SYNTHETIC SEISMOGRAMS WITH HIGH-FREQUENCY SCATTERING FOR THE MOON. J. F. Lawrence[1] and C. L. Johnson[2], [1]Stanford University (397 Panama Mall, Mitchell Building, Room 360, Stanford, CA 94306; jflawrence@stanford.edu), [2]University of British Columbia (6339 Stores Road, Vancouver, BC V6T 1Z4, CANADA).

Introduction: We investigate the seismic scattering effects of a highly heterogeneous regolith layer on the Moon, and how shallow heterogeneity effects high-frequency seismograms. Lunar seismograms recorded during the Apollo Passive Seismic Experiment (APSE; 1969-1977) differ from Earth-based seismograms in that they poses only high-frequency waves that have long, apparently incoherent coda.

The limited number of stations, along with the 10-bit digitization of the data and scattering have resulted in challenges to analyzing the data. The APSE data contain limited ray paths through the mantle and crust, with no ray s through the deepest lunar mantle or core. The arrival times of P- and S-wave data are difficult to measure due to noise, and later-arriving waves are entirely masked. Consequently, there exists great uncertainty in moonquake locations and interior velocity structure [1,2].

In this investigation we present theoretical seismograms generated using a new modified version of the phonon method [2]. The synthetic seismograms are generated with several models, illustrating 1) what degree of scattering is appropriate for lunar seismograms, 2) what lunar structures are currently seismically detectable given the high degree of scattering, and 3) what network geometries are most appropriate for potential future lunar seismic networks.

Method: This modified seismic phonon technique [1] is ideal for lunar seismograms because it generates high-frequency synthetic seismograms using a highly efficient paradigm. The seismic phonon method allows individual phonons (lattice vibrations) to scatter within the medium. When a phonon encounters a heterogeneity, it scatters (forward, back, or askew) with probability determined by the elastic constants and snells law. The sum of many phonons approximates the full wave with far fewer computations. The medium can be parameterized as 1) a stochastic model of heterogeneity, 2) as a predetermined 3D model, or 3) some combination of stochastic and pre-determined. Advantages of this method include the low computational requirements necessary for other methods to yield high-frequency synthetics.

Stochastic Heterogeneity: Stochastic models of heterogeneity can be used to quickly evaluate the appropriate degree of heterogeneity necessary to simulate the observed scattering in lunar synthetics. The appropriate level of scattering is determined by minimizing the difference theoretical and recorded seismic energy decay over time from *P*-wave onset. Scattering between 60% and 80% obscures later waves and generate sufficiently long coda to simulate lunar records (Fig 1 &2).

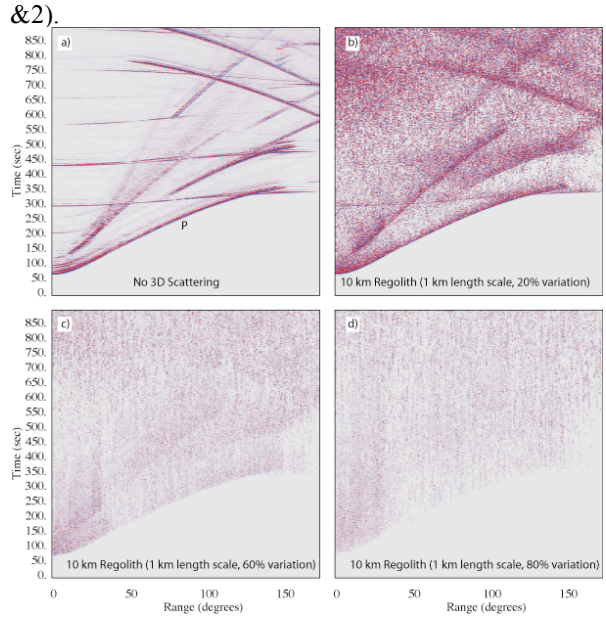

Figure 2: Synthetic phonon seismograms calculated with a) no scattering, and scatterin of b) 20%, c) 60%, and d) 80% on 1km scale lengths to 10 km depth.

As heterogeneity increases in amplitude and/or reduces in scale, the scattering at high frequencies increases. The appropriate level of scattering is determined by comparing the envelopes (positive instantatious amplitude without phase) of the wave observed and synthetic forms.

Discussion: The strong degree of shallow phonon scattering required to match observed lunar seismograms suggests that 3D heterogeneity within the regolith layer dominates the lunar seismograms. Any potential future lunar seismic network must either compensate for the high degree of scattering or the accept limitations in experimental outcome. Without accounting for scattering, the data quality would result in greatly limited uncertainty of moonquake locations and lunar structure. A dense lunar seismic array (cluster of stations) would provide an experimental design for interferometric techniques that could better extract the desired moonquake signals from the "noise".

When we account for actual noise and the poor digitization of the signals compared to modern earth-

based studies, the effect of scattering is compounded further.

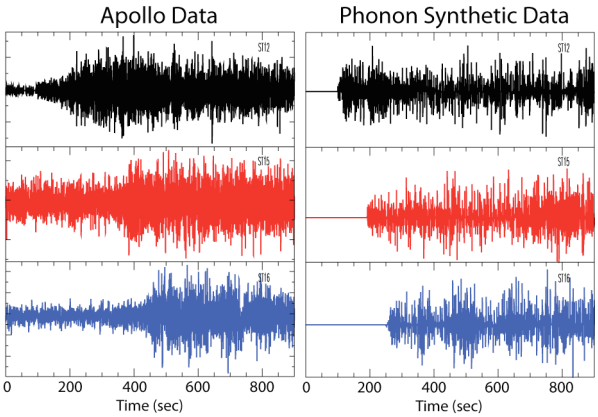

Figure 3: Observed and synthetic phonon seismograms for a deep moonquake (1975,304,06:34). The synthetic seismograms were generated with 60% scattering, 1km scale length, to 10 km depth. Note, the synthetics seismograms are noiseless.

References: [1] Nakamura Y. (1983) *JGR, 88,* 677–686. [2] Jeannine Gagnepain-Beyneix, Philippe Lognonné, Hugues Chenet, Denis Lombardi and Tilman Spohn, (2006) Phys. Earth and Planetary Int., 159, 140-166. [3] Shearer P. and P. Earle (2004) *Geophys. J. Int.*, 158, 1103-1117.