DETERMINING THE SHALLOW SURFACE VELOCITY AT THE APOLLO 17 LANDING SITE. D. Phillips[1] and R. C. Weber[2], [1]University of Alabama in Huntsville, Physics Department (deanna.phillips@uah.edu), [2]NASA Marshall Space Flight Center.

Introduction: Many studies have been performed to determine the shallow surface velocity model at the Apollo 17 landing site. The Lunar Seismic Profiling Experiment (LSPE) had both an active component with eight explosive packages (EPs) and a passive experiment collecting data at various time intervals. Using the eight EPs, the initial shallow surface velocity model was determined to be 250 m/s in the first layer of depth 248 m, 1200 m/s with a depth of 927 m in the second layer, and 4000 m/s down to a depth of 2 km in the third layer [1]. [2], [3], and [4] have performed variations on this study to produce new velocity models shown in Table 1.

Recent studies have also been re-analyzing the passive LSPE data and have found three different thermal moonquake event types occurring at different times within the lunar day [5]. The current goal of the project is to co-locate these thermal moonquakes to physical surface features to determine the cyclic breakdown of rocks over the course of a lunar day. [6] presented a thermal moonquake location algorithm using first order approximations, including a standard misfit and constraining the events to the lunar surface only. To improve these approximations, a shallow surface velocity model is needed.

Velocity Model: Relocations of the EPs with the velocity models from previous studies did not produce results within acceptable parameters [7]. However, the velocity models given in Table 1 all used single arrival time methods without including uncertainty estimations. A velocity model is found by plotting distance versus time and fitting straight lines to various segments. The inverse slope is the velocity while the depth can be found via the intercept. The given velocity models apply a single best fit line per segment of datapoints, while the uncertainties can provide various fits within a given error parameter. The uncertainty range can be found with a chi-squared algorithm and a Monte Carlo Markov Chain approach.

The first step in finding the uncertainty range was to find arrival times and accurate coordinates for all eight EPs. [4] published two sets of arrival times for six of the eight EPs. Comparing the velocities using two different sets of coordinates, they demonstrated that changing the coordinates of the EPs change the velocities and layer depths significantly. [8] published a new set of coordinates for all eight EPs and four geophones using a combination of LROC images and original astronaut images from the surface. New arrival times for all eight EPs can be found by using various filters, including a bandpass filter, an average magnitude filter, a sliding window polarization filter, a short term-long term average (STA/LTA) ratio, and a Wiener filter. All these filters have been used in various forms to choose arrival times for Apollo 12-17 data, with new parameters chosen specifically to fit the LSPE EP data. These new arrival times chosen with various filters are similar to those published by [4] but include all eight EPs and uncertainty regions. Combined with the new coordinates provided by [8], these new arrival times can be used to find a new model for the shallow surface velocity at the Apollo 17 landing site.

Table 1: Shallow Surface Velocity Models

<table>
<tr><th>Depth</th><th>Preliminary Science Report [1]</th><th>Cooper [2]</th><th>Heffels [4]</th><th>Sollberger [3]</th></tr>
<tr><td>0-4 m</td><td rowspan="5">250 m/s</td><td>100 m/s</td><td rowspan="4">285 m/s</td><td>100 m/s</td></tr>
<tr><td>4-32 m</td><td>327 m/s</td><td rowspan="2">370 m/s</td></tr>
<tr><td>32-60 m</td><td rowspan="4">495 m/s</td></tr>
<tr><td>60-96 m</td><td rowspan="4">500 m/s</td></tr>
<tr><td>96-248 m</td><td rowspan="4">580 m/s</td></tr>
<tr><td>248-390 m</td><td rowspan="4">1200 m/s</td></tr>
<tr><td>390-410 m</td><td rowspan="5">960 m/s</td></tr>
<tr><td>410-773 m</td><td rowspan="3">1100 m/s</td></tr>
<tr><td>773-927 m</td><td rowspan="4">1825 m/s</td></tr>
<tr><td>927 m-1 km</td><td rowspan="3">4000 m/s</td></tr>
<tr><td>1-1.385 km</td><td rowspan="2">N/A</td></tr>
<tr><td>1.385-2 km</td><td>N/A</td></tr>
</table>

Figure 1 demonstrates the velocity fit for the first two layers for a new velocity model without considering uncertainty. Preliminary analysis suggests that the layer 1 velocity is 228 m/s or about 50 m/s lower than [4]. The new layer 1 has a depth of 266 m or a significant increase from 96 m found in [4]. The preliminary velocity for layer 2 is 1109 m/s which is also a significant increase from [4]. These velocities and depths are different from previously published values due to the inclusion of EP7. Additional analysis is needed for EP1 in the third layer.

