Modeling Seismic Waveforms in a Highly Scattering Moon. Jean-Francois Blanchette-Guertin[1], Catherine L. Johnson[1,2], Jesse F. Lawrence[3]. [1]University of British Columbia (6339 Stores Road, Vancouver, BC V6T1Z4, CANADA; jguertin@eos.ubc.ca), [2]Planetary Science Institute (1700 Fort Lowell, Suite 106, Tucson, AZ 85719), [3]Stanford University (397 Panama Mall, Mitchell Building, Room 360, Stanford, CA 94306).

Overview: Synthetic seismograms for a suite of scattering models of the Moon have been generated using a modified version of the phonon method [1,2]. Each model assumes that scattering on the Moon occurs in a near-surface layer (the scattering layer). The characteristic decay times of the signals are measured and quantitatively compared with the same decay times measured on the Apollo Passive Seismic Experiment data (APSE, 1969-1977) [3,4].

Modeling of seismic waveforms in a highly heterogeneous media allows us to investigate the effects of the scattering layer thickness, the mean distance between scatterers, intrinsic attenuation (Q_i) as a function of depth and frequency and the source function (impact vs. quake) on the resulting recorded signals. A thorough investigation of these parameters will allow us to identify suites of lunar models that reproduce the APSE data attributes and thus constrain the scattering properties of the Moon.

Table 1: Scattering characteristics of the 3 models used for generating the synthetics seismograms analyzed here. T_{SL} is the thickness of the near-surface scattering layer, and ∂_s is the distance between scatterers in the layer.

	T_{SL} (km)	∂_s (m)
Model 1	1	50
Model 2	10	50
Model 3	10	500

Synthetic Seismograms: The modified phonon method tracks individual quantized lattice vibrations ("phonons") through a scattering 1D heterogeneous medium. We assume an isotropic medium with heterogeneity length scales (scatterers) in the range 50-500 m. Scatterers have random orientations, and occur within a near-surface scattering layer that has a thickness of 1-10 km. This layer may represent the scattering properties of the lunar megaregolith. Phonon amplitudes and arrival times are recorded at surface locations.

We calculate seismograms for three different scattering models of the Moon (Table 1 and Figure 1) and three different source depths (0, 20 and 1100 km), all using the velocity and density profiles from [5]. We calculate synthetics at two sampling frequencies (7 and 40 Hz), corresponding to the long-period (LP) and short-period (SP) APSE data. The three source depths used are typical of recorded impacts, shallow moonquakes and deep moonquakes respectively. We model signal degradation caused by limited analog-to-digital resolution with noise (~1-3 digital units) to simulate the quality of the APSE data. The resulting synthetic signals are convolved with the APSE instrument responses.

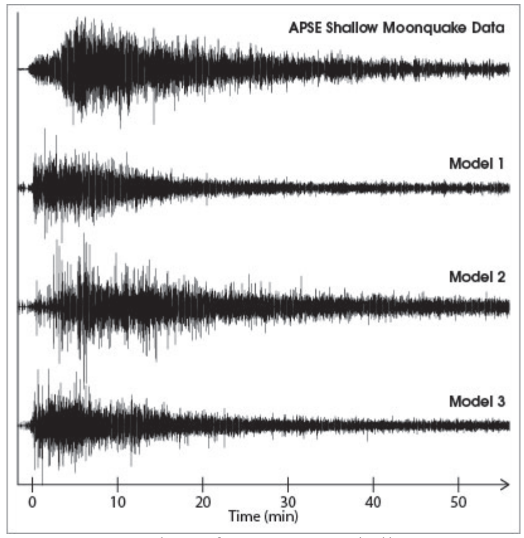

Figure 1: Examples of an APSE shallow moonquake seismogram (recorded on the LP-X component), as well as synthetics from the 3 models for 20 km deep sources (showing the radial component). All signals have an epicentral distance of ~20°.

Synthetic and APSE data analysis steps: Each of the synthetic and APSE seismograms was processed as follows:

1. Deconvolve the APSE instrument response
2. Bandpass filter the signals into three LP bands and four SP bands: 0.25-0.75 Hz, 0.75-1.25 Hz, 1.25-1.75 Hz, 2-4 Hz, 4-6 Hz, 6-8 Hz and 8-10 Hz.
3. Generate the signal envelope.
4. Average the envelopes for the horizontal channels (assumes horizontal isotropy).
5. Smooth the envelope function using a 5 minute (LP) or 35 second (SP) running window, keeping the 75th percentile (empirically determined).
6. Determine visually where the amplitude starts decaying exponentially (the beginning of the fit).
7. Determine the time at which the amplitude is twice the background noise. This determines the end of the fit.

