LARGE SCALE MAPPING OF THE APOLLO 17 LANDING SITE BASED ON LUNAR RECONNAISSANCE ORBITER CAMERA (LROC) AND APOLLO SURFACE IMAGES.
I. Haase[1], M. Wählisch[2], F. Ankenbrand[3], M. Kobrow[3], C. Maslonka[3], P. Gläser[1], J. Oberst[1,2], and M.S. Robinson[4], [1]Dept. of Planetary Geodesy, Technische Universität Berlin, Germany, [2]German Aerospace Center (DLR), Dept. of Planetary Geodesy, Berlin, Germany, [3]Beuth University of Applied Sciences, Berlin, Germany, [4]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA. (isabel.haase@tu-berlin.de)

Introduction: The Apollo 17 mission is characterized by the longest traverse path, the largest sample mass returned and the largest number of recorded images. To improve the cartographic and geologic context of the returned samples and the invaluable "on site" imagery we determined and mapped astronaut and hardware positions along the crew's 30 km long traverse path. For this, historic surface images and Narrow Angle Camera (NAC) images of the Lunar Reconnaissance Orbiter Camera (LROC) [1] were jointly analyzed by applying network adjustments to angular measurements made in the surface images.

Accurate maps of the landing sites and the Extravehicular Activities (EVAs) routes and way-points will not only improve interpretation and reanalysis of the unique Apollo observations, but also support potential future landings within that area, e.g. as proposed by the so-called "Part Time Scientists" group of the Google Lunar X-PRIZE competition.

LROC NAC DTM and Orthomosaic: LROC NAC stereo image pairs of the Taurus-Littrow Valley with resolutions of 0.5 to 1.3 m/pixel were used to produce a 1.5 m gridded Digital Terrain Model (DTM). The DTM consists of five stereo models and was generated using an adapted version of the DLR Stereo Photogrammetric Processing System [2], originally developed and routinely used for Mars Express HRSC image processing. The most recent SPICE kernels were integrated to account for lunar gravity models recovered by GRAIL [3], [4] and temperature dependent influences on the pointing of the camera [5]. The DTM was used to ortho-rectify ten LROC NAC images of that area, which were combined to a 0.5 m/pixel orthomosaic. Coordinates of the central station of the Apollo Lunar Surface Experiments Package (ALSEP) [6], which can be identified in one of the images, were used for lateral reference. For vertical control we co-registered the NAC DTM to the cross-over improved LOLA tracks available in that area [7].

Determination of Astronaut and Equipment Positions: Ground based images taken by the astronauts were used in combination with orbital images of the current Lunar Reconnaissance Orbiter (LRO) mission to determine accurate positions of the astronauts at the moment of image acquisition. These determinations were achieved by applying the geodetic resection method, where angular measurements made in the surface images are accurately tied to reference points identified in controlled LROC NAC orthoimages. By means of a 2D least-squares network adjustment we assessed the position and pointing (azimuth angle) of the astronaut's camera. Individual camera locations of at least four single frames per panorama were determined with accuracies of 2 m and better (< 1 m for most cases), depending on the number of angular measurements made in these frames and the distances to the observed features. If possible, single frames taken in all four directions were chosen and the mean of the adjusted camera positions was defined to be the final panorama station. Stereo views from two different locations provided by certain panoramic frames allowed mapping features which are not resolved in the LROC NAC images, e.g. small ALSEP instruments, the remotely detonated Explosive Packages (EPs) or the Lunar Roving Vehicle (LRV) in various positions.

Traverse Station Maps (1:1,000): We determined camera positions for all of the station panoramas, which were routinely taken at each major stop along the traverse (18 panoramas from 9 stations). Using calibrated Hasselblad cameras, the astronauts usually took two panoramic image sequences per station, mainly for positioning and illustrative purposes. Based on our determined camera locations, the respective parking position of the rover and EP positions were derived by triangulation. Scanned Hasselblad frames and detailed descriptions of the three EVAs are available at www.hq.nasa.gov/alsj/a17, for example.

Station maps at a scale of 1:1,000 covering an area of 70 m x 80 m on average were created based on the 0.5 m-scale LROC NAC orthomosaic. For example, Figure 1 shows the map of station 9, the only station where three panoramas were taken. Although following the overall design of the planimetric maps published in 1973 by [8], we chose to only include details, for which locations were secured by our analysis. Hence the sample sites were not incorporated. In addition to the station maps as shown in Figure 1, we prepared orthophotomaps about twice as large (145 m x 170 m) to supply more details and a wider context to the smaller area maps.

ALSEP Maps (1:1,000 and 1:3,000): Geolocations of the two (full) panoramas taken at the ALSEP site were determined and, based on that, coordinates of all of the ALSEP instruments were derived by applying triangulation. Depending on the dimension of the particular object, the determined geolocations of some of the instruments could be visually affirmed by features imaged in the LROC NAC image. Here, an image taken from a low orbit altitude was used providing a pixel scale of 25 cm/pixel.

