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Large Impacts Detected by the Apollo Seismometers: 2. Impactor Mass Estimation

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Meteoroid impacts are important seismic sources on the Moon. As they continuously impact the Moon, they probably are a significant contribution to the lunar micro-seismic background noise. They also were associated with the most powerful seismic sources recorded by the Apollo seismic network. We have selected for our analysis three large meteoroids impacts (impacts on day the 13th and the 25th of January and the 14th of November 1976) and show that their mass can be estimated with rather simple modeling technique.

The comparison between the signals recorded by Apollo seismic stations and synthetic amplitudes of seismograms was used to determine the momentum transfer of the impactors. Only the vertical components at each station have been used. In order to calibrate and check our results, we first started with the artificial impacts for which the characteristics of the source (impact velocity and mass), its location and time are well known from the National Aeronautics and Space Administration's tracking information. For this purpose, we have computed synthetic seismic waveforms in a spherical lunar model, up to 2.5 sec in signal period. This approach does not model the scattering and lateral variations effects and cannot be used for a direct comparison with the recorded waveforms. It however models partially the reverberation processes in the shallow low velocity zone and allows us to compute a rough estimation of the seismic energy in a given time window. Its square root, equivalent to the mean rms in the window, is proportional to the seismic impulse, i.e. the time integrated seismic force. We generally observe amplitudes within 10-30 % of those estimated by synthetic seismograms. The dispersion is in agreement with estimates by Lognonné et al . (2009), but here the agreement is found directly with the synthetics.

The validity of this approach was confirmed for the artificial impacts, and we therefore used it to determine the momentum of some of the largest natural impacts recorded by Apollo.

For all these impacts, we have determined the values of the seismic impulse by matching the energy in the observed and modeled waveforms. To get the mass of a meteoroid we should correct for the ejecta effects, which lead to a mv product smaller by a ratio 1.5 to 1.7 as compared to the seismic impulse. This gave estimates on the mass and size of the meteoroids. Current estimates of the size of the meteoroids (diameter of 2-3 meters) indicate that they could create craters of about 50-70 meters in diameter. The estimated mass of the largest impacts observed during the 7 years of activity of the Apollo seismic network provides an explanation for the non-detection of surface waves on the seismograms. Future seismometers must have performances at least 10 times better than Apollo in order to get these surface waves from comparable impacts. Such a resolution will also allow the detection of several impacts of low mass (1-10 kg) at a few 10s to hundred km of each station, which might be used to perform local studies of the crust.