Archiving the Apollo active seismic data

MATTHEW BRZOSTOWSKI and ADAM BRZOSTOWSKI, Schlumberger

The Apollo missions included several scientific experiments on the Moon, some of which were dedicated to seismic exploration. The seismic experiments consisted of both passive and active instruments. The passive seismic data were initially analyzed and studied by a group of scientists from Columbia University, the University of Texas, MIT, and the University of Hawaii led by Garry Latham. Yosio Nakamura (University of Texas), a member of that group and a leading authority on the internal structure of the Moon and moonquakes, has continued to study that data. Besides measuring natural seismic activities in the Moon's interior, the passive data also recorded man-made impacts such as the S-IVB (third stage of the Saturn launch vehicle) and LM (lunar module) crashing into the surface. The active seismic experiment included the use of three different sources fired either while the astronauts were on the Moon or remotely after they had departed. The active data was studied by a group headed by Robert Kovach (Stanford).

However, the active data as well as the other ALSEP (Apollo Lunar Surface Experiment Package) data have been in a format not necessarily conducive for modern-day analysis. Finding someone who could actually read this format was a four-year act of frustration. Salvation came when the skills of Nakamura were volunteered to help with the effort. As Nakamura states, "Digital data acquisition of scientific data was still in its infancy at the time and very few standard formats, if any, existed. For example, the SEG-Y format was published in 1975, several years after the first ALSEP was flown." The archived copies at the NSSDC (National Space Science Data Center) were "reformatted at JSC (Johnson Space Center) from the transmission format into a PI (Principal Investigator) tape format. They were still pure binary bit strings, like the raw data from the Moon, but rearranged and time stamps added."

Nakamura has a long history of recovering various Moonquake events from the passive seismic data and thus was very familiar with the logic behind the engineering. His help, plus the remembrances of Bob Kovach, was a breakthrough in reading the data. The next stage involved unraveling the mystery of what we were reading. As it turned out, some of the information on what was contained on the records was inaccurate. Also confusing, from an exploration perspective, was the way the data were recorded. The active seismic systems were actually turned on at the beginning of the experiments and thus were recording continuously before the first source was ever fired until some time after the last source was fired. Obviously, issues of determining time zero (and any source or recording system delays) and then extracting a conventional record of finite length had to be resolved. Fortunately, trace displays were available from the Preliminary Science Reports, and mission logs including voice recordings with time stamps were available to check the accuracy of our assumptions as the puzzle was solved. The end result of all this is that the data are now available in a table or spreadsheet form and, more importantly, in SEG-Y format. This will that ensure future generations can use the data, especially as we prepare equipment and procedures for further exploration when we return to the Moon.

Figure 1. Apollo 14 backup astronaut Joe Engle training with the thumper source on 27 August 1970. The 21 initiators were in the large base on Engle's right. The cable wrapped on that end carries the "fire" signal back to the Central Station (see Figure 4). The end on Engle's left has a selector switch for each initiator and the geophone wire spooled around it for future deployment (see Figure 2). The "fire" switch can be seen under the cuff checklist strap on his left wrist.

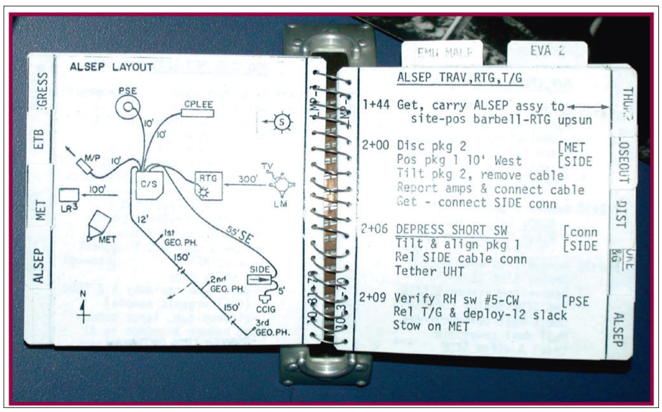

Figure 2. Diagram from the Apollo 14 EVA1 Cuff Checklist depicting how the three geophones (GEO. PH.) were to be deployed. The mortar (M/P) was never fired. You can also see the geophone for the Passive Seismic Experiment (PSE). C/S is the Central Station. The thumper is not depicted.