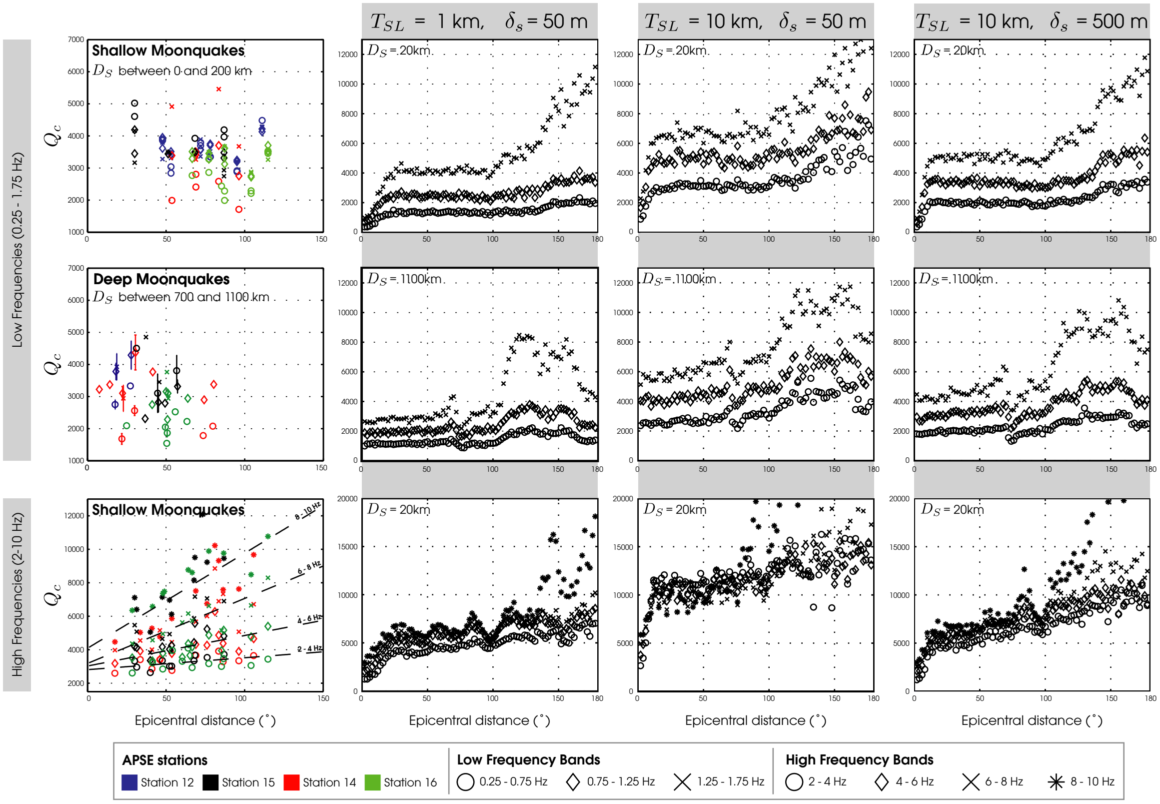

Figure 2: APSE results (left) for shallow (LP and SP) and deep (LP) moonquakes, and synthetic results from the three scattering models in Table 1, for comparable source depths.

8. Least-squares fit an exponential decay curve of the form e^{-t/τ_d} to the decaying section of the smoothed envelope. τ_d is the characteristic decay time.
9. Convert τ_d to the frequency-specific decay factor $Q_c = \pi f_c \tau_d$, where f_c is the central frequency of the frequency band analyzed. Q_c^{-1} represents the fraction energy dissipated after one period of oscillation.

Observations from preliminary synthetic results: We show Q_c for our synthetic seismograms for the scattering models in Table 1 and two source depths, together with the results for the APSE data [4] in Figure 2. Initial modeling results indicate:

- Q_c for a given LP band is lower for deep events than for shallow events (seen in the APSE data).
- SP Q_c values are generally larger than LP values (seen in the APSE events).
- A dependence of Q_c on frequency is seen in the 0.25-1.75 Hz band (not seen in the APSE data).
- There is no dependence of Q_c on frequency in the 2-10 Hz band (not seen in the APSE data).
- Q_c is nearly constant over the range of epicentral distances covered by the APSE data in the LP bands (0-150˚).
- The magnitude of Q_c increases with increasing scattering layer thickness and with decreasing distance between scatterers.
- Shallow events exhibit a sharp increase in Q_c at short epicentral distances, whereas deep events do not, suggesting shallow events can be classified as local or teleseismic events. All deep events are teleseismic.

Conclusions: None of the 3 models investigated reproduce all the characteristics of the APSE data. We continue to compare APSE data with synthetic seismograms generated from more model types, including those with low-velocity layers, variable-scattering layers, deep scattering layers, and variable Q_i with depth and frequency Such comparisons will illuminate what suites of models could represent the Moon, and what steps could be taken in future lunar seismic experiments to mitigate the negative influence of scattering.

References: [1] Shearer, P. and P. Earle (2004) *Geophys. J. Int.*, 158, 1103-1117. [2] Lawrence, J. F. and C. L. Johnson (2010), *LPSC 41*, Abstract #2701. [3] Blanchette-Guertin, J-F. et al. (2011), *LPSC 42*, Abstract #1374. [4] Blanchette-Guertin, J.-F. et al. (2011), *JGR*, submitted. [5] Weber, R. C. et al. (2011), *Science*, doi: 10.1126/science.1199375.