RESTORATION OF THE TRITON VOYAGER 2 IMAGING DATA IN SUPPORT OF GEOLOGIC MAPPING.

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Overview: Images returned by NASA's Voyager 2 spacecraft in 1989 revealed Neptune's largest moon Triton to be enigmatic. The moon's now-recognized status as a captured Kuiper Belt Object (KBO) [1, 2], the subsequent discovery of numerous other large trans-Neptunian objects [3], and NASA's New Horizon flyby of Pluto (also a KBO) [4], have provided new context and a new impetus for understanding Triton's surface. To enable this understanding, we are improving the usability of the Voyager 2 Triton data and creating a new USGS geologic map of Triton [5]. Here we describe our effort to improve data usability by archiving calibrated and cleaned images of Triton with improved image locations (updated Spacecraft, Planet, Instrument, C-matrix (pointing), and Events – SPICE – C kernels).

Triton: Triton's surface is sparsely cratered [6] and consists of terrain morphologies largely unknown elsewhere in the solar system, including the so-called cantaloupe terrain, extremely smooth plains, dark spots, and double ridges an order of magnitude larger than those observed on Europa [see, e.g., 7]. Active plumes erupt dark material onto the surface [8] and indicate "winds" in Triton's thin atmosphere [9]. Triton's unique surface may result from tidal heating during its capture into a retrograde orbit [e.g., 10]; however, similarities to Pluto [4] suggest its surface may be somewhat typical of large KBOs. Reassessing Triton's unique geology requires revisiting the Voyager 2 Triton data, a small but challenging dataset.

Improving data usability: Voyager 2 returned 43 images of Triton with a pixel scale of less than 2 km/pixel (useful for geologic analysis). These images currently require a significant amount of technical overhead to use. The data suffers from two primary challenges: poor image quality, and poor relative image location. Although a "global" image mosaic is publicly available, it does not include all of the image data, and image resolution is degraded in some areas. The goal of this work is to improve the original Voyager 2 images themselves, and thus provide the community with a dataset that is substantially easier to use.

Image Quality: Many of the Triton images include line-drops (lines of NULL pixels) and noise, and all include corner markers and camera reseaux, which were integrated into the Voyager Imaging Science System (Fig. 1). Several images also suffer from substantial camera blur. Each of these problems can be corrected to some degree. We use the Integrated Software for Imagers and Spectrometers (ISIS3) [11] to process 41 Triton images to a radiometrically calibrated, "clean" level 1 state. To do so, we first ingest the data, add reconstructed SPICE kernels, and perform the standard Voyager 2 radiometric calibration. We then use ISIS's standard tools to identify and replace reseaux marks with NULL pixels. We then apply a series of small-window (typically 3x3) lowpass filters on the NULL pixels to "fill in" the data gaps. Noise filtering is applied when necessary, which uses an averaging box car filter to remove bad pixels. Finally, masking is used to replace corner marks by NULLs, and these are again filled in with a lowpass filter. Image blur remains a problem on some images, and reducing or removing it remains for future work. Figure 1 provides an example of an image before and after our processing is complete.

Image locations: The relative location of images on Triton's surface are inaccurate by as much as 300 km. Using sets of individual images (i.e., rather than the global mosaic) is therefore impossible unless the user has the technical ability to control the data (Fig. 2). To improve image locations we created a photogrammetric tie point network and performed a least square bundle adjustment [12] to update the image pointing.

We experimented with multiple approaches to network development, starting with a dense, feature-based matching approach. However, Triton's surface morphology and the challenging image geometry (high incidence and emission angles) led to a substantial number of false matches and a poor bundle solution. We therefore adopted an alternative approach that uses an extremely sparse network (402 tie points, and 1470 image measures), and area-based matching. The sparsity of the network permitted us to visually confirm every tie point match. Tie points were manually added for images in which automated matching failed (often due to incorrect a priori overlap information). Bundle adjustment provided an adequate solution to update the image pointing kernels. Image locations are now accurate to within a few kilometers (a few pixels). These updated image locations now enable the construction of a denser tie point network to provide an even more robust global photogrammetric solution. Although work continues, our current solution already enables geologic mappers to utilize the entire Voyager image dataset as an ancillary mapping data.

Data Release: This work will result in the public release of two data products. First, we will archive the calibrated and cleaned versions of the images with updated pointing information. Second, we will archive the updated SPICE kernels themselves. This will enable users to perform their own image processing technique, but retain the updated image location information. Both products will be available in the PDS Annex.

