UTILIZATION OF DIGITIZED APOLLO AND LUNAR ORBITER IMAGERY FOR MAPPING THE MOON.
M.R. Rosiek[1], B.A. Archinal[1], R.L. Kirk[1], T.L. Becker[1], L. Weller[1], B. Redding[1], E. Howington-Kraus[1], and D. Galuszka[1], [1]U.S. Geological Survey, 2255 N. Gemini Dr, Flagstaff AZ 86001, mrosiek@usgs.gov.

Introduction: We are evaluating the utility of using modern "softcopy" digital mapping techniques for extracting digital elevation models (DEMs) from Lunar Orbiter (LO) and Apollo imagery. This imagery was used in the 1960s-70s for mapping, mission planning, and control purposes. Previous work with LO imagery was difficult due to image artifacts, and the mapping was not controlled to any horizontal or vertical datum [1]. Mapping with Apollo imagery used 2 different control networks. The hardcopy maps that resulted are the Lunar Topographic Orthophotomap (LTO) and Lunar Orthophotomap (LO) map series [1].

Since these maps were produced, the lunar control network has been improved [2] and the LO images are now available as digitized images with the image artifacts greatly reduced [3]. The tools available for "softcopy" mapping permit the generation of DEMs, from which contour maps can be made if desired, but the digital DEMs contain more detailed topographic information that can also be used for image rectification, photometric correction, slope analyses, etc. Use of the current control and datum ensures that the topographic data can be used in conjunction with data from current and future missions. Thus, the products enabled by this study supersede earlier maps.

Source Data: Lunar Orbiter imagery was collected by 5 missions, LO-I through -V, during 1966–1967. Stereo imagery is provided both by the overlap of images for global mapping and by deliberate targeting of specific sites of interest. LO IV coverage of the nearside includes 6°-wide bands of stereo at 0° and ±30° latitude, and from about ±60° to the poles (>25% of the nearside in all). The resolution of the imagery is between 30 and 100 m. The other LO missions returned stereo imagery of spot areas with higher resolution (10 - 40 m) [4]. These images were used for Apollo landing site selection, but the full topographic information was not extracted because errors in reconstructing the images from sections scanned on the spacecraft produced artifacts in the form of linear "cliffs" in the stereomodels.

Apollo 15, 16, and 17 imaged ~20% of the Moon immediately under their orbital tracks using both a frame mapping camera and a panoramic camera. The frame camera was a Fairchild Metric Camera with a 4.5 in by 4.5 in film format. Stereo imagery is obtained by overlapping imagery along the flight line and between flight lines. When digitized at 10 µm, a Metric Camera image provides a useful resolution of about 15 m/pixel. The panoramic camera was an Itek panoramic camera with 45.24 in by 4.5 in film format. Stereo imagery is obtained by using forward and aft looking images acquired along the same flight line. When digitized at 10 µm, a panoramic image has a resolution at image center of about 2 m/pixel and at the edge of the image the resolution is about 4 m/pixel. Additional information on the digitization process is provided below.

The site mapped in this project is the Rima Hadley region, including the Apollo 15 landing site. This area has excellent coverage by LO and Apollo images, and previous mapping products exist to compare with our results. We selected images 4102_H3 and 4103_H1 from LO IV, images 5105_MED, 5106_MED, 5107_MED, 5106_H1, 5106_H2, and 5106_H3 from LO V, images 0583, 0585, and 0587 from Apollo 15 Metric Camera, and images 9809, 9811, 9814, and 9816 from the Apollo 15 panoramic camera. Figure 1 shows the image footprints.

