Restoration of Very High Resolution Lunar Orbiter Images Charles J. Byrne[1] and Arlin P. S. Crotts[2], [1]Image Again, charles.byrne@verizon.net, [2]Columbia University, Astrophysics Laboratory, arlin@astro.columbia.edu .

Introduction: Five Lunar Orbiter missions were flown from 1966 through 1967. They covered nearly all of the Moon's surface, with many selected sites at very high resolution. With renewed interest in the Moon, several projects have recovered archival material and converted the images from analog to digital form, making them permanently available for comparison with modern images, using the Moon as a record of activity. This abstract reports on the results of a NASA LASER grant to process archived film strips or 'framelets' that have been scanned and digitized by a USGS Astrogeology team, one of several efforts to produce these images, invaluable because they show the Moon 45 or more years ago. Many of the Lunar Orbiter sites were chosen for scientific interest and have recently been re-imaged by the Lunar Reconnaissance Orbiter and similar probes. The new images are at similar resolution to that of Lunar Orbiter, pixels of less than 1 m^2.

Analysis of changes: We are exploring by manual and automated analysis changes that have occurred between these epochs (Crotts et al., in preparation). These changes might include impacts and in many cases mass wasting. Some sites encompass known episodes of radon outgassing [1, 2] detected in the intervening time interval.

History of digitization projects: A nearly global set of digital images were produced at the Lunar and Planetary institute (LPI) under the direction of Jeff Gillis, now Jeff Gillis-Davis. That project used a digital camera to photograph a set of hard-copy images featured in [3]. These digital images, about 700 by 1000 pixels, were placed online at LPI (http://www.lpi.usra.edu/resources/lunar_orbiter/) and then de-striped and published [4, 5].

The USGS Astrogeology Team under the direction of Lisa Gaddis scanned and digitized a set of framelets, partly from the global coverage set that had been digitized by LPI and partly from a selection of sites that had been photographed at very high resolution (low elevation orbits). These digitized framelets (940 by 16,500 pixels) are available in the Planetary Data System at http://pdsmaps.wr.usgs.gov/PDS/public/lunar_orbiter/LO_Archive.html [6].

Under a recent NASA LASER grant through Columbia University, Arlin Crotts has selected images of scientific interest, and Charles Byrne has written software to process the USGS framelets to reduce a number of geometric and noise artifacts and assembled them into full resolution images (typically 20880 by 15820 pixels). A reduced resolution image of LO5-188M is shown in Fig. 1.

Character of the digitized images: The Lunar Orbiter images digitized at full resolution are very different than the images from a Charged Coupled Device (CCD) as used in today's spacecraft and pocket cameras. For example, the Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC)) takes a swath 5000 pixels wide and up to 50,000 pixels long (250 megapixels total) [7]. A medium resolution Lunar Orbiter frame is 18460 by 15820 pixels (292 megaapixels total) and each of the high resolution subframes is 20880 by 15820 pixels (330 megapixels per subframe and about 990 megapixels per frame).

Mosaic images can be constructed from multiple CCD images, but there are inevitable problems of view angle and photometry as the spacecraft moves and the sun angle shifts. Problems with Lunar Orbiter images include artifacts imposed by scanning the spacecraft negative into framelets, nonlinearity introduced by the Ground Recording Electronics (GRE), and aligning the framelets for assembly. The challenge is to measure and remove these artifacts, to approach the images that would have been achieved by directly producing and digitizing a positive from the spacecraft negatives.

Results: All of the high-quality framelets that were digitized by USGS have been processed for the following sites: V-46 (Harbinger Mountains), V-48 (Aristarchus), V-49 (Cobra Head) and V-50 (Aristarchus Plateau). The results will be contributed to the Lunar Orbiter node of the Planetary Data System. Altogether, about 2,000 framelets have been processed and assembled into 18 medium resolution frames and 48 high resolution subframes.

Figures 2 through 5 show progressively enlarged images of the complex lava flows in the Harbinger Mountains, as an example of the scope and detail of each Lunar Orbiter exposure.

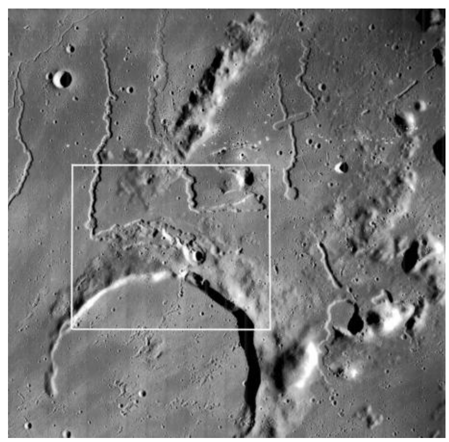

Figure 1: The crater drowned by a massive lava flow is Prinz (46 km) in the Harbinger Mountains (LO5-188M). The meandering rills are the last of a series of lava flows. The rectangular area outlined in white is enlarged in Figure 2.

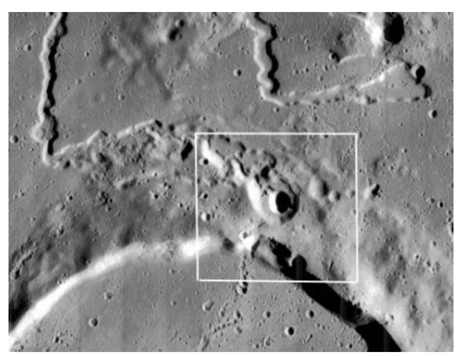

Figure 2: This enlargement of the rim of Prinz shows a caldera, the source of the main flow to the North. The smaller crater is a lesser source of lava that has overflowed the caldera and run to the South, onto the flooded floor of Prinz.

