: An example of a pond (lower left) in a depression.

Topographic Analysis: We use a high resolution shape model [5] for Eros derived using SPC topography. Key strengths of SPC are that it can make use of images with a variety of illuminations, viewing geometries, and resolutions, and that the resolution of the topography in any given region is nearly as good as that of the best images used [5]. An accurate shape model is critically important for topographic analyses, because the irregular shape of the asteroid results in a highly non-intuitive distribution of slopes.

We took from [6] the locations and sizes of 334 ponds, referenced to the shape model determined using stereogrammetry, archived in the PDS shortly after the NEAR mission. We identified a subset of 55 ponds that appear in images that have been registered to the SPC shape model [5], and have updated the locations of these ponds on the new shape model. For each of these, we have examined the SPC topography along transects through the center of each pond. Figure 2 shows the locations of two such ponds superimposed on an Multispectral Imager (MSI) image which has been projected onto the shape model using the APL Small Body Mapping Tool [7].

We find that the floors of many ponds do not appear be flat (note that "flat" does not necessarily imply "level"). That is, there is no obvious break in slope between the crater wall and floor. The topography through Ponds 53 and 80 are shown in Figures 3 and 4, respectively. Pond 53 appears to be flat; pond 80 is more bowl-shaped.

Of the 55 ponds we examined, we find that only 12 have clearly flat floors in the SPC topography. 21 of the ponds do not have flat floors. A further 17 ponds appear to be flat in one direction only (usually east-west) and curved in the other. We have failed to identify the remaining five ponds as clear topographic depressions. We found no correlation with geographic location with respect to which ponds have or do not have flat floors in the SPC topography.

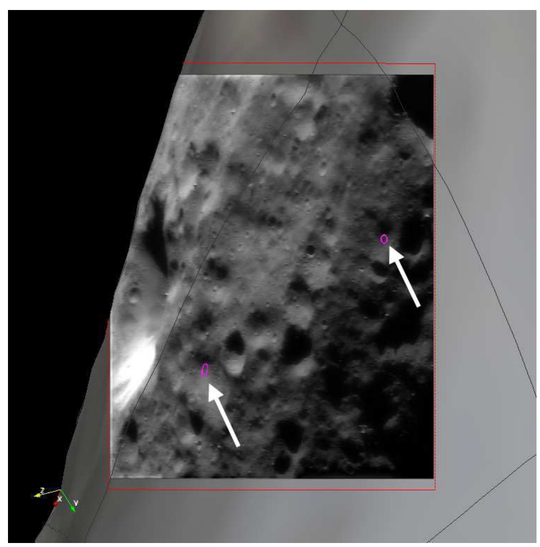

Figure 2: Ponds 52 (right) and 53 (lower left) superimposed on MSI image 136814364 projected onto the Gaskell shape model of Eros. Ponds are outlined in magneta, and indicated by arrows. Note that because the image is located on a limb, the ponds are tilted away from the camera somewhat.

Altimetry: The disagreement noted here between the flatness of ponds in the SPC topography and that determined through stereogrammetry [1] points to the need to tie our SPC

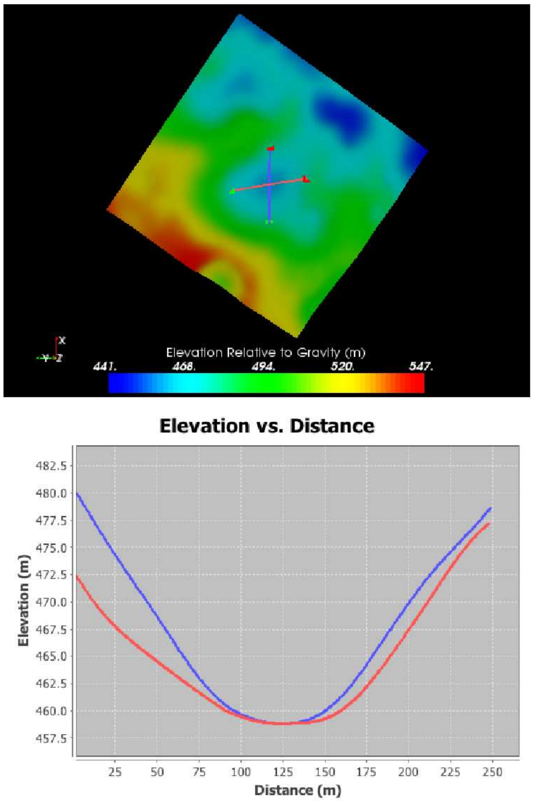

Figure 3: An example of a pond with a flat-floor. Top: Map of Pond 53 showing elevation with respect to gravity, shown with two transects across the pond. Bottom: Elevation along the two transects shown in the map view.

