NEAR SURFACE STRUCTURE FROM AN ACTIVE-SOURCE SEISMOLOGY STUDY OF APOLLO 11 ASTRONAUT ACTIVITIES. A. S. Khatib[1], N. C. Schmerr[1], B. Feist[2], J. B. Plescia[3], and N. E. Petro[4] [1]University of Maryland, College Park MD (akhatib1@umd.edu), [2]NASA Johnson Space Center, Houston TX, [3]Johns Hopkins University Applied Physics Laboratory, Baltimore MD, [4]NASA Goddard Space Flight Center, Greenbelt MD.

Introduction: The Passive Seismic Experiment Package (PSEP) deployed during the Apollo 11 extravehicular activity (EVA) in 1969 was designed to investigate the structure of the moon and its tectonic activity [1]. The short period seismometer in the experiment package picked up seismic events caused by the movements and activities of the astronauts as they completed their EVA and re-boarded the lunar module (LM). The Apollo passive seismic team labeled events produced by astronauts as type A and noted that they are strongest when the astronauts are in contact with the LM [1,2]. Here we find potentially astronaut-caused events in the seismic data and perform an active-source seismology study to obtain a local velocity structure of the subsurface of the landing site at Tranquility Base.

Previously, we detected an estimated 25 seismic events caused by the movements and activities of the astronauts as they interacted with the surface, their equipment, and each other. The study obtained travel times by calculating the difference between the time the event registers in the audio signal, taken from the live correspondence between the astronauts' and Mission Control in Houston Texas, and in the seismic signal. Distances between the events and the PSEP are obtained using a cropped high-resolution image of the landing site from the Lunar Reconnaissance Orbiter and a preliminary traverse map from the US Geological Survey [3] and supplemented using photography and video footage from the EVA.

Impact: Analysis of astronaut-caused seismic events during the Apollo 11 EVA could potentially yield seismic velocities at a much closer range than has previously been possible: in Apollo 14 and 16, astronauts deployed 91-meter-long linear arrays of geophones for their active source experiment, resulting in a source-seismometer separation of approximately 45 meters, and the seismic refraction experiment in Apollo 17 had source-seismometer distances ranging from 60 m to 3 km [4]. In comparison, the PSEP on Apollo 11 was placed about 17 meters south of the LM [1]. Detecting these nearer seismic events could be a feasible way to study local, shallow subsurface structure without dedicating mission time to an active source seismic study that focuses on close ranges and could be used in future lunar and planetary missions if effective.

Astronaut Activities as Seismic Sources: The PSEP seismometers were activated at 04:39:20 UTC [5,6], and the astronauts terminated their EVA at approximately 05:11:13 UTC. During this time, sources of events include Aldrin hammering into the surface for the first core tube sample at about 4:46:36 UTC and Armstrong accidentally dropping the Hasselblad film pack while loading equipment back into the LM at 5:03:01 UTC; there are other signals that have undefined source events, between 4:45 UTC and 5:10 UTC that provided velocity estimates. While the instrument remained on after the astronauts reentered the LM and registered source signals for events that occurred after the EVA ended (such as the ejection of the portable life support systems [PLSS] and the launch of the LM from the lunar surface), the study focuses only on the approximately 32-minute time window of the remainder of the EVA itself.

Our preliminary results from the study suggest that the velocity estimates range from 20 m/s to 150 m/s; while this range of values overlaps with previous studies that confirm the existence of a shallow, low-velocity layer [7], here we present several refinements to our analysis that will constrain the event timing and location and improve our estimate for velocity of the near subsurface. Specifically, we investigate how event timing involves knowledge of wave resolution of the seismic signal, the transmission times between when the events occur on the lunar surface and when they were detected on Earth, and the associated uncertainties. We plan to show the effect of these parameters on our velocity estimates.

Quantification and minimization of uncertainties: Our velocity estimates are dependent upon two primary variables: relative position of the source and seismometer on the surface of the Moon, and the relative timing between the source and instrument, obtained by using the audio recordings of astronaut activities, and the time stamps of the seismometer data. The travel time of an event is essential for calculating velocity estimates of the subsurface, but there are uncertainties associated with event picks in both the audio and the seismic data, as well as with the time corrections applied to them.