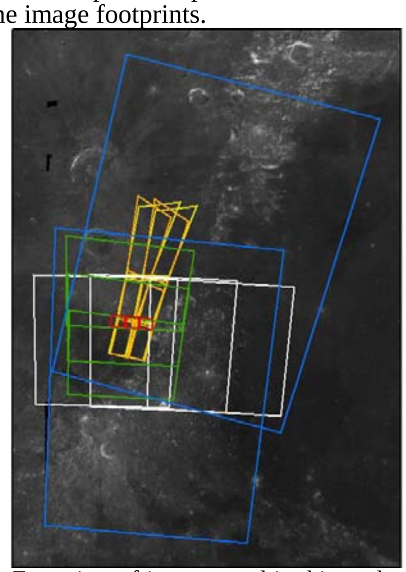

Figure 1. Footprints of images used in this study, shown on a Clementine image mosaic with north at top. Blue: LO IV frames 4102_H3 and 4103_H1; Green: LO V frames 5105, 5106, and 5107; Red: LO V frames 5106_H1, 5106_H2, and 5106_H3; White: Apollo 15 Metric frames 583, 585, and 587; Orange: Apollo 15 forward looking pan frames 9809 and 9811; Yellow: Apollo 15 aft looking pan frames 9814 and 9816.

Procedures: We are using a commercial photogrammetric workstation with SOCET SET (® BAE Systems) software to view the images in stereo, select control and tie points, and collect our DEMs. The LO and Apollo images, obtained by digitization of film as described below, are imported into the workstation in TIFF file format, obtained by digitization of film as described below. Support data were obtained from the National Space Science Data Center and entered by hand. Camera model information for the LO missions and Apollo missions was entered into camera model files used by the workstation. The workstation provides camera models for frame and panoramic sensors.

Digitization: LO images, including those needed for this study, are being digitized and reconstructed under a separate project [2]. This process starts with scanning the 35 mm framelets at 25 µm spot size, averaging the pixels to 50 µm raster (which preserves image detail better than scanning at 25 µm), and then geometrically transforming and mosaicking the framelet images to reconstruct the LO sub-frames. The reconstruction process is guided by measurements of reseau marks on the framelets and fiducials along the frame edges, and largely eliminates the discontinuities present in earlier, hand-mosaicked versions that produce artifacts in stereo mapping.

We have 3rd generation negatives and 4th generation film positives of the Apollo images in our data holdings and selected the latter to digitize. 2nd generation positives available at JSC or LPI could be scanned for future operational mapping and might yield slightly better image quality, but such scanning must be done with a photogrammetric-quality scanner to avoid introducing geometric distortions in the images that will affect mapping, and must allow for digitization of fiducial and timing marks around the image edges.

We tested digitizing the images with 5, 10, and 25 µm spot size with a Vexcel Ultrascan 5000 scanner. Although the 5 µm spot size provided the most detailed images, the improvement over 10 µm was minimal and did not justify the much larger file sizes. Scanning at nominal exposure times and 8 bits/pixel was found to yield equal image quality, even in highlights and shadows, as long-exposure scanning at 16 bits/pixel and was therefore adopted. An Apollo metric image can be digitized in 1 pass and at 10 µm spot size the file size is 140 MB. The 45.24 in length of a panoramic image exceeds the width of the scanner used, so these images were digitized in 5 overlapping sections. Timing marks are recorded every 2.5° along the edges of the panoramic film, and the images were digitized so that each section shares a common timing mark with its neighbors. With a 10 µm spot size the file size is 300 MB for each section. The sections were used individually for mapping, rather than being reconstructed into complete Pan images.

Interior Orientation: Interior orientation is the reconstruction of the location of the scanned pixels within the sensor. For frame sensors this is based on image measurements of fiducial marks and the known locations of these marks; for the panoramic images, timing marks are used.

Bundle Adjustment: Bundle adjustment is a least squares solution that adjusts camera position and pointing along with control point locations to minimize misregistrations of the images to one another and to ground control. Initial estimates of camera position /pointing are part of the manually entered support data. For ground control, we visually identified points in the Unified Lunar Control Net 2005 [2] and measured their locations on the LO and Apollo images. We also selected tie points, whose locations are unknown, to tie the LO and Apollo images and stereopairs together. Bundle adjustments were run for each set of images alone and for the complete set of data. Table 1 summarizes the bundle adjustment results.