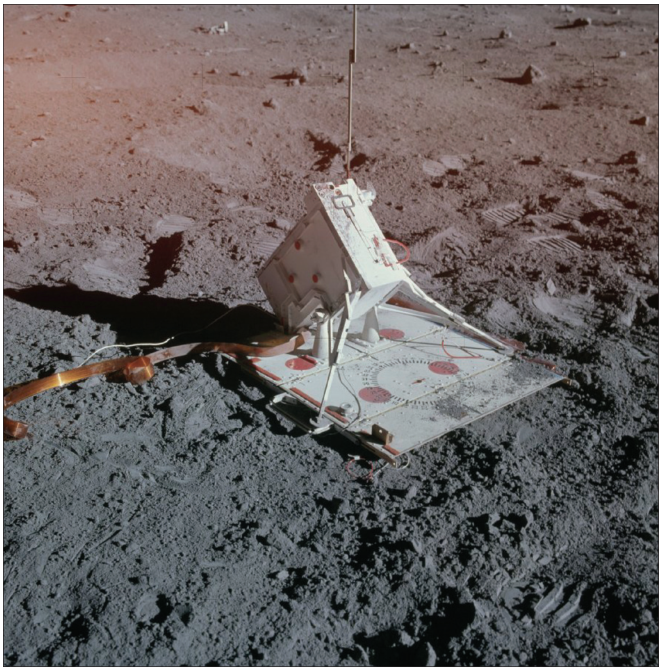

Figure 3. Apollo 16 mortar containing the four rocket-propelled grenades of which three were launched.

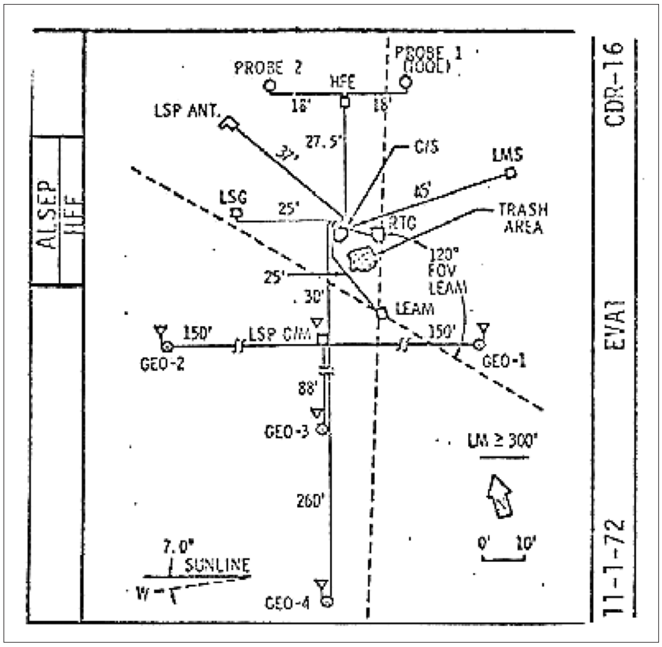

Figure 5. Apollo 17 EVA-1 Cuff Checklist diagram depicting the planned deployment of the four geophones, GEO-1 through GEO-4.

