DIGITIZING APOLLO LANDING SITE FEATURES AND TRAVERSES FROM LROC IMAGE DATA.
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Introduction: In preparation for the six landed Apollo missions, a large number of lunar surface features associated with the sites were identified and named. During extra vehicular activities (EVAs) at the each of the landing sites, the surface regolith was disturbed by the walking and roving astronauts. With the collection of high-resolution Lunar Reconnaissance Orbiter Camera (LROC) images at each of the sites, we are, for the first time, able to accurately map the locations of the surface features and traverses in a Geographic Information Systems (GIS) database. In order to map these features with a significant degree of accuracy, we used new global datasets derived from stereo imaging and laser altimetry for our basemaps. These datasets include the Global Lunar DTM (GLD100) model and the 100 m/pixel global mosaic. We georegistered high-resolution stereo images to our basemaps using SOCET SET to locate the Apollo surface features for digitization into an ArcGIS geodatabase. The resulting products will be released as shapefiles through the LROC Planetary Data System (PDS) node.

Global Base Images And Lunar DTMs: With the arrival of the Lunar Reconnaissance Orbiter (LRO) at the Moon in 2009, and its subsequent six years in orbit, images and surface measurements containing unprecedented detail have been acquired. Derived image products from these data provided the basis of mapping the Apollo surface features. Moderate resolution global images and high-resolution images of the six landing sites were brought into ArcGIS and projected onto the IAU2000 standard lunar coordinate system, in which the Moon has a mean radius of 1737.4 km [1].

For this project, two high-resolution global datasets were used. The first is a 100m/pixel global mosaic. Using images acquired between November 2009 and February 2011, the LROC team produced an image mosaic that was comprised of over 15,000 images. The images were geometrically projected to a lateral surface accuracy of ~40m [2] and photometrically corrected for a consistent representation of the surface albedo. In addition, the images used were acquired at a lighting incidence between 55°-70° for the most favorable lighting to reveal geomorphology.

The second product is a global digital terrain model (DTM). Through the combination of comprehensive image coverage by the LROC Wide-angle Camera (WAC) and the Lunar Orbiter Laser Altimeter (LOLA), a geodetically accurate 100 m/pixel Global Lunar DTM of the Moon (GLD100) was generated [3].

To visually identify the landing site features, we superposed multiple, overlapping sets of high-resolution (0.35-0.65 m/pixel) LROC Narrow-angle Camera (NAC) images that had been acquired under several different lighting angles. From the NAC stereo pairs of these sites, DTMs were generated using SOCET SET [4], to ensure the best surface registration of the surface features.

Named Apollo Site Surface Features: Planning for the Apollo lunar landings resulted in the naming of nearly 280 features associated with the six sites that would be visited by Apollo astronauts. 78 of these features were officially recognized by the International Astronomical Union (IAU), while 199 remained unofficially named. Although unrecognized by the IAU, these feature names were referenced by the astronauts and ground crew during the respective missions, and by the science community in literature following the missions. In the interest of historic preservation, we digitized all of the Apollo landing site features, which include craters, small massifs, fractures, and small maria embayments, into an ArcGIS geodatabase.

The initial part of our project was to update the 78 officially named landing site features (LSF). The coordinates of the LSF were obtained from the IAU list of official lunar nomenclature [5,6]. These coordinates were based on Lunar Obiter, which were poorly registered to the lunar surface, and laser ranging of the retroreflectors at the Apollo 11, 14, and 15 sites [7]. Using LROC NAC images and improved lunar geodesy, the LSF were easily identified, and the respective geographic coordinates and attribute table were updated.

Prior this work, the unofficially-named LSF (ULFS) had never been compiled in comprehensive GIS or mapped in a useful format. We researched Apollo-era documents, which include planning maps, annotated images, and voice transcripts, to compile all features and associated names that were referenced during the six Apollo landed missions [8]. Most labels in the documents plainly pointed to the intended feature, although some regional names had ambiguous placement (e.g., no leader, or the label was in a cluster of features), and a few feature names were not consistent between different maps of the same area (e.g., Lee-Lincoln; Double Dot). In a few cases, descriptive map annotations were incorrectly taken as feature names (e.g., “Double”) and later removed. Like the LSF, the ULSF were mapped as point features in our geodatabase, and were given attributes of latitude, longitude, mission, and a status of “unofficial”.