Table 1 – Bundle Adjustment Summary

			Control Points		
Source	GSD (m/pixel)	RMS (pixel)	X (m)	Y (m)	Z (m)
Apollo Metric	13.7	0.62	356	516	650
Apollo Pan	1.9 – 3.3	1.16	126	400	475
LO V med	11.6 – 12.4	1.36	321	429	1485
LO V med+high	1.6 – 12.4	1.74	303	422	1177
LO IV	31.5 – 34.7	1.47	379	494	579
ALL	1.6 – 34.7	2.79	342	524	516

GSD=ground sample distance, RMS=root mean square residual of bundle adjustment in image space, X, Y, Z=RMS horizontal and vertical components of error in locations of ground control

The Apollo Metric images provide the best results. Relatively high residuals for LO V may be the result of residual distortions in the reconstructed images. The increased error in the solution with all data is mainly due to having more measurements per point, and matching points across images with different resolutions.

DEM Extraction: Digital Elevation models were extracted based on each source of imagery, except the unpaired LO V high resolution image. Default automatic matching parameters were used with success, there were no major artifacts or mismatched areas. Minor editing will be needed to remove spike features, errors in shadowed areas and along hill sides where the matcher did not follow the slope (Figure 2).

Output Products: Based on the DEM orthorectified images, controlled mosaics, and contours can be produced. These could be provided by themselves or as part of a finished map with grid and collar data. These products can be exported to ISIS and in formats usable by GIS and visualization packages.

Analysis: We are analyzing our DEMs and will provide estimates of horizontal resolution and vertical precision in our poster. We note here that the LO DEMs do not exhibit the "cliffs" or stripping that was evident when DEM extraction was attempted using the hardcopy images. The Apollo metric and panoramic images provide the highest resolution results.

Conclusion: Softcopy stereomapping techniques can readily be applied to scanned lunar images to produce controlled DEMs, orthoimage mosaics, and other products that will be useful in future mission planning and scientific analysis. The full value of the legacy datasets from LO and Apollo has yet to be exploited.

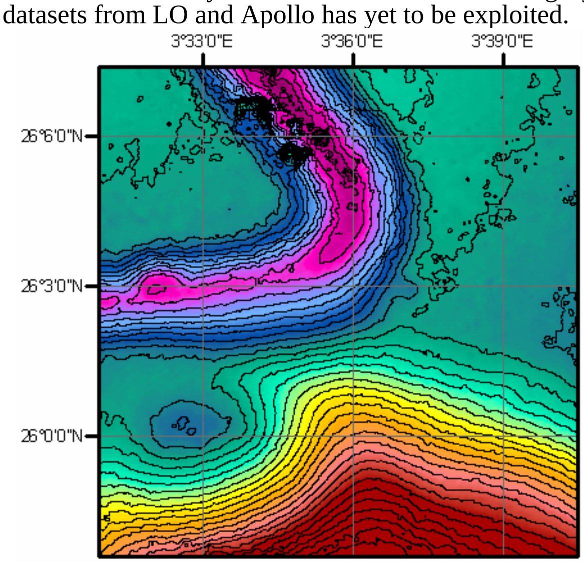

Figure 2. Unedited DEM from Apollo panoramic imagery, simple cylindrical projection, north at top. Contours are at 25 m interval with color coded DEM shown in the background. Artifacts (spikes) requiring limited editing are visible on walls of Rima Hadley, top center. Apollo 15 landing site is just off the top of this image.

References: [1] WU, S.S.C. and Doyle, F.J., Planetary Mapping, 1990, pp. 169-207. [2] Archinal, B.A. et all *LPSC 2006.* [3] Weller, L. et all *LPSC 2006.* [4] Hansen, T.P. Guide to Lunar Orbiter Photographs, 1970, NASA SP-242.