HIGHEST RESOLUTION TOPOGRAPHY OF 433 EROS AND IMPLICATIONS FOR MUSES-C.
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The highest resolution observations of surface morphology and topography at asteroid 433 Eros were obtained by the Near Earth Asteroid Rendezvous (NEAR) Shoemaker spacecraft on 12 February 2001, as it landed within a ponded deposit on Eros [1,3,4]. Coordinated observations were obtained by the imager and the laser rangefinder [2], at best image resolution of 1 cm/pixel and best topographic resolution of 0.4 m. The NEAR landing datasets provide unique information on rock size and height distributions and regolith processes. Rocks and soil can be distinguished photometrically, suggesting that bare rock is indeed exposed. The NEAR landing data are the only data at sufficient resolution to be relevant to hazard assessment on future landed missions to asteroids, such as the MUSES-C mission which will land on asteroid 25143 (1998 SF36) in order to obtain samples. In a typical region just outside the pond where NEAR landed, the areal coverage by resolved positive topographic features is 18%. At least one topographic feature in the vicinity of the NEAR landing site would have been hazardous for a spacecraft.

The principal science objectives of the NEAR Shoemaker landing on Eros were to measure surface features at the highest possible resolution, exceeding by an order of magnitude that achieved in previous low-altitude flyovers of Eros [e.g., 2,5]. During the descent, the images were acquired at intervals that alternated between 20 and 45 seconds. These images were buffered and returned in real time and were not stored onboard for later downlink, because it was not known if the spacecraft would survive contact with the surface. The laser rangefinder was boresighted with the imager and measured ranges to the surface twice per second throughout the descent.

Fig.1 shows the last four images returned by NEAR Shoemaker with the laser boresight positions marked at the times the images were acquired. The laser boresight was determined by correlating orbital imaging and altimetric data and was assigned to image line = 220 and sample = 260 [6]. The boresight spots are connected with lines to approximate the laser track, although the laser boresight actually interpolated between the spots in an irregular manner because spacecraft thrusters were firing throughout the time interval shown.

The measured laser ranges were combined with the spacecraft trajectory and pointing data to determine the Eros latitude, longitude, and radius (distance from the center) of the laser spots, using the standard NEAR laser rangefinder processing [7]. These spot locations were reduced to elevation relative to a geoid (at constant gravitational and centrifugal potential) by the methods used in [6] and [2]. However, the resulting

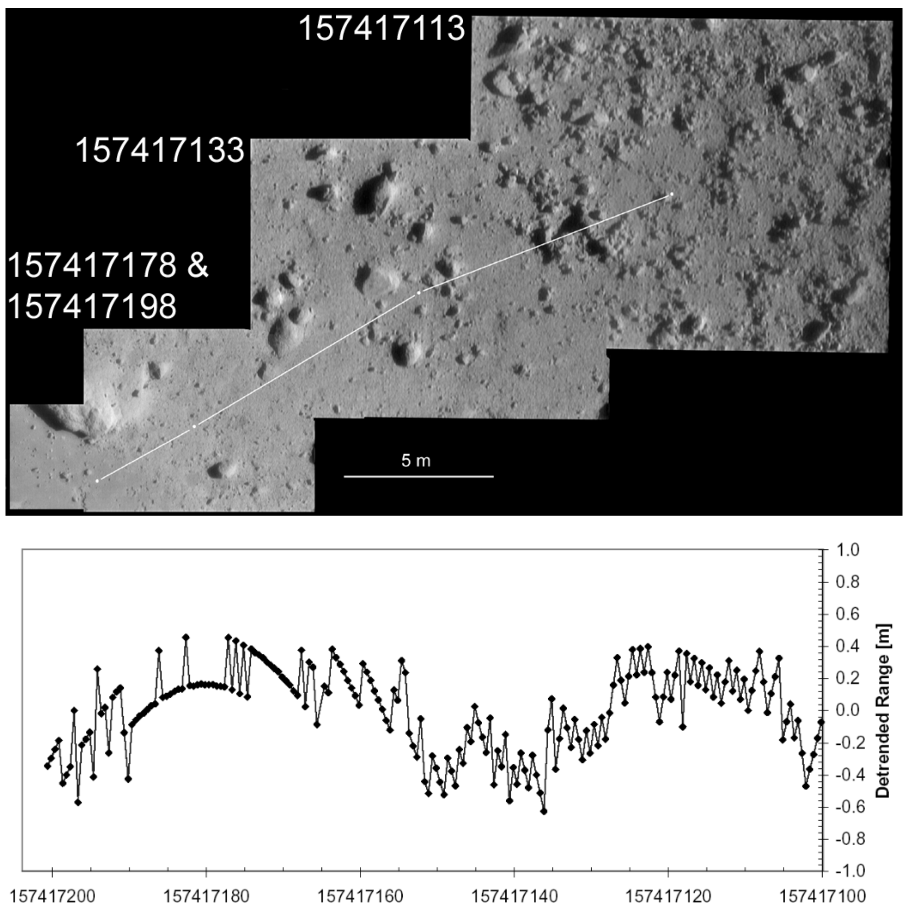

Fig 1 Last four images from NEAR Shoemaker, with laser spots marked and connected with white lines. Last spot is within a pond [1], at altitude 119 m. Mission elapsed times (MET) shown for each image. (Lower panel) Quadratically detrended range versus MET (increasing to left).

elevation profile was not satisfactory, because the distance scale along the mean local surface was not consistent with the image scale. The mean local surface from a global shape model [7] was inclined to the boresight by ~20° so there is minimal foreshortening of the images (as is also evident from visual examination). Hence the image scale of Fig 1 correctly estimates the distance between the first and last of the four laser spots as ~25 m, whereas the standard laser data processing produced a distance of 87 m. This discrepancy could be explained by an error of <0.8 m/s in the spacecraft velocity component along the surface (well within the uncertainty).

