Analysis of Rediscovered Data from Apollo 17's Lunar Seismic Profiling Experiment: Evidence for Events Associated with Sunrise

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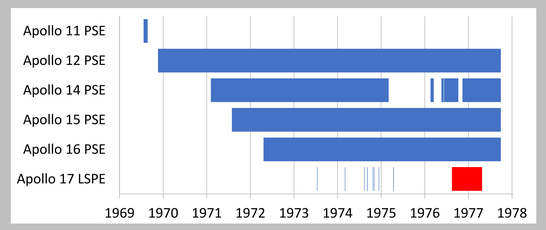
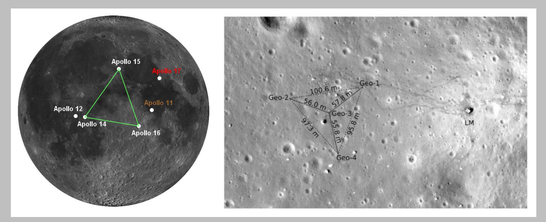
Introduction and Goals

- Three goals for this study:
  - Identify additional detections of deep moonquakes from Apollo 17 LSPE data that correlate with Apollo 12–16 PSE data
  - Correlate meteorite impacts from Apollo 15 and 16 PSE SP data and Apollo 17 LSPE data
  - Investigate potential of using Apollo 17 LSPE geophones as a small-aperture array to locate thermal events
- Apollo 12, 14, 15, and 16: Passive Seismic Experiment (PSE) with Long Period (LP) instruments and a Short Period (SP) instrument components
- Apollo 17: Lunar Seismic Profiling Experiment (LSPE) with 4 geophone components
- LSPE data (Aug. 15, 1976 – Apr. 24, 1977) was never thoroughly analyzed neither independently nor in conjunction with simultaneous seismic measurements made at Apollo 12, 14, 15, or 16.

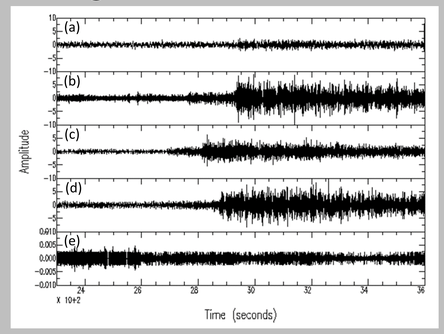


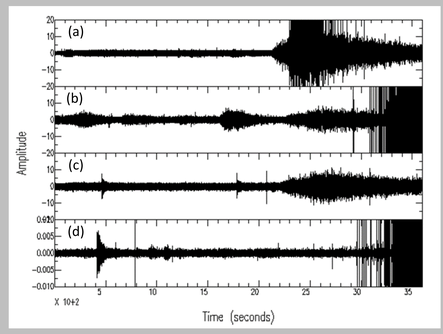


Top: Period of observation for each Apollo station from 1969 to 1977. Bottom Left: Apollo 11, 12, 14, 15, 16, 17 landing sites. Apollo 17 is red because it is not currently in the seismic network. Apollo 11 is brown because it does not contribute to seismic network. (Adapted from Kawamura et al., 2015) Bottom Right: Apollo 17 LSPE geophone locations and the location of the lunar module. (Heffels et al., 2017)

Deep Moonquakes and Meteorites

- Deep moonquake analysis focused on the moonquake clusters closest to the Apollo 17 site: A1, A6, A7, A18, and A22.
- Correlation analysis affected by sensitivity of instruments. PSE SP and LSPE geophones frequency ranges overlap, while PSE LP instruments have a lower frequency range.
- Meteorite impact analysis focused on the 31 known meteorite impacts detected at one or more Apollo stations during the LSPE data range.
- Apollo 17 geophones were not designed to measure distant events, and meteorite impacts close to the other stations were likely not large enough to produce seismic energy detectable at such large distances.

