LROC NAC FEATURE MOSAICS: AN EFFECTIVE TOOL FOR LUNAR INVESTIGATIONS. A. C. Martin, P. E. Gray, M. R. Henriksen, M. S. Robinson and the LROC Team, Arizona State University, School of Earth and Space Exploration, PO Box 873603, Tempe AZ, 85287-3603 (acmart19@asu.edu)

Introduction: High spatial resolution (0.5-2 m/pixel) images captured by the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Cameras (NACs) are used for the production of Feature Mosaics (FMs) [1]. Feature Mosaics are radiometrically, geometrically, and photometrically corrected mosaics of two or more NAC pairs that provide an accurate cartographic framework for regional areas of interest. Since entering lunar orbit in June of 2009 the LROC NACs have captured 1,065 FM image sets consisting of 2 to 10 NAC pairs, with an average of 3 pairs. Of those image sets, 233 have been processed into FMs.

The LROC NAC system consists of two cameras, NAC-Left and NAC-Right, offset from each other by 2.85°, which capture images simultaneously with an average 135-pixel overlap between the left and right images [1]. The elliptical orbit altitude varies from ~30-200 km, so a pair of NAC images spans ~25-200 km downtrack and ~3-20 km crosstrack. Sets of image pairs for FMs are captured from sequential orbits to reduce variation in lighting conditions and pixel scales within the mosaic. The spacecraft slews cross-track to ensure image overlap. These sequences result in areas with a median coverage of 2400 km^2 at a median pixel scale of 1.3 m, with uniform lighting geometry (~2.7x more coverage than a single NAC pair at the same pixel scale).

Processing: FMs are processed using USGS Integrated Software for Imagers and Spectrometers 3 (ISIS3) [2]. Images are radiometrically corrected, noise is removed using *lronaccal* while *lronacecho* increased image sharpness, and *a priori* spacecraft position and pointing information is applied using the Navigation and Ancillary Information Facility (NAIF) SPICE system, creating Level 1 cubes [2,3].

To initialize a control network, *findimageoverlaps* first locates the overlaps, *autoseed* distributes unregistered tie points inside the overlaps, and finally *pointreg* registers them in each image per a registration parameter file. The control network is then opened in *qnet*, where ground points (constrained) and additional tie points (free) are manually selected. About 30 ground points are added to the network for 3 NAC pairs; the number varies depending on the number of pairs involved. Ground points control the images to a NAC digital terrain model (DTM) orthophoto (if available) or a nadir-looking NAC pair projected onto the Wide Angle Camera (WAC) GLD100 DTM [4,5]. Tie points control an image to another image. The automatically-generated points from the network are used as a base that manually-created tie points are added to. After all the points are added, a bundle adjustment is performed using *jigsaw*, minimizing re-projection error between images and observed sites [6]. Jigsaw provides residual projection errors for all tie points which are corrected or removed until the maximum point residual is <5 pixels and the overall residual value, *Sigma0*, is <1.0 pixels [6]. Images are photometrically corrected with *lronacpho* for images <60° incidence or *photomet* for images >60° incidence. The corrected cubes are then map-projected using *cam2map* and mosaicked with *automos* [7].

Processing an average 3-pair FM takes ~1 week if there are minimal seam offsets. The CPU time takes ~20 hours while human editing take ~8 – 10 hours. FMs are processed in parallel to account for the long runtimes of process scripts. The final products, mapped in either Equirectangular or Polar Stereographic projections, are released as Reduced Data Records (RDR) to the LROC PDS archive [8].

Feature Mosaics Applications: FMs are ideal for detailed studies of landforms >5 m and enable accurate coordinate derivation (+/- 20 m) [9], geologic mapping, hazard analysis, crater counting, video visualization, and many other applications.

FMs tied to a NAC DTM extend the photo-mosaic area while retaining the DTM horizontal map accuracy with consistent lighting. Furthermore, obtaining FM sequences under varying lighting is useful because it allows for a better understanding of the geologic material and structures that are represented in these areas (**Figure 1**).

Past and present research uses FMs in many different ways. Current research applications of FMs include: planning of future human and robotic lunar exploration, studies of geomorphology and geology applied to fundamental problems, such as physical volcanology, and the study of spatial relationships among morphologies. Previous research [10] includes mapping maria extents and lobate scarps with FMs. In [11], Apollo landing site features and traverses were digitized and [12] mapped the Apollo 11 traverse using a set of FMs created from the highest resolution images available at a variety of lighting geometries. Making it easy to switch between FMs and to ensure the accuracy of the final traverses, FMs were controlled to align to the NAC DTM up to 1 m.