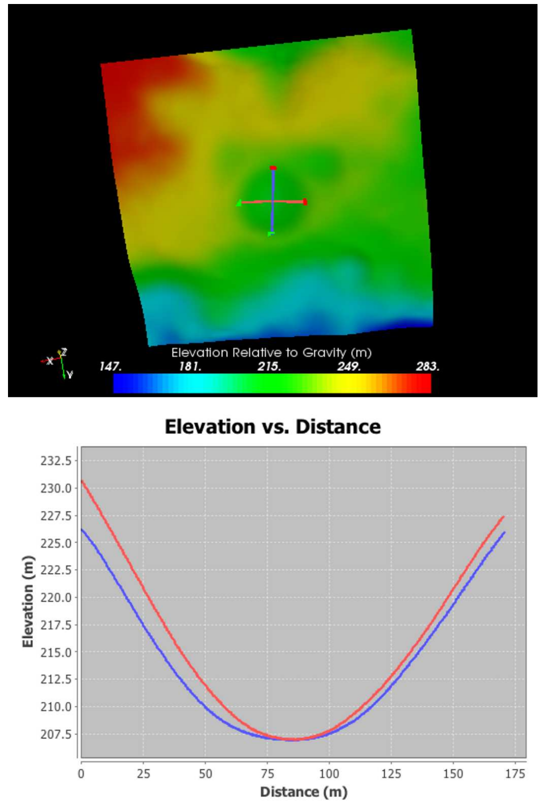

Figure 4: An example of a pond without a flat floor. Top: Map of Pond 80 showing elevation with respect to gravity, shown with two transects across the pond. Bottom: Elevation along the two transects shown in the map view.

topography to an independent dataset. The most accurate Eros topography measurements are those made by the NEAR Laser Rangefinder (NLR). Although accurate, altimetry has poorer coverage than the topography generated by either of the imaging techniques. We have identified only a few ponds containing NLR tracks as did Dombard [4], and Cheng [2] noted only one pond with multiple tracks. However, while few ponds contain NLR tracks, the NLR data elsewhere can be used as additional constraints for the SPC topography and improve the fidelity of the shape model.

Even when NLR tracks cross ponds, the data do not necessarily match the shape model. While the data within a given track are extremely accurate with respect to each other [2,4], the entire track may be offset from its actual location, due to uncertainties in spacecraft pointing, sometimes by as much 100m. Correcting for such offset errors using a manual approach (e.g., [8]), indicate that the SPC topography closely matches the NLR topography to within a few m [9], although a more detailed comparison is required.

Discussion: Of the subset of ponds identified by [1 and 6] that we have examined, we find that only $\sim 25\%$ have clearly flat floors in SPC topography. We do not necessarily consider these a separate class of features, as the flatness is not the only distinguishing characteristic of the ponds; they are also fine-grained and clearly delineated.

However, if flatness is not universal, we can re-examine the existing hypotheses for the origin of pond material. Electrostatic levitation of fine regolith [1] remains plausible; however the material may adhere to the slopes of the depressions. We note that seismic shaking subsequent to formation is not required if the ponds are not flat. Seismic shaking [2] may occur, but need not occur to such a degree as to bring the material to an equiponential. We have not noted any correlation between pond flatness and presence of a central boulder. The presence of pond material following the topography within bowl-shaped craters would support an external source rather than a central one. Erosion of a boulder [4] within a depression should lead to a more obvious break in slope within the craters than we currently observe. However errors in the SPC approach might be hiding such breaks and need to be carefully evaluated. Furthemore, there is convincing experimental evidence that boulders could be disaggregating by thermal processes [10].

References: [1] Robinson, M. S. et al. (2001), *Nature* 413, 396-401. [2] Cheng, A. F. et al. (2002), *M&PS* 37, 1095-1105. [3] Hughes, A. L. H. et al. (2006), *Icarus* 195, 630-648. [4] Dombard, A. J. et al. (2010), *Icarus* 210, 713-721. [5] Gaskell, R. W. et al. (2008), *M&PS* 43, 1049-1061. [6] Thomas, P. C. (2002) et al., *Icarus* 155, 18-37. [7] Kahn, E. G. et al. (2010), *LPSC* 42, 1618. [8] Cheng, A.F. et al. (2002). *Icarus* 155, 51-74. [9] Ernst, C. M. et al. (2012), *LPSC* 43, this mtg. [10] Delbo, M. et al. (2011), *EPSC-DPS Joint Meeting* 522.