Uncertainties associated with event signal. The PSEP seismometer used in this study is the short period (SP) instrument, since it is most capable of recording higher frequency events characteristic of human-caused activity. The sampling frequency of the SP seismometer is 48 Hz, corresponding to 20.8 milliseconds between each sample. This sampling frequency contributes to an uncertainty in the picking of the seismic event, as the astronaut-generated signals were inherently high-frequency and not fully captured by the low sample rate of the instruments. To demonstrate this, a 0.5-second-long trace from an active-source seismology study conducted in Federal Hill, Maryland in 2019 – in which an 8 kg sledgehammer is collided with a 0.5-inch-thick aluminum plate about 50 meters away from a seismometer sampling at 8000 Hz – is down-sampled from the original sample rate to 50 Hz, which is close to the SP sampling rate (Fig. 1). When this is done, the original point at which the event pick was made is significantly less prominent and more difficult to differentiate from background noise, obscuring when the event really occurs.

Another cause of uncertainty from the low sample rate of the SP seismometer is the difficulty in ascertaining whether the feature being picked as the onset of an event is a pressure wave (p-wave) or a surface wave (s-wave) arrival, or somewhere in between. This would explain the wide range of velocity estimates we have obtained so far, since we could be equating two entirely separate phases.

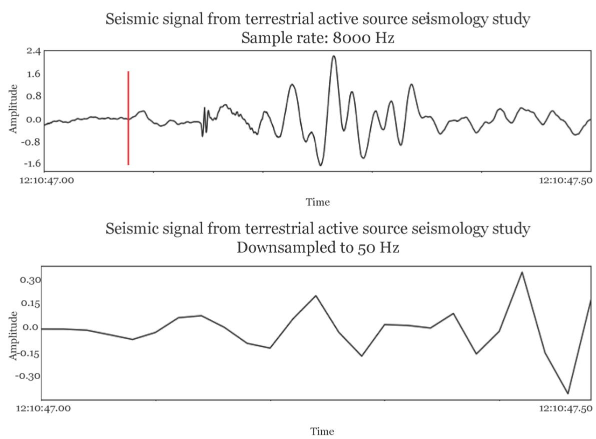

Fig. 1. (top) A trace taken from an active source seismology study conducted in Federal Hill, Md, that shows the impact of a hammer-stroke at 50 m from a geophone, at 8000 Hz sampling frequency; the red line denotes the P-wave arrival on the trace. (bottom) The same trace, down sampled to 50 Hz.

Uncertainties associated with transmission times: Time corrections that account for transmission delays as the signals travel from the lunar surface to Earth are necessary for both the audio and the seismic signal to calculate accurate travel times.

In the auditory data, the events are time-stamped in UTC with their times of reception in Mission Control in Houston, Texas, as taken from the digital archive of the Apollo 11 mission, Apollo in Real Time [8]. These timestamps fail to account for the transmission time between when an event occurs on the surface and when it is heard in the Mission Control room. We estimate that the uncertainty of this transmission delay is in the tens of milliseconds. It is not well-documented which transceiver station received communication signals from the lunar surface, as such adding to transmission delay uncertainty. The largest distance lies between Houston and Honeysuckle Creek in Australia [9] (and hence largest possible delay). Here we calculate the latency of the signal between its reception at the tracking station and its reception in Houston. Verifying these details and calculating travel times of telephone signals can narrow down the uncertainty of the transmission delay of the audio signal.

In the seismic data, the events were transmitted in real-time from the PSEP to a network of range stations in chunks every 0.06037 seconds. A time correction is applied to the seismic data as well to account for signal transmission delays, but the uncertainties can be narrowed down by ascertaining which range stations were used to receive data in the first 30 minutes of the PSEP's operation.

Calculating more accurate measures for transmission times and accounting for uncertainties in the event signal may shift or narrow the initial range of our initial velocity estimates and could help prove that this method is feasible to be used on future planetary and lunar missions. However, future seismic analysis of human-caused activity on a lunar or planetary mission requires a higher sampling rate on the seismometers to get accurate picks on separate phases of events, as well as consistent timestamping across all equipment packages.

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