Feature Mosaics work well for crater counting and mapping because they give an accurately map-projected base, with consistent lighting over a large area relative to single NAC pairs. Having a map-projected controlled mosaic accurately preserves the shapes of the craters and allows for image alignment with no seam disruptions (**Figure 2**).

FMs are also used by the LROC team for video visualization. These usually use a DTM mosaic for topography data, with a FM draped on top to provide lighting that is more consistent and illustrative of the video's message than DTM mosaic orthoimages [13].

Finding Feature Mosaic Products: There are several ways for users to browse and retrieve FMs and images targeted for FMs via the LROC website and PDS node including: Searching the PDS node, browsing ACT-REACT Quickmap, and viewing shapefiles (downloaded or via Lunaserv) in GIS software.

The LROC RDR Search interface for the PDS node can be found at [8]. Users can search for controlled FMs

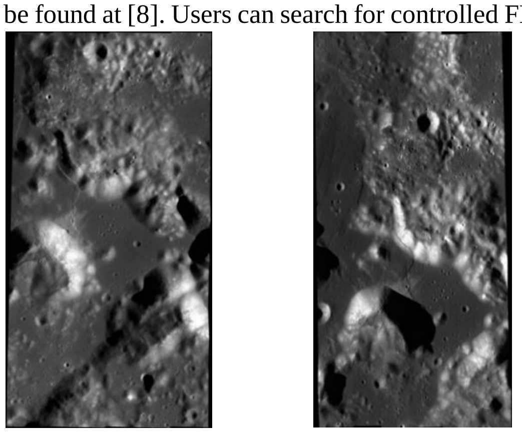

Figure 1. (Above)Apollo 17 Landing Site mosaics: (left) Low-Sun A and (right) Low-Sun B. While both sites cover a similar area and have an incidence angle of about 72°, Low-Sun A has an eastern sun direction and Low-Sun B has a western sun direction allowing for shadowed regions to become exposed.

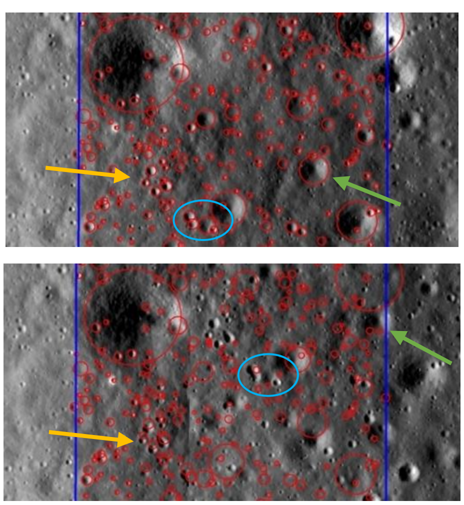

Figure 2. Section of a crater counting block for Mandel'shtam. (Top) Controlled Mosaic (Bottom) uncontrolled images. Notice the crater offsets (bottom) due to unaligned images. [14].

by feature name or coordinates, browse all existing FMs, or download shapefiles with FM locations. Quickmap is an online tool with many lunar data sources, including two related to FMs (see table below) [15]. Lunaserv is an open-source Web Map Service (WMS) implementation designed to support planetary bodies [16]. The LROC instance of Lunaserv contains regularly updated layers for many lunar data sources including shapefiles of controlled and targeted FMs. Users can access Lunaserv with any WMS-capable GIS software or online with Lunaserv Global Explorer (LGE). For more information on Lunaserv and to access the data, go to [17]. Access to these and additional resources can be found in the archive section of the LROC website [18].

LROC RDR Search Interface	* Search by feature name, coordinate, or browse all existing FMs * Completed FMs shapefile: *SHAPEFILE_CONTROLLED_MOSAIC* * Targeted images for FMs shapefile: *SHAPEFILE_FEATURED_MOSAICS*
ACT-REACT Quickmap	* Completed FMs layer: *LROC NAC -> NAC ROI Mosaics* * Query-able vector layer for targeted images for FMs: *LROC NAC -> Feat. Mosaics Observations*
Lunaserv (WMS)	* Completed FMs shapefile: *luna_nac_controlled_mosaics* * Targeted images for FMs shapefile: *luna_nac_featured_mosaics*

Summary: LROC NAC Feature Mosaics provide an accurate and seamless high-resolution data source with consistent lighting free from visual discontinuities over areas larger than a single NAC pair useful for a variety of scientific and visual tasks. An average of 15 new mosaics are released to the PDS every 3 months. All released FMs can be found using a wide variety of tools, including shapefiles, Quickmap, Lunaserv, and the LROC PDS interface. Work is ongoing to improve the controlled mosaic production process, including further increases to accuracy and more use of automation.

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