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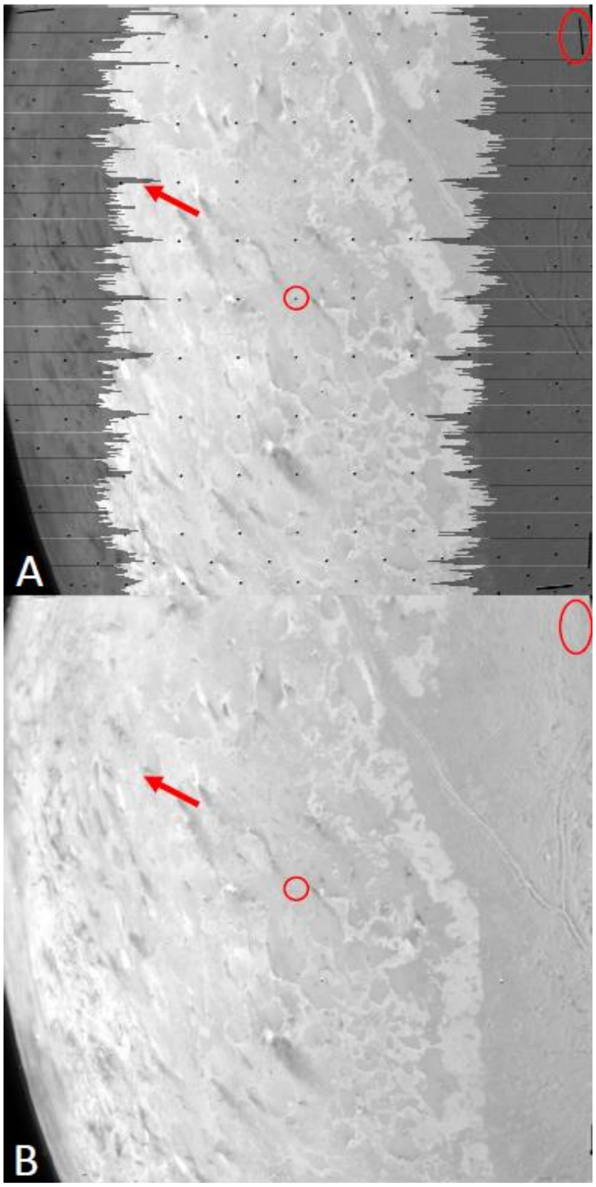

Figure 1: Example of image quality enhancement. The original image (A) is marked by line-drops (red arrow), reseaux marks (red circle), and corner marks (red ellipse), all of which have been removed in the final version (B).

References: [1] McKinnon, W. et al. (1995) in *Neptune and Triton*, U of Arizona Press. [2] Agnor C., Hamilton D. (2006) *Nature* 441, 192-194. [3] Brown, M. (2004) in *The solar system beyond Neptune*, U of Arizona Press. [4] Stern, A. et al. (2015). *Science* 350, aad1815. [5] Martin E. et al. (2018) *Planet. Geo. Map.* #7026. [6] Schenk P., Zahnle K. (2007) *Icarus* 192, 135-149. [7] Croft, S. et al. (1995) in *Neptune and Triton*, U of Arizona Press. [8] Soderblom, L. (1990) *Science* 250, 410-415 [9] Hansen, C. et al. (1990) *Science* 250, 421-424. [10] Ross, M., Schubert, G. (1990) *GRL 17*, 1749-1752. [11] Keszthelyi, L. et al. (2014) *LPSC* 45, #1686. [12] Brown, D. (1958). *RCA Data Reduction Technical Report*, 43.

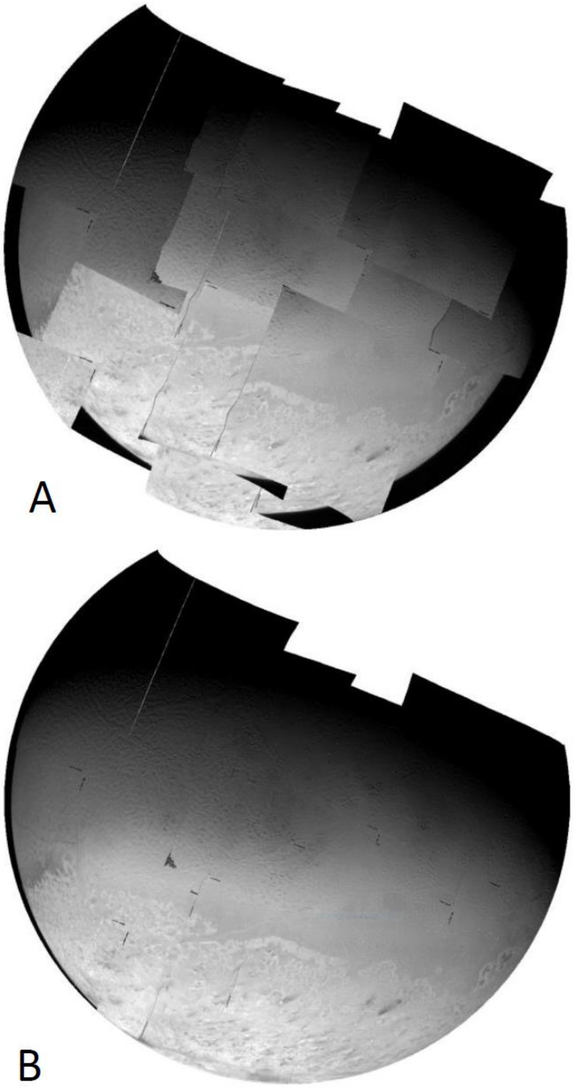

Figure 2: An orthographic mosaic of 16 Voyager 2 images of Triton before (A) and after (B) photogrammetric control. A total of 41 images were included in the bundle solution. Here, image quality improvements are incomplete.