**Improved Coordinates of the Apollo 17 Lunar Seismic Profiling Experiment (LSPE) Components.**

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**Introduction:** The acquisition of new high-resolution orbital images of the lunar surface allows for the reanalysis of historic Apollo experiment data. A method to accurately tie Apollo "on site" photography to images acquired by the Narrow Angle Camera (NAC) of the Lunar Reconnaissance Orbiter Camera (LROC) [1] was previously used to map the Apollo 17 landing site and the astronauts' traverses [2]. Positions of the instruments of the Apollo Lunar Surface Experiment Package (ALSEP), left behind by the Apollo crew, were determined at decimeter-level accuracy [3]. In this work we concentrate on the Geophysical Station deployed at the Taurus-Littrov Valley. An array of four identical geophones were set up by the astronauts to record the vibrations of the lunar crust as induced by the lunar module (LM) ascent, its subsequent impact [4] and by eight explosive packages (EPs), which were remotely detonated one after the other, after the crew had departed. In order to improve the travel-time-distance data of the recorded seismic signals we identified the geolocations of both, the active seismic sources and receivers.

**Charge Deployment:** To explore the Apollo 17 landing site and to move further from the LM to perform scientific investigations the crew used a Lunar Roving Vehicle (LRV). During three Extra-Vehicular Activity (EVA) periods they drove more than 30 km across the valley. On their way they emplaced eight explosive charges (57−2,722 g) at pre-assigned locations, either "enroute" by setting them down on the ground without getting off the LRV (Figure 1) or during pre-planned traverse stops. The crew approached the designated sites with their LRV using navigation system readings such as the computed range and bearing (in 100 m and 1° increments, respectively) in relation to the SEP (Surface Electrical Property) transmitter. This information was provided by means of an odometer and a gyroscope mounted to the LRV. The position error at the end of the traverse was determined to be smaller than 100 m [5].

**Data:** *LROC NAC.* Stereo images (0.5 m/pxl) from the LRO primary mission phase were used to derive 1.5 m/pxl DTMs. We applied the DLR Photogrammetric Stereo Processing System [6], which was originally developed for the MEX HRSC experiment and modified for LROC applications. In a second step the DTMs were co-registered [7] to crossover-improved LOLA tracks [8] of the same region to achieve the most accurate absolute positions. The DTMs were then used for image rectification to a stereographic map projection. A high res-olution LROC NAC image (M168000580R) with a ground resolution of 0.25 m/pxl was acquired during a one-month low orbit period. It covers the immediate surrounding of the LM and was used to identify the ALSEP instruments, the geophone network and the four charges situated closest to the LM (EP-2, -3, -4, and -8).

*Apollo 17 Hasselblads.* For surface photography the Apollo astronauts used two calibrated Hasselblad Electric Data Cameras (60 mm focal length, 70 mm film), which were modified for photogrammetric applications. Among others, they documented the deployment of the charges by taking single "locator" images of the EPs with prominent features in the background or by taking a so-called "rover-" or "LRV-pan": A sequence of panoramic images taken from the passenger's seat while slowly driving around the charge. Scanned Hasselblad frames are available at www.hq.nasa.gov/alsj/a17.



*Figure 1: Deployment of a seismic charge from the rover's seat during Apollo 17 Training (source: NASA).*

**Method:** Because of the LRV's wheel size and design, usually its tracks are not visible in the LROC images. Only near the LM, where the exhaust plume disturbed the surface, the tracks have more contrast. Also, the geophones are too small to be resolved in the NACs and, against what one might expect, in the orbital images the EP's detonation sites are not distinguishable from the surrounding regolith either. Hence, we used the Apollo surface images in combination with the high-resolution LROC orthoimages to geometrically reconstruct the moment of image acquisition and to determine accurate

lunar fixed ME-coordinates (Mean Earth/Polar Axis) of the astronaut's or LRV's position, respectively.

For this, digitized Hasselblad images were used to measure horizontal angles between three or more prominent surface features (see Figure 2). The same features were identified in the LROC NAC orthoimage providing control point coordinates (line, sample). Within a weighted least-squares adjustment the observed angles were fitted to these control points. We assessed the locations of image acquisition and relative (inner) accuracies by applying a free network adjustment. In order to derive selenocentric body fixed coordinates from the determined image coordinates we used the ME-coordinates of the ALSEP's central station given by Davies and Colvin [9] to be consistent with the Lunar Laser Ranging (LLR) frame.