Apollo Science Payloads And Traverses: During their explorations on the surface of the Moon, the Apollo astronauts deployed science payloads and disturbed the regolith while walking or driving the Lunar Roving Vehicle (LRV). We mapped the resulting traverses into our geodatabase. To resolve details of the traverses required image resolutions of 0.35-0.7 m (although up to 2.0 m/pixel would reveal the presence of traverse but no detail). Utilizing images with differing incident light angles over the same area also helped to locate the traverses. Incidence values of 30°-60° were better in accommodating changing surface topography, whereas lower incidences, 0°-30°, provided better variations in albedo.

Deployed science payloads were identified by bright surface reflections, usually in association with a concentration of disturbed regolith. Where ambiguous, we reviewed post-mission documents to determine the name and location of the payload. Our mapping of these features is currently on-going.

The traverses were identified in the LROC-NAC images by two different morphologies. The walking traverses are generally broad, up to two meters wide, because the astronauts walked side-by-side or re-walked over same path. As a result, they are darker and not sharp-edged. This “muddy” appearance made the traverses easier to see on the NAC images, but detail was more difficult to discern, mostly in the case of over-printing. In this case, we solved the problem by placing a single line through densest part of the walking traverse.

The LRV tracks consist of two narrow, distinct, parallel lines, approximately 2.3 m apart, made by 23 cm wide wheels. They have less contrast than the walking traverses because the regolith does not appear to have been as disturbed as much. As a result, the clarity of the tracks are sensitive to solar incidence angle, the unevenness of terrain, and sometimes the direction of travel. In general, lighting conditions are best when the solar incidence was 45° to 60° and illuminated an E/W course. In many places the traverses were not visible. Mapping of these hidden traverses was mitigated by interpolation of a path between two visible ends of an apparent single line of travel. Where there was no obvious corresponding path of travel, we referenced the pre-mission planning maps or the voice transcripts made during the time of the traverse to infer a location.

Attributes added to the geodatabase include: traverse (EVA) number, traverse direction (away/return), and length (in meters) of the traverse segment between intersections.

In the mapping of traverses, the spacing of verticies along the path was dependent upon the image resolution and frequency of change in traverse direction. Where pixel resolution was about 0.5m/pixel, we digitized a vertex every 5-8m (10-16 pixels) for finer detail, and up to 20m (40 pixels) for straighter lengths.

Products Generated: When the projects are completed, there will be a five shapefiles for each of the six landing sites. There will be three pointfiles: updated LSF, ULSF, and science payload locations; and two line files: walking traverses, and roving traverses (the latter for Apollo missions 15-17). Shapefiles are considered proprietary/open source and can be used by a variety of GIS software. Each file will contain metadata, based on FGDC (Federal Geographic Data Committee) [9] standards. The finalized products will subsequently distributed through the PDS, LROC node, as part of the “extra” data products.

References: [1] http://ode.rsl.wustl.edu/moon/pagehelp/quickstartguide/index.html?coordinate_system.htm. [2] Speyerer, E.J., et al. (2014), Space Sci Rev, doi:10.1007/s11214-014-0073-3. [3] Scholten, F., et al. (2012), JGR 117, E00H17, doi:10.1029/2011JE003926. [4] Burns, K.N., et al. (2012), doi:10.5194/isprsarchives-XXXIX-B4-483-2012, 2012. [5] http://planetarynames.wr.usgs.gov/Page/MOON/target [6] http://planetarynames.wr.usgs.gov/GIS_Downloads [7] Davies, M.E. and T.R. Colvin (2000) JGR 105(E8), 20277-20280. [8] Apollo Lunar Surface Journal: https://www.hq.nasa.gov/alsj/frame.html. [9] https://www.fgdc.gov/.