The elevation profile from the standard laser data processing yielded a total decrease in elevation of only 3 m over the track of Fig. 1. Although this decrease in elevation from the RHS of Fig. 1 to the pond in the LHS is consistent with other evidence that ponds are located in gravitational lows, when the spacecraft trajectory error is considered, any elevation change can only be constrained to be <3m in magnitude [8]. The track is close to level, but the pond cannot be confirmed to be at the lowest elevation. This assessment is supported by the lower panel of Fig. 1, which shows the measured ranges after removal of a quadratic trend: the residuals are 0±0.5 m over the entire track. The pond boundary, identified as a textural contact in the images [1], cannot be identified in the detrended range profile (it was crossed at MET~157417186). The laser sampled a boulder of height <0.5m (close to the resolution limit) near MET 157417145 and another set of features near MET 157417125 which may be associated with a cluster of boulders in Fig. 1.

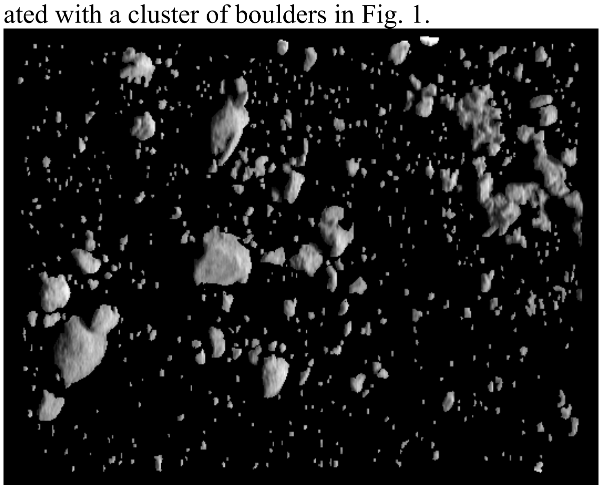

Fig. 2 Synthetic image constructed of 'rock' pixels from image at MET 157417133 (second of the four frames in Fig. 1) placed on a black background. Imaged region is 12.7 m across, resolution 2.4 cm/px.

The image at MET 157417133 was analyzed to identify areas as 'rock', shadowed, and regolith. Positive relief features were assigned as rock, using shadows (at solar incidence angle 62.5° from a global shape model) and morphology, provided that they extended at least three pixels. Separations of rock from regolith were performed independently by each author, with results consistent within 1% (see Fig. 2).

The rock pixels in Fig. 2 comprised 18% of the total pixels exclusive of shadows. This is also the probability that a randomly selected point in the region shown in Fig. 2, for landing or for sampling, will strike rock. Analysis of shadow heights in this region also shows that the boulders are typically equant, i.e., heights are similar to extent in the image plane. Based upon these analyses, the topography in this region is generally within 1 m, but not always so. Fig. 3 is an image obtained just prior to the four images of Fig. 1, and a boulder >3 m high is discerned. This boulder would have been hazardous for a spacecraft landing. The height of this boulder was estimated from shadow length; the cloddy boulder just to its right in Fig. 3 was sampled by the laser and has ~1 m topography.

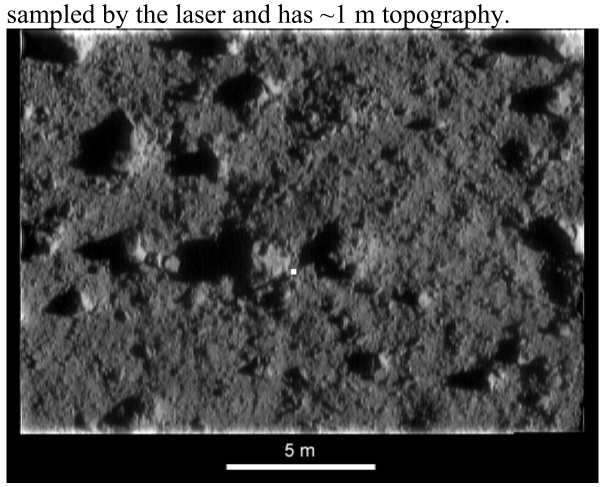

Fig. 3 Image at 388 m altitude at 3.7 cm/px, white dot marking the laser boresight. The boulder just left of the spot is >3 m high, but the boulder to the right, of similar extent in the image, is 1 m high from laser data.

Also of interest from the analyses of Fig. 2 is a comparison of photometric properties of rock pixels and regolith pixels (shadows larger than ~3 cm excluded). Although the median brightnesses of rock and regolith were the same within 2%, the rock was much more contrasty: the standard deviation of rock brightnesses was 40% of the mean, versus 16% of the mean for regolith. This photometric difference suggests a textural difference, at few cm-scales or less, between areas identified as rock versus regolith. This work was supported by NASA and the MUSES-C Project.

References:[1] Veverka et al. (2001) *Nature*, **413**, 390-393; [2] Cheng et al. (2001) *Science* **292**, 488-491; [3] Cheng et al. (2002) *Meteoritics and Planetary Science* **37,** 1095-1106; [4] Robinson et al. (2001) *Nature* **413**, 396-400; [5] Veverka et al. (2001) *Science* **292**, 484-488; [6] Cheng et al. (2002) *Icarus*, **155**, 51-74; [7] Zuber et al. (2000) *Science,* **289**, 2097-2101. [8] Cheng and Barnouin-Jha in preparation.