*Table 1: ME-coordinates of the geophone array (preliminary)*

| Geophone | Latitude [°N] | Longitude [°E] | $\sigma_x$ [m] | $\sigma_y$ [m] |
|---|---|---|---|---|
| 1 | 20.192036 | 30.766723 | 0.4 | 0.7 |
| 2 | 20.191393 | 30.763247 | 0.6 | 0.8 |
| 3 | 20.190879 | 30.765086 | 0.7 | 0.3 |
| 4 | 20.189274 | 30.765499 | 1.8 | 0.6 |

**Results and Outlook:** We determined initial ME-coordinates for the array of geophones (Table 1) as well as four (out of eight) detonation sites (Table 2) (see Figure 3). The locations of the geophones were calculated in a combined network adjustment including 93 angular measurements made in 19 different Hasselblads. These frames are part of three, so called "station panoramas" taken at different positions inside the ALSEP area. The change of perspective provides us with three independent networks of angular directions, which intersect at the unknown locations of the geophones. The standard deviations $\sigma_x$ in latitude and $\sigma_y$ in longitude direction refer to the inner accuracies estimated by the free network adjustment and reflect the quality of the angular measurements. So far, the charge sites were adjusted independently from one another using just one locator image or a single frame (see Table 2) of an LRV pan, respectively. By including all angular measurements into one combined least-squares adjustment and by increasing the number of observations we will further refine our results. Subsequently, we will expand our investigation to identify the sites of the seismic charges positioned at greater distances from the LM (EP-1, -5, -6, and -7) and the ascent stage impact site using a 0.5 m/pxl scale LROC NAC orthomosaic covering the entire valley.

**References:** [1] M.S. Robinson et al (2010) Space Sci. Rev., 150, 81–124. [2] I. Haase et al (2012) *JGR, 117(E5)*. [3] I. Haase et al (2012) EPSC, p. 74. [4] R.L. Kovach et al (1973) NASA SP-330, 10.1–10.12. [5] E.C. Smith et al (1973) NASA TN 0-7469. [6] K. Gwinner et al (2009) PERS, 75(9), 1,127–1,142. [7] P. Gläser et al (2010) EPSC, p. 296. [8] E. Mazarico et al (2012) J. Geod., 86(3), 193–207. [9] M.E. Davies and T.R. Colvin (2000) JGR, 105(E8), 20,277–20,280.

*Table 2: Approximate positions of the Explosive Packages, which were deployed near the Lunar Module*

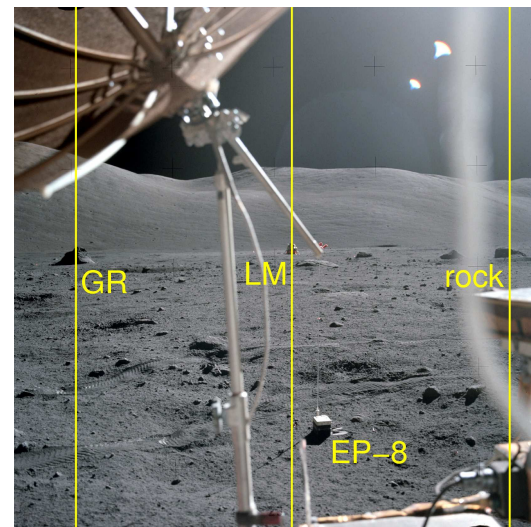| EP | Hasselblad | Latitude [°N] | Longitude [°E] |
|---|---|---|---|
| 2 | AS17-134-20457 | 20.19151 | 30.77821 |
| 3 | AS17-143-21936 | 20.19178 | 30.77515 |
| 4 | AS17-135-20569 | 20.18881 | 30.75775 |
| 8 | AS17-145-22184 | 20.18835 | 30.76161 |



*Figure 2: "Locator" image of the seismic charge EP-8 taken from the driver's seat out to the LRV's front. The yellow lines depict image rows of identical directions. (Hasselblad frame A17-145-22184)*
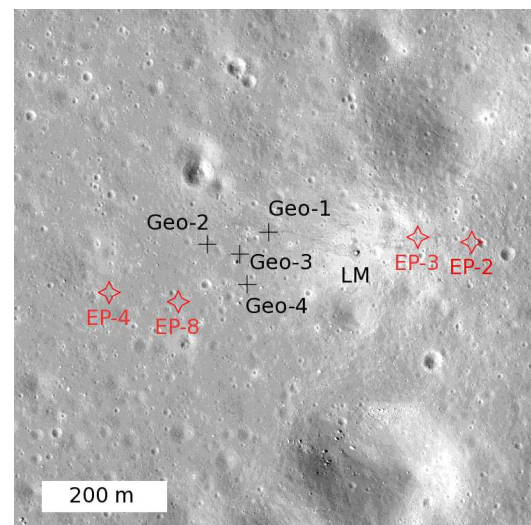


*Figure 3: LROC NAC orthoimage (M168000580R) of the Apollo 17 landing site showing the determined positions of the detonated charges (red stars) and the geophones (black plus signs).*