Verifying the location algorithm [7] has suggested an asymmetric velocity profile surrounding the landing site. In addition to finding a new velocity model for the location algorithm, we can divide the landing site into an east and west configuration to test this hypothesis. This velocity asymmetry would be mostly likely due to shallow ejecta layering and only seen in the top most layer. The eastern profile velocity and depth can then be found with EP4 and EP8 while the western profile can be found from EP2 and EP3 as shown in Figure 2. A preliminary velocity difference of 50 m/s is apparent between the two different profiles seen in Figure 3.

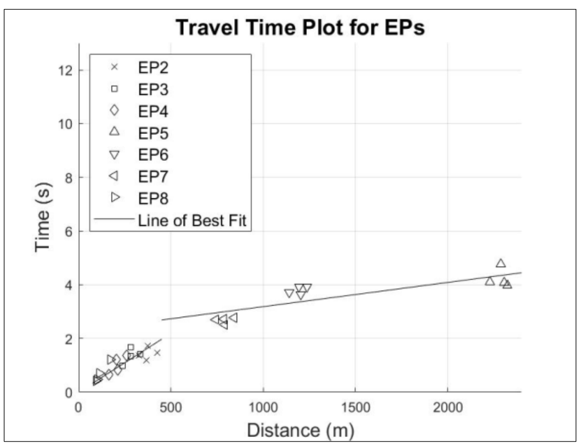

Figure 1 – Preliminary travel time plot for EPs

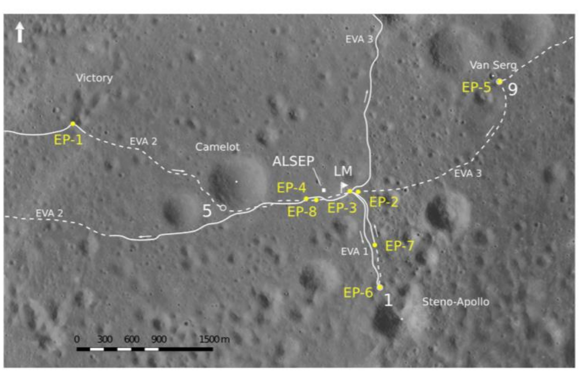

Figure 2 – Apollo 17 EP Locations from [8]

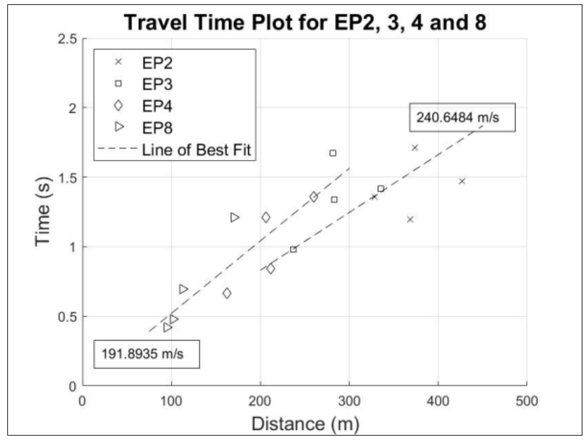

Figure 3 – East versus west side of array travel time plot for EPs

Terrestrial Analog: Recently, a terrestrial analog study was performed on the Cinder Lake Crater Field near Flagstaff, Arizona as part of the San Francisco Volcanic Field (SFVF) 2019 Field Season. The Cinder Lake Crater Field was originally created during the Apollo era to train the astronauts on lunar terrain and geography providing an excellent analog location. We performed multiple tests including a calibration experiment, a moveout line, and a wavelength replica of the Apollo 17 LSPE active experiment for a terrestrial analog comparison. Using this data, we can test the asymmetric velocity model of the Apollo 17 landing site against the crater field as the field should be uniform. Additionally, using the terrestrial analog data will provide an excellent avenue to verify the uncertainty of our velocity and location model. After finding the uncertainty range of the velocity model, we can verify the location model with the eight EPs. Ultimately the goal is to determine the physical location of thermal moonquakes and correlate them to surface features to better understand lunar surface processes.

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