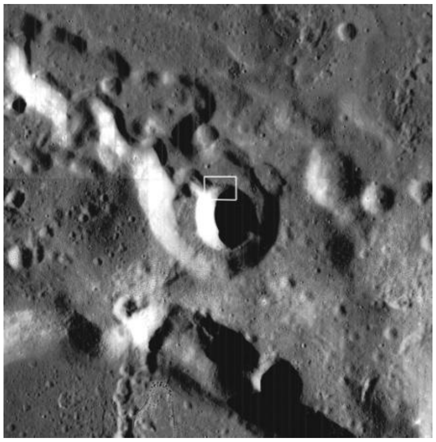

Figure 3: This image, a composite of parts of high resolution images LO5-187H2 and LO5-188H2, shows the detail of the flow from the smaller source crater (1.7 km). In addition to the southern flow, another flow ran along the left bank of the older channel.

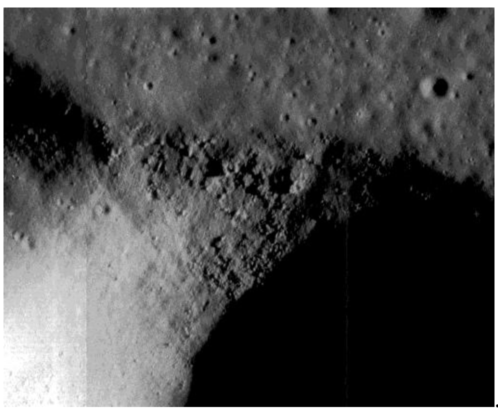

Figure 4: This image, a small part of LO5-187H2, is 920 m wide. It shows detail of the spillway of the northbound lava flow, including boulders on the floor of the spillway. The lower left corner of this image has been over-exposed.

Processing method The spacecraft readout process [3] distorted the geographic shape of the framelets by skewing them in the X and Y directions. Further, the synch recovery process allowed the width of the framelets to vary with image brightness. In the initial photographic system design, linearity patterns and reassembly dashed reference lines were provided to allow measurement and compensation of these effects. In later missions, a pre-exposed geometric pattern of reseau crosses was added to allow measurements to be made on assembled frames. USGS used these reseau crosses to rectify the framelets as well as the frames, a process that worked well for their cartographic purposes, but did not restore the geometric variations at the edges of the framelets, where they fit together.

In the process reported here, the approach was to restore the framelet image areas to precise rectangular shape so they fit well when assembled. This required programmed recognition of the linearity pattern and the dashed lines. Templates were constructed to match the patterns and the digital images were examined for best fit to the marks. The centers of those dashes that were identified were fitted with second-order reference lines. The linearity pattern was used to remove Y skew and align the top edges of the framelets. The left and right dashed lines were used to remove X skew and equalize the width of the image. The number of pixels between the dashed lines was adjusted for the correct aspect ratio. Those dashes that were identified (the great majority) were reduced by interpolation with surrounding pixels,

After rectification, the framelets were filtered to minimize horizontal and vertical patterns induced by the two scanning processes (one in the spacecraft and one in the GRE). This filter also reduced random noise in the area where the two-dimensional spectrum indicated that the high-frequency signal had been reduced in the spacecraft.

The framelets are then trimmed in width so that the image is a fixed width in pixels and the first pixel of each line in a subframe represents the image adjacent to the last pixel of the preceding frame. This width was constant for all frames and subframes processed (all from Mission 5). Assembly is then straightforward: simply put the framelets together in an array, ready for output in an image format.

At this point, the images are geographically seamless but vary systematically in brightness across each framelet because of the brightness signature of the Cathode Ray Tube (CRT) in the spacecraft. The signal from the spacecraft represented this signature multiplied by the optical transmission through the spacecraft negative. Unfortunately, the GRE transfer function is nonlinear, so to remove the CRT signature it is first necessary to estimate the nonlinearity of the GRE and restore the image to linearity with the transmission through the negative. After linearization, the CRT signature was then estimated by averaging across all framelets in the assembled image. The image was then corrected by dividing by the CRT signature, as a function of width across each framelet. This was quite successful as long as the image was within the range of the 9-step gray scale, but not for over-exposed or under-exposed parts of the images (see Figure 4). This should not be a problem with the data digitized from archival magnetic tapes.

Magnetic Tape Project: The NASA Lunar Orbiter Reconstruction Project (LOIRP) [8] under the direction of Dennis Wingo has reconditioned magnetic tape drives that can read the 1478 tapes recorded at the Deep Space Information Facility and stored at JPL. These tapes, although still analog, are free of artifacts induced by the Ground Recording Electronic Equipment, although they retain artifacts of the spacecraft scanning mechanism. This project produces a digitized product with much more dynamic fidelity.

References: [1] Gorenstein, P and Bjorkholm, PJ, Phys. Earth and Planet. Interiors, 14, 289, 1977. [2] Lawson, SL et al., JGR 110, E09009, 2005, summarized in Crotts, APS, ApJ, 687, 692, 2008. [3] Bowker and Hughes, *Lunar Orbiter Photographic Atlas of the Moon*, NASA SP-206, 1971. [4] Byrne, CJ, *Lunar Orbiter Photographic Atlas of the Near Side of the Moon*, Springer, New York, 2005. [5] Byrne, CJ, *The Far Side of the Moon: A Photographic Guide*, Springer, 2008. [6] NASA Dives into its Past to Retrieve Vintage Satellite Data, Science, Vol. 327, March 12, 2010. [7] Bowman-Cisneros, E., and Eliason, E, Lunar Reconnaissance Orbiter, LROC RDR Data Products Software Interface Specification, ASU, 2008. [8] Wingo, DR, Recovering High Resolution Lunar Orbiter Images from Analog Tape, LPSC 2009, Abstract 2517.