DETERMINING THE SHALLOW SURFACE VELOCITY AT THE APOLLO 17 LANDING SITE.

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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 [5] and have found three different thermal moonquake event types occurring at different times within the lunar day. The current goal of the project is to collocate the thermal moonquakes to physical surface features to determine the breakdown of lunar rocks. However, to locate shallow surface events, an accurate velocity model is needed. [6] presented a thermal moonquake location algorithm using first order approximation, including surface events only. To improve these approximations, a shallow surface velocity 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. Velocity models can be found by plotting distance versus time and fitting straight lines to various segments. The inverse slope is the velocity and the depth can be found via the intercept. The given velocity models fit a single line best fit line per segment, while the uncertainties can provide various fits with similar error parameters. 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 previous and updated 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. These new arrival times chosen with the various filters combined with the updated coordinates can be used to find a new model for the shallow surface velocity at the Apollo 17 landing site.

Figure 1 demonstrates the fit for the first two layers for the 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] with a depth down to 266 m or significant increase from 96 m. The preliminary velocity for layer 2 is 1109 m/s.

Table 1: Shallow Surface Velocity Models

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

These velocities and depths are generally higher than previously published but are still preliminary values. Additional analysis is needed for EP1 in the third layer. Additionally, the topographic map of the Apollo 17 landing site along with the configuration of the eight EPs (shown in Figure 2), suggests an asymmetric velocity profile surrounding the landing site. This velocity discontinuity is most likely due to crater bombardment and only seen in the top most layer. Considering the EP placement, we can divide the landing site into an east and west configuration for the top layer. The eastern velocity and depth can be found via EP4 and EP8 or 192 m/s and 222 m. The western profile has a velocity of 240 m/s and depth of 281 m found via EP2 and EP3. These results can be seen in Figure 3.

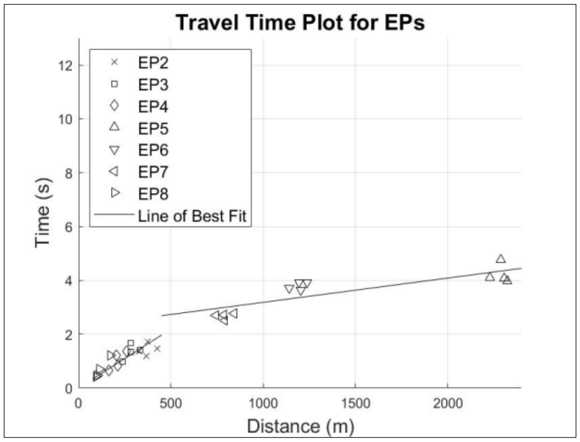

Figure 1 – Preliminary travel time plot for EPs using new arrival times and updated coordinates from [8].

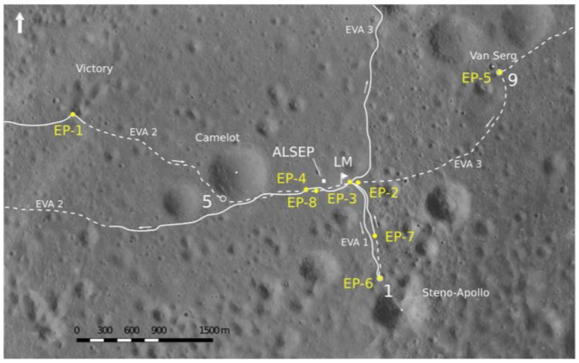

Figure 2 – Apollo 17 EP Locations from [8]

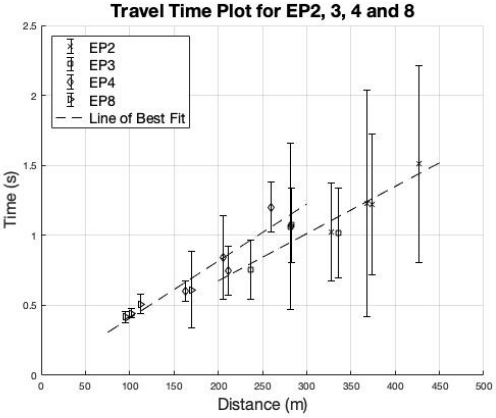

Figure 3 – East versus west side of array travel time plot for EPs using new arrival times and updated coordinates from [8].

Terrestrial Analog: To collaborate this asymmetric velocity profile of the Apollo 17 landing site, there was a terrestrial analog study performed to scale on the Cinder Lake Crater Field near Flagstaff, Arizona. This field was originally created during the Apollo era to train the astronauts on lunar terrain and geography. We performed multiple tests including a calibration experiment, a moveout line, and a wavelength replica of the Apollo 17 LSPE active experiment. 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, the terrestrial analog will yield additional insights about the Apollo site such as the subsurface layers and the ability of the location algorithm to recover sources under a controlled experiment. The terrestrial analog was performed with several instruments of different frequency resolutions enabling a comparison of detection capabilities.

Acknowledgments: This work was supported by NASA Headquarters un-der the NASA Earth and Space Science Fellowship Program – Grant 80NSSC18K1318.

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