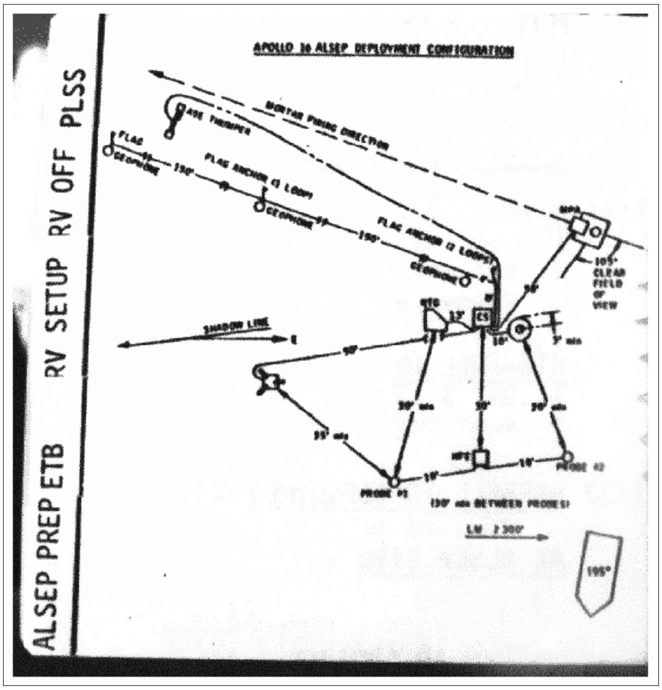

Figure 4. Apollo 16 Cuff Checklist depicting how the three Apollo 16 geophones, thumper, and mortar were to be deployed. Note the mortar is pointing in the opposite direction to the Apollo 14 deployment (see Figure 2) besides being offset laterally.

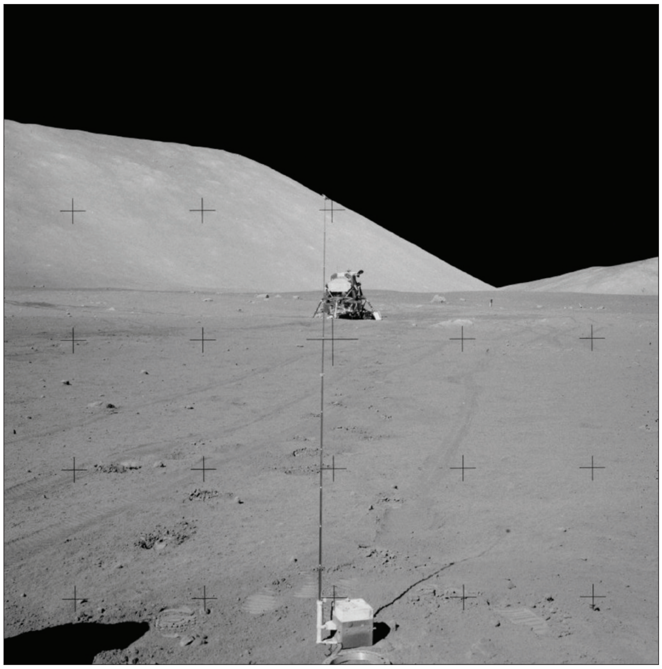

Figure 6. Explosive package No. 3 (of eight) with the Apollo 17 Lunar Module (LM) in the background.

The Experiments

The active seismic experiments used a thumper for Apollo 14 and 16, a rocket propelled grenade for Apollo 16, and an explosives package for Apollo 17. The experiments used three geophones on Apollo 14 and 16 (referred to as the ASE or the Active Seismic Experiment) and four geophones on Apollo 17 (referred to as the LSPE or the Lunar Surface Profiling Experiment). All of the geophones used a moving-coil-magnet with a natural resonant frequency of 7.5 Hz. Only the thumper was used by the astronauts while on the surface, while the grenade and explosives packages were set up by the astronauts but fired once they had departed for obvious safety reasons.