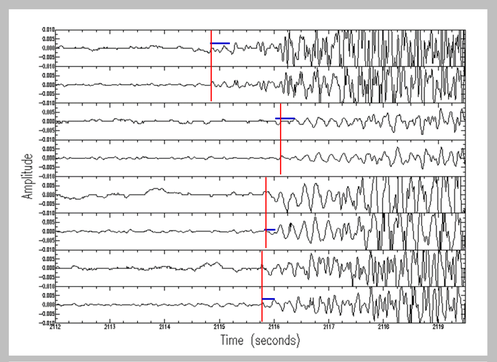




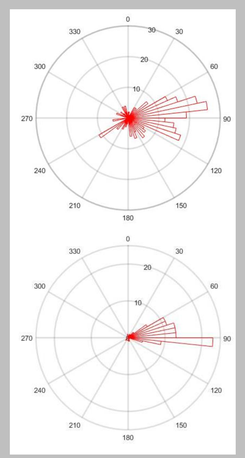
Left: Deep moonquake from cluster A6 seen on 08/26/1976 hour 12 at (a) Apollo 12lpy, (b) Apollo 14lpy, (c) Apollo 15lpy, (d) Apollo 16lpy, but not on (e) Apollo 17 LSPE geophone 1. Right: Meteorite impact seen on 04/17/1977 hour 23 at (a) Apollo 14 PSE SP, (b) Apollo 15 PSE SP, (c) Apollo 16 PSE SP, but not on (d) Apollo 17 LSPE geophone 1.

Thermal Events

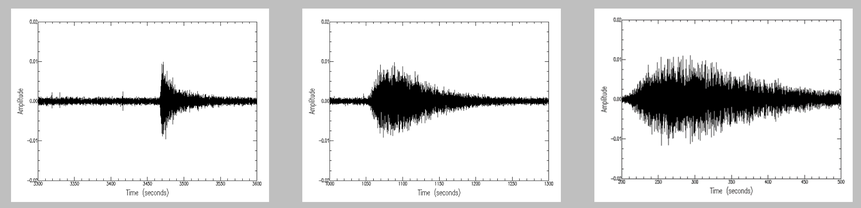
- Identified diurnal enhancements of events
  - Hand analysis: two enhancements of events with a gap of 9 hours at sunrise
  - Hidden Markov Models (HMMs): enhancements of events at both sunrise and sunset
- Arrival times identified for 609 events
- Classifications waveforms (temporal distribution)
- Preliminary arrival direction analysis (azimuth)

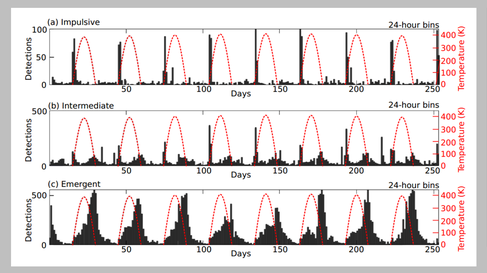


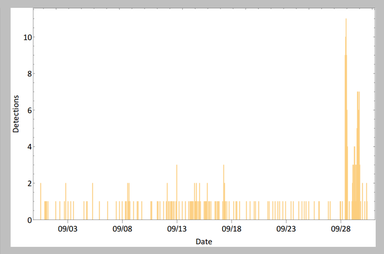
Determining arrival times from Apollo 17 LSPE geophones. Red indicates the arrival time, while blue indicates the uncertainty region. From top trace to bottom trace: raw and processed geophone 1 data, raw and processed geophone 2 data, raw and processed geophone 3 data, and raw and processed geophone 4 data.



Polar histogram of event directions for subset events (top) and sunrise enhancement events only (bottom). North is 0°, East is 90°, and continues clockwise, with each bin containing 6°.







Top Left: Sample of Impulsive event, Top Middle: Sample of Intermediate event, Top Right: Sample of Emergent event. Bottom Left: Analysis from HMMs shows the three types of events broken down in 24 hour time bins for 8 months of data. The red curve is temperature based on the solar flux. Bottom Right: Histogram of hand analysis results showing all events broken down into hour time bins for September 1976. The impulsive peak is made of two separate enhancements, separated by a delay.

Results

- Sunrise and sunset events have different waveforms.
- Sunrise events have two different enhancements and may be caused by different phenomena suggesting multiple origins of thermal events.
  - Sun warming different part of landscape, such as the Lee-Lincoln scarp
  - Expansion and contraction of rocks around the Lunar Module
  - The varying time interval between initial insolation and peak temperature: rocks have higher thermal inertia than soil, hence they may fail later.
- The directions of events are mainly random outside of sunrise and sunset times.
- Further exploration into impact of solar cycle on lunar surface and locations of seismic events

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References

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