With the primary focus being on the ALSEP instruments we created a map at a scale of 1:1,000 that covers an area of about 120 m x 110 m around the "Geophone Rock", including the array of four Geophones located south of the ALSEP central station. A second orthophotomap at a somewhat lower scale of 1:3,000 covering an area of 500 m x 770 m, additionally includes the region near the descent stage of the Lunar Module (LM) standing about 196 m east of the ALSEP site. This map gives a good overview of the extravehicular activities of the astronauts close to the LM, with their tracks visible in the image. It also includes the final parking position of the LRV and the locations of the four (out of eight) EPs which were deployed relatively close to the immediate landing site.

Traverse Map (1:15,000): The determined coordinates were also integrated into a new Apollo 17 Traverse Map, covering an area of about 14 km x 12 km of the Taurus-Littrow Valley, from 30.4294° to 30.9162° in longitude and from 19.9771° to 20.3639° in latitude. According to LRO project standards, planetocentric coordinates are related to the Mean Earth/Polar Axis (ME) lunar reference system. As the tracks of the Apollo rovers are mostly not detectable in LROC NAC images and therefore cannot be traced, the route of the astronauts between stations were reconstructed by adapting the traverses taken from the NASA Apollo 17 Traverse Map (sheet 43D1S2(25)) published in 1975 by the Defense Mapping Agency Topographic Center (DMA TC).

To serve as base of the map, the controlled LROC NAC orthomosaic was projected in a Transverse Mercator Projection with true scale at 30.7°E (= central meridian) using a sphere with R=1737.4 km as reference shape. The printed map has a scale of 1:15,000 and includes a graticule, contour lines with equidistances of 50 m and the astronauts' traverses and rover stops. Craters, massifs, and mountains are labeled with IAU-approved names where available and with commonly used feature names elsewhere. Center coordinates and diameters of named craters were re-measured for mapping purposes and are provided as supplementary information.

Outlook: Currently we are preparing a comprehensive report on this cartographic study—starting from photogrammetric stereo processing to the final map products, including catalogs of the determined feature coordinates. The Apollo 17 traverse map 1:15,000 and the large scale station maps will be published via the Planetary Data System (PDS). In addition to the printable PDF version, geospatial data file formats will be released, e.g. shapefile and .kml, for Geographic Information System (GIS) and Google Moon applications.

References: [1] Robinson, M.S., et al. (2010) *Space Sci. Rev., 150,* 81–124. [2] Gwinner, K., et al. (2009) *PERS, 75(9),* 1127–1142. [3] Lemoine, F.G., et al. (2014) *Geophys. Res. Lett., 41,* 3382-3389. [4] Mazarico, E., et al. (2013) *LPSC XLIV*, Abstract #2414. [5] Speyerer, E.J., et al. (2014) Space Sci. Rev., doi: 10.1007/s11214-014-0073-3. [6] Davies, M.E., and Colvin, T.R. (2000), *JGR, 105(E8),* 20277–20280. [7] Gläser, P., et al. (2013) *PSS, 89,* 111–117. [8] Mühlberger, W.R., et al. (1973) *Apollo 17 Preliminary Science Report, NASA SP-330,* 6-1.

Acknowledgment: This work has been funded by a grant (50OW1503) from the German Federal Ministry for Economic Affairs and Energy. We thank the NASA LRO project and the LROC Science Operation Center team for excellent lunar image data.

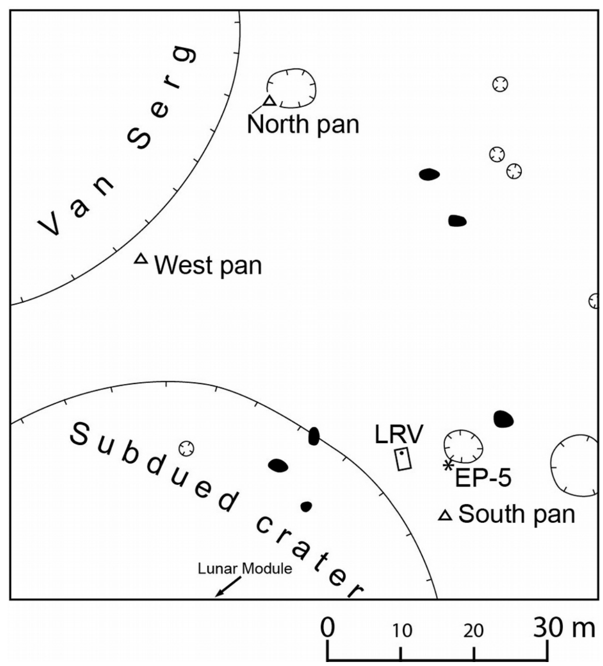

Figure 1: Map of the Apollo 17 Traverse Station 9, showing the newly-determined positions of the panorama sites, the parking position of the rover (LRV) and the detonation site of the Explosive Package 5 (EP-5).