LUNAR ORBITER: Digitization and Cartographic Processing. L.R. Gaddis, T. Becker, T. Sucharski, A. Gitlin, R. Kirk, and A. Howington-Kraus, Astrogeology Team, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ (lgaddis@usgs.gov).

Introduction: Digitization and cartographic processing of 5 Lunar Orbiter (LO) IV frames (109H, 110H, 114H, 115H, and 114M) are now complete, and these data are available online at http://wwwflag.wr.usgs.gov/USGSFlag/Space/LunarOrbiter/lunorbWebtop.html. Coverage of these data extends from Eratosthenes crater on the west to Mare Serenitatis in the east, and from Aristoteles crater in the north to Rima Hyginus in the south. Geologic features in this area encompass a wide variety of lunar units, processes, and ages, and they include parts of the Apennine Mountains, the KREEP-rich Apennine Bench Formation, Rima Bode pyroclastics (Figure 1), Mare Vaporum, Sulpicius Gallus, and the Imbrium basin ejecta southeast of the basin rim. These data products demonstrate our capability for digitizing and cartographically processing the LO data.

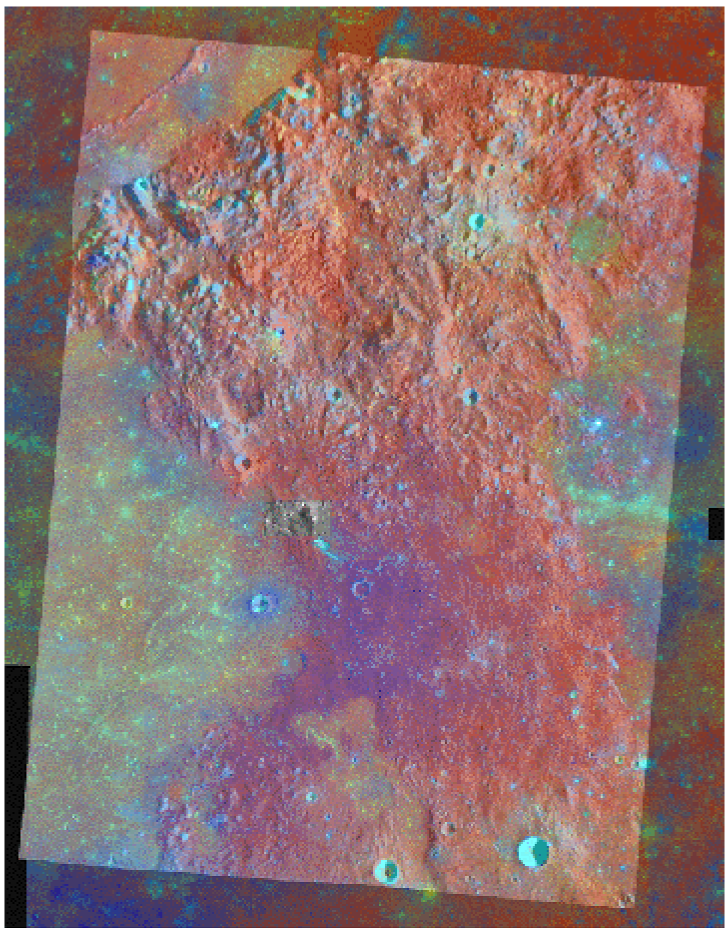

Figure 1. Coregistered LO and Clementine UVVIS color-ratio mosaics of the Rima Bode region of the Moon (LO-IV 109H2).

Background: The full LO dataset consists of 967 medium-resolution and 983 high-resolution frames (Bowker and Hughes, 1971). The LO images were photographic products acquired on the spacecraft in five missions (LO I through V) while in orbit over the lunar surface (Eliason *et al.*, 1999). The original high-resolution photographic exposure consisted of a 55 mm x 219.18 mm scene on 70 mm film. The LO data were transmitted to Earth as analog data after onboard scanning of the original film into a series of strips. Upon receipt on the ground, data for each framelet were written onto 35 mm film covering 20 mm x 66.44 mm, thus the film strip written on Earth was 7.5 times larger than the strip on the spacecraft. Photographic prints from these film strips were hand mosaicked into sub-frame (for high-resolution data) and full-frame (for medium-resolution data) views and widely distributed. The resulting outstanding views were of generally very high spatial resolution and covered a substantial portion of the lunar surface, but they suffered from a "venetian blind" striping (e.g., Gillis, 2000), missing or duplicated data, and frequent saturation effects that hampered their use.

