COMPREHENSIVE PROCESSING OF THE APOLLO LUNAR SEISMIC EVENT DATA. R. C. Bulow,[1] C. L. Johnson[1], and P. M. Shearer[1] [1]Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California, San Diego

Introduction

The Apollo Passive Seismic Experiment consisted of four seismic stations deployed on the lunar surface between 1969 and 1972. Data were recorded continuously from deployment until 1977. Previous studies often used only small subsets of all the available data due to computational limitations. In our study, event data (lunar seismic signals detected in the continuous time series) in their entirety are converted into a standard format for seismological analysis. Events have been previously classified into three types: deep moonquakes, shallow moonquakes, and impacts. The tapes containing the data, which we obtained from the IRIS Data Management Center, contain just under 11,000 events - the bulk of the approximately 12,000 catalogued events.

Several programs to view and filter the data are used to improve data quality. Data with various irregularities such as timing errors or telemetry problems are corrected or removed. These modifications allow for modern processing techniques to be applied consistently to the remaining data. Based on our preliminary analyses we estimate 97.6% of the data are usable for further study.

This work permits a range of investigations, using stacking techniques that do not require waveform coherence. The poor signal-to-noise ratio of the lunar seismograms renders conventional automatic detection methods (used for terrestrial seismic events) ineffective for these data. Using recently-developed techniques and our processed version of the data, we will focus on three main goals: better identification and cataloguing of moonquakes, moonquake locations, and estimating lateral variability in scattering properties of the lunar regolith.

Background

The four stations comprising the Apollo Passive Seismic Experiment were part of ALSEP, the Apollo Lunar Surface Experiment Package. The package was designed to be portable and lightweight for ease of deployment by the astronauts. Each station consisted of a three-component long period seismometer and a one-component (vertical) short period seismometer.

Original examination, data quality control, and moonquake classification were performed in the 1970's [1]. Improvements in computational resources, along with planning for upcoming lunar missions has led to recent renewed interest in the Apollo-era seismic data. Current studies include investigations of deep moonquake sources ([2]; Nakamura, private communication).

I. Catalogue designations

Many of the events we are examining have been previously classified [1] into three main types: deep moonquakes, shallow moonquakes, and impacts. We hope to reproduce and improve upon this process. Every event will be cross-correlated with every other event to produce a measure of similarity for each event pair. This will be done on both the time series and their envelope functions.

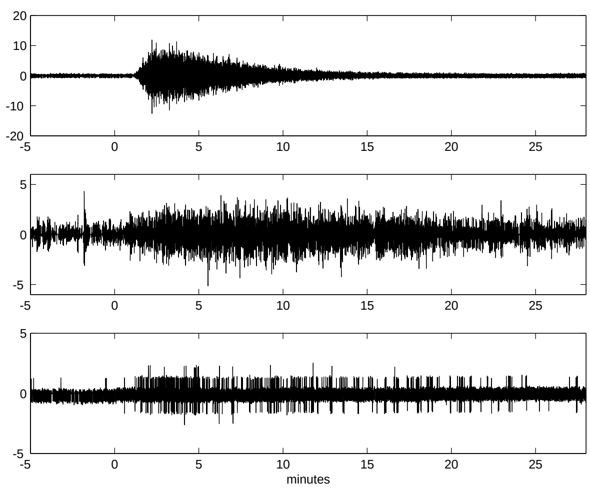

Figure 1: High, medium, and low-quality traces

Figure 1 shows three examples of lunar seismic traces. The top trace is an example of a very clean event, with a relatively high signal-to-noise ratio (SNR). Unfortunately, most events have inferior SNR on one or more recorded channels (bottom trace). This may arise from relatively low signal levels or from noise spikes caused by telemetry problems or instrumental glitches. We hope to classify as many of these low SNR events as possible by devising waveform similarity measures that are robust with respect to incoherent signals and noise problems in the data. To do this we plan to compute envelope functions for each trace prior to applying cross-correlation. This may be difficult for traces with low SNR and large numbers of noise spikes.

Using each event's similarity measure, cluster analysis can then be applied to group the events. Cluster analysis arranges items hierarchically. Each seismic trace begins in a class by itself. In small steps, the criterion as to what is and is not unique is relaxed. As a result, more traces are linked together, allowing identification of event clusters.

Currently, we are in the process of 'grading' the events to aid in the correlation effort. This consists of visually inspecting each trace of every event and assigning it a grade of 'A,' 'B,' or 'C' based on the quality of the trace. For example, the top trace of Figure 1 would receive the grade 'A,' the middle trace 'B,' and the bottom trace 'C.' The grading technique considers several qualities including SNR, initial impulse coherence, and envelope shape. Table 1 shows a breakdown of the grading results.

Table 1: Breakdown of events:

total: 10,748

	previously classified		
deep	shallow	impact	Other
3,145	28	1,744	5,831

Our quality assessment:

grade 'A'	grade 'B'	grade 'C'
3%	11%	86%

II. Event Location

We may be able to estimate the distance from a lunar seismic event to the Apollo stations through the identification of systematic patterns in the shape of an event's envelope function. An envelope function "outlines" a seismic trace by preserving its amplitude (but not phase) information. Closer events can be expected to have impulsive onsets, while distant events would have more emergent onsets. This will provide a way to estimate locations for many events that have not been previously located, providing crucial information about the internal structure of the moon.

III. Scattering Characteristics

Close surface impacts, distant surface impacts, and moonquakes will produce different types of scattered wave trains, travelling through separate regions of the moon's scattering zone. [3] By taking our best locations for the catalogued events and looking for systematic variations of scattering strength with position, we may be able to identify areas that have more or less scattering than the lunar average. Comparison of these results with mapped surface features and with previously inferred crustal and upper mantle structure will provide new information on the lunar interior. For example, scattering data may be able to differentiate between the heavily cratered lunar highlands and the relatively flat, undisturbed maria.

References:

[1] Nakamura et al. (1981) *Galveston Geophysics Laboratory Contribution No. 491*, Tech. Rept. No. 18.
[2] Oberst, J., and Mizutani, H. (2002) *LPSC XXXIII.*
[3] Toksoz, Dainty, Solomon, Anderson (1974) *Reviews of Geophysics and Space Physics*, Vol. 12, No. 4.