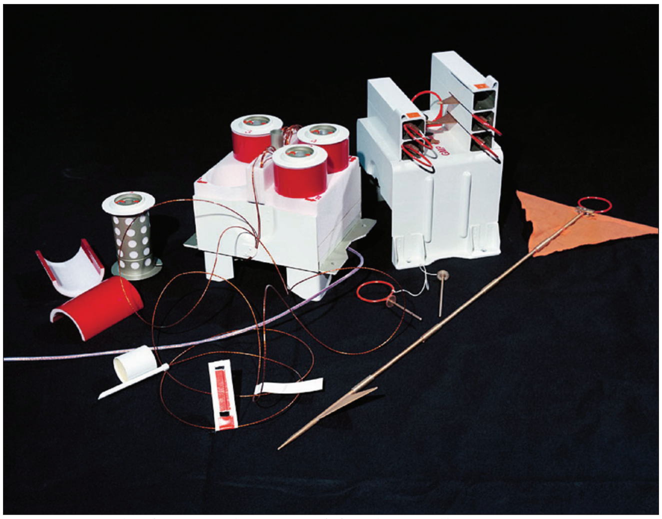

Figure 7. The four geophones used for the Apollo 17 active seismic experiment (LSPE or Lunar Seismic Profiling Experiment). Check out the pin flag!

Figure 8. One of the geophones depicted in Figure 7 "planted" at the Apollo 17 landing site.

The thumper, see Figure 1, used 21 "standard Apollo initiators" as an explosive point-source to thump the ground. The idea was to thump every 4.572 meters (15 feet) along the 2D line represented by the three point-receiver geophones spaced 45.72 meters (150 feet) apart. This thumper experiment is actually the closest thing to what an explorationist would call a conventional reflection or refraction survey. Apollo 14 recorded 13 thumper records and Apollo 16 recorded 19 thumper records.

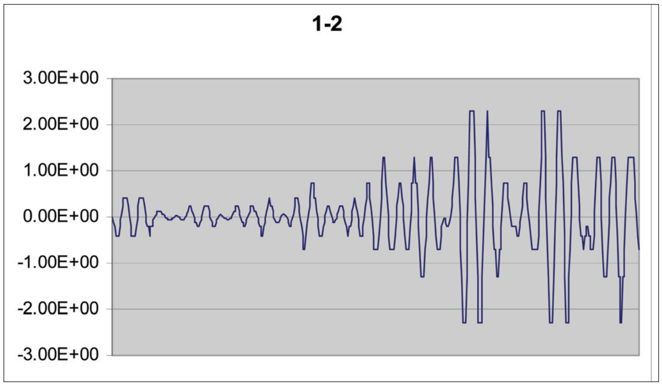

Figure 9. The Apollo 14 seismic data recorded at geophone number 2 and thump number 1. About one second of data is depicted. The vertical scale is measured in Volts. Data courtesy NASA and the NSSDC.

The four geophones used on Apollo 17 were laid out in a T-shaped pattern of approximately 80 × 90 m as shown in Figure 5. The explosive packages were of various charge sizes placed at various offsets from the geophones. Figure 6 shows one of them deployed. Figures 7 and 8 show the geophones before and after deployment. The charge sizes and longer offsets were designed to get a better understanding of deeper layers.

The Data

Figure 9 is a representative trace display and is characteristic of the type of data recorded. This trace was used with others to measure first-arrival times for deriving the near-surface velocity. A surprisingly low velocity of approximately 100 m/s was found. Couple that low velocity with the obviously ringy nature of the recording, and you have a very unique data set.

The data obviously lend themselves to reprocessing using modern imaging and signal-to-noise improvements. Lessons learned should be used to guide future lunar seismic exploration both for understanding the geologic history of the Moon and for economic exploitation. Fortunately, the data can now be accessed from the NSSDC not only in the original raw form but also in table or SEG-Y format.

Suggested reading. The original data are archived at the NSSDC (*http://nssdc.gsfc.nasa.gov/*), while information about the experiments, including the PSRs may be found at *http://history.nasa.gov/alsj/*. TLE

Acknowledgments: All images are courtesy of NASA.

Corresponding author: MBrzostowski@comcast.net