Data Processing: Archival LO positive film strips (Bowker and Hughes, 1971) were scanned commercially at 25 microns/pixel (e.g., ~16 m/pixel for high-resolution frames). Each scanned film strip consists of a 16377 x 766 pixel image, with overlap between strips of ~37 pixels. Our processing of these digital data included (1) *geometric rectification and mosaicking* into sub-frames (3 subframes or 96 strips per frame), (2) *cosmetic processing* (largely destriping and noise removal), and (3) *cartographic control* through coregistration to the 750-nm Clementine image base via manual tie-pointing and warping (Figure 2).

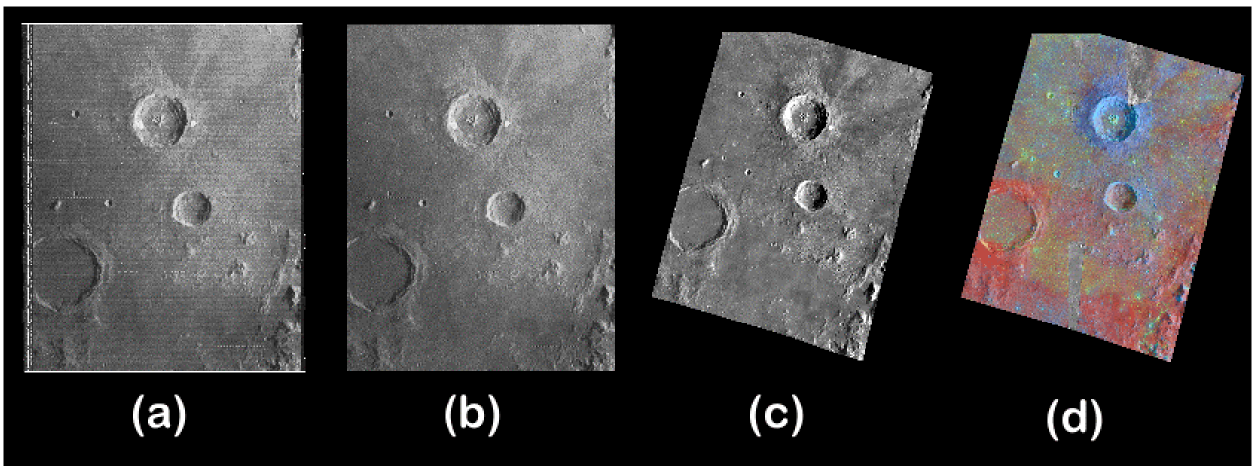

Figure 2. Examples of processing stages for LO-IV subframe 110-H1. (a) Raw digital mosaic. (b) Destriped mosaic, with excess data trimmed. (c) Geometrically rectified or warped mosaic. (d) Mosaic with Clementine color overlay (r=750/415 nm; g=750/950; b=415/750).

Geometric rectification and mosaicking. We made use of several aspects of the original LO film to perform the geometric rectification. Prior to the LO flights, the photographic film was exposed with strip numbers, nine-level gray-scale bar, resolving power chart, and reseau marks. Each film strip has ~35 reseaux, and a single high-resolution frame has ~2185 reseaux. Reseau locations were manually identified and used to compensate for film distortion in the creation of the digital mosaic and in the geometric rectification process (Figure 2a). Geometric rectification was performed using a weighted least-squares fit to a 1^{st} order polynomial describing the orthogonal positions of the reseaux.

Cosmetic processing. Cosmetic clean-up focused largely on the removal of stripes through the application of spatial filters. To minimize artifacts during this process film numbers and other extraneous data were assigned to a null value. An image of the striping pattern is created for each subframe mosaic by applying a series of low- and high-pass spatial filters with parameters that define the approximate widths of the stripes. This image of the stripe pattern is then subtracted from the subframe mosaic, substantially improving the appearance of the mosaic (Figure 2b). Improvements to this process are possible and would include temporary removal of the reseaux and other bright features that produce ringing and aliasing artifacts during filtering.

