ACTIVE-SOURCE SEISMOLOGY FROM ANTHROPOGENIC SOURCES DURING THE APOLLO 11 LUNAR MISSION. A. S. Khatib\textsuperscript{1}, N. C. Schmerr\textsuperscript{2}, B. Feist\textsuperscript{1}, J. B. Plescia\textsuperscript{1,3}, and N. E. Petro\textsuperscript{4} \textsuperscript{1}University of Maryland, College Park MD (akhatab1@umd.edu), \textsuperscript{2}NASA Johnson Space Center, Houston TX, \textsuperscript{3}Johns Hopkins University Applied Physics Laboratory, Baltimore MD, \textsuperscript{4}NASA Goddard Space Flight Center, Greenbelt MD.

Introduction: The Passive Seismic Experiment Package (PSEP) deployed by the Apollo 11 astronauts in 1969 provided the first seismic data from another body in the Solar System [1,2]. The primary sources of seismicity in the Apollo 11 seismic data were the movements and activities of the astronauts, ascent of the Lunar Module (LM), and thermoelastic and volatile venting from the LM descent module. Here we use these anthropogenic sources of seismic signal to perform an active-source seismology study to obtain a local velocity structure of the subsurface of the landing site at Tranquility Base.

Background: The PSEP instrument package was deployed by astronauts Neil Armstrong and Buzz Aldrin on July 21st, 1969 during their extravehicular activity (EVA). The instrument was comprised of 3 long period (LP) seismometers aligned to measure surface motion in the horizontal and vertical directions and 1 short period (SP) seismometer aligned to measure surface motion in the vertical direction. The SP seismometer is of particular interest to this study, as it is capable of recording higher-frequency events characteristic of anthropogenic activity with an approximate sampling frequency of 48 Hz (20.8 milliseconds between samples). As the instrument was placed approximately 16.8 m from the LM and actively collected data during the EVA and the LM’s departure from the surface, it recorded seismic signal from a number of anthropogenic events. The PSEP remained active until final turnoff on August 27, 1969, after the system failed to receive and execute commands [1].

Anthropogenic Seismicity: The SP seismometer recorded seismic events due to the astronauts’ activities on the Moon during their EVA and after they reentered the LM. The locations of these activities in relation to the LM and the PSEP have been marked on traverse maps and observed in great detail by the Lunar Reconnaissance Orbiter Camera Narrow Angle Camera (LROC NAC) [3]. The PSEP seismometers were activated at 04:39:20 UTC [4,5], and the astronauts terminated their EVA at approximately 05:11:13 UTC. Fig. 1 shows the location of astronaut seismic sources, including the hammer strokes from the first and second core tube sample collection, taken on the north side of the LM, parts of the solar wind array striking the ground during assembly, and the camera pack dropping onto the surface as the astronauts loaded equipment back into the LM before reentering the surface.

While the astronauts did not directly interact with the surface after the conclusion of the EVA, they remained on the surface for approximately 12 more hours until their launch from the lunar surface at 17:54:00 UTC; during this time, seismic sources include the pressurization and depression of the LM, a jettison of the astronauts’ portable life support systems (PLSS), movement within the LM, and the launch of the LM.

All of these seismogenic events occur at distances of 14 m to 24 m away from PSEP (Fig. 1).

**Figure 1.** The locations of anthropogenic seismic events during the astronauts’ EVA and after they reentered the LM are plotted in relation to the passive seismometer, which is at the origin. Locations taken from USGS traverse maps [3].

Audio and Seismic Timing: The time of arrival of the seismic signal to the PSEP is crucial to the constraint of approximate seismic velocities, and should differ from the time of the signal generation by a factor of milliseconds. For the SP instrument, our time resolution is approximately 20.8 milliseconds, corresponding to 4-5 samples for a 14 meter distant source. The time delay between source generation and arrival is calculated using the time differences between the event signals in the seismic data taken from PSEP and the event signals in the audio signal, taken from the astronauts’ microphones from their correspondence with Mission Control in Houston, Texas. At the onset of each event (e.g., detecting each hammer stroke to the ground in the audio and seismic signal) the time associated with record of the event in the audio signal will be assumed to be the time of the signal generation, and the time...
associated with the signal in the seismic data will be the time of arrival. Using the relative time delay between the two signals, as well as the approximate distances using traverse maps of the Apollo 11 landing site, the seismic velocities can be evaluated for the array of distances across Tranquility Base.

A time correction must be made to more accurately constrain the time of arrival of these events to the passive seismometer.

**Future work:** Analysis of anthropogenic noise in passive seismic data can be an effective way to study local subsurface structure without dedicating mission time specifically to an active source seismic study. The seismic packages deployed during Apollo 17 and earlier missions detected high-frequency signals from thermoelastic stresses by the LM descent stage and mission equipment left on the surface [6]. If this technique proves effective in yielding seismic velocities for the geology under Tranquility Base, it can be used in future lunar and planetary missions, provided the equipment packages are designed so the event signals can be time-stamped consistently.

**Acknowledgments:** We thank Dr. Yosio Nakamura for discussions concerning the seismic transmission timing.

**References:**