Cartographic control. The digital LO subframe mosaics are cartographically controlled through coregistration to the Clementine 750-nm controlled image base via manual tie-pointing and warping with a weighted least-squares fit to a 2nd order polynomial (Figure 2c). Future improvements to this process could include the development of a LO camera model and comparison to the Clementine coordinate system for updating the LO spacecraft pointing information and evaluating optical distortion of the LO camera.

This process allowed us to produce LO mosaics that were colorized with an overlay of Clementine UVVIS color-ratio data (Figure 2d). We hope to use these match-point data as input to ISIS software (e.g., Eliason, 1997; Gaddis *et al.,* 1997; Torson and Becker, 1997) for creation of a LO camera model. Implementation and application of such a model will permit creation of a true LO cartographic product through a "bundle-block" adjustment in which image coordinates are mapped into orientation and/or ground coordinates prior to reprojection and final mosaicking. This process also will allow detailed comparison to the Clementine coordinate system, updating of the LO spacecraft pointing information, and evaluation of the optical distortion of the LO camera. To simulate such a cartographic product, we used the simple framing camera model in the LHZ Systems SOCET SET photogrammetric software to create stereo views and a digital mosaic that is accurately tied to the Clementine 750-nm image base for southeastern Imbrium basin (Figures 3 and 4). Note that edges or "cliffs" between overlap areas are virtually absent in the stereo anaglyphs (Figure 4).

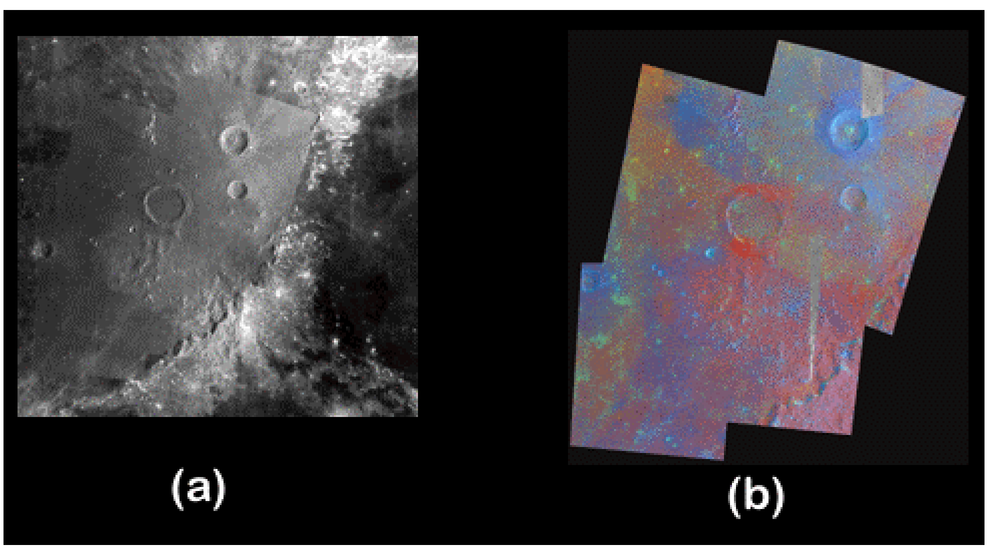

Figure 3. LO simulated cartographic product for southeastern Imbrium basin. (a) LO mosaic (frames) superimposed on Clementine 750-nm image base. (b) LO mosaic with coregistered Clementine color-ratio overlay (r=750/415 nm; g=750/950; b=415/750).

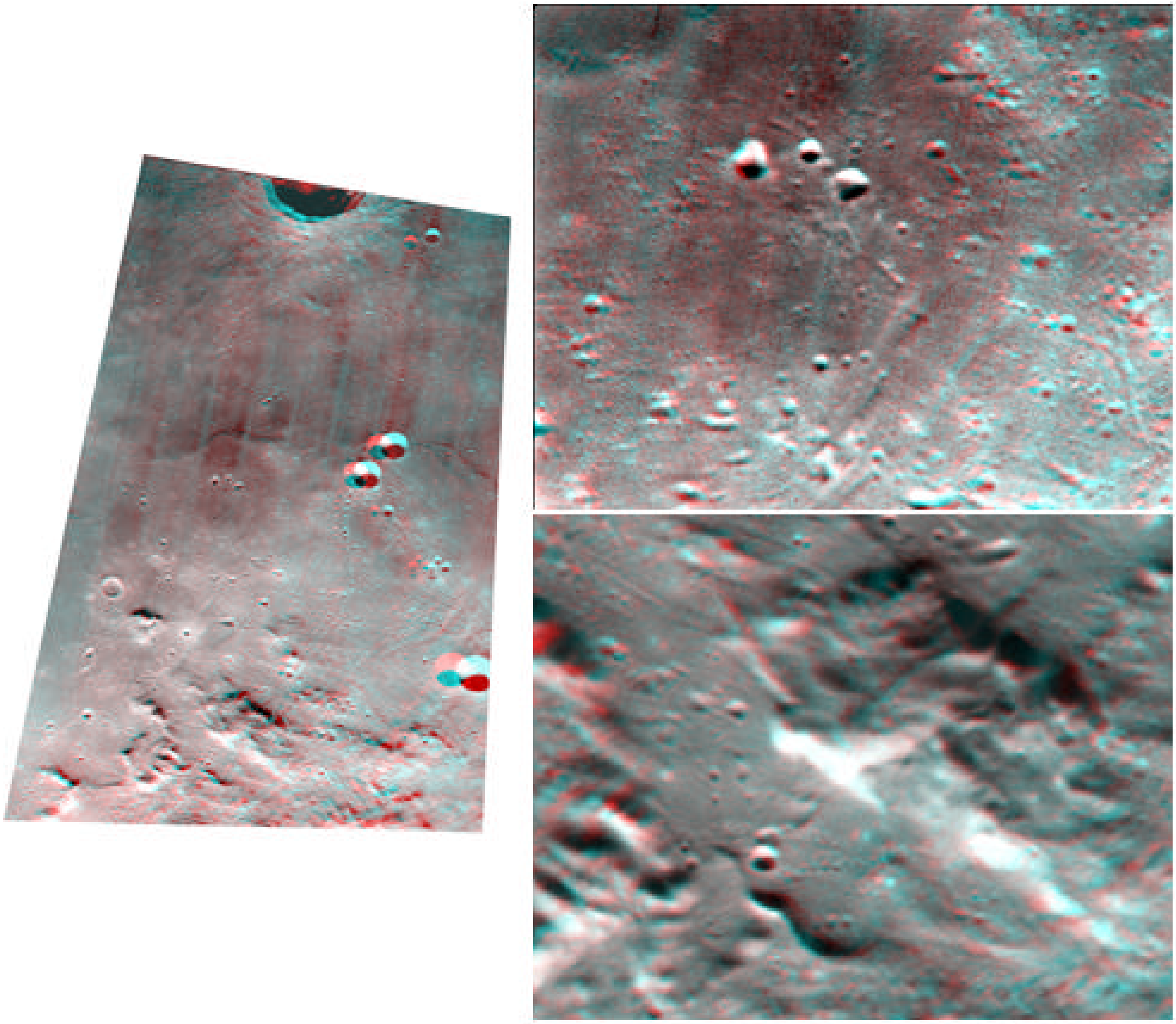

Figure 4. Stereo views of overlapping portions of LO frames 114H3 and 115H1. This region of overlap (at left) is south of Archimedes crater (North is to the right). At right are enlarged views of flat (top) and hilly (bottom) portions of the view at left.

Summary and Future Work: Reduced resolution final products are available online and they include digital mosaics for 13 subframes, as well as ISIS processing procedures for reseau location, destriping and cosmetic correction. Full resolution and interim products (e.g., rectified subframe mosaics without destriping) are available upon request.

Only a fraction of the LO data have been processed as described. We hope to create a digital archive of LO data that has global coverage so that we can create a mosaic comparable to that of Clementine. Global coverage of the Moon with LO data at high spatial resolution would be possible with ~400 frames from LO IV and LO V. Digitization of other lunar photographic products, including Apollo Pan and Metric data, is also a future possibility. The LO, Apollo Pan, and Metric data are of considerable interest for softcopy stereotopographic mapping of the Moon at different scales.

References:

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