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Large Impacts Detected by the Apollo Seismometers: 1. Seismic Source Model

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Detection of surface waves, generated by meteoroid impacts, provides enormous information on regional outer layers of the Moon. Moreover, the future seismic experiments on the Moon might be performed in conjunction with monitoring of lunar flashes to provide both the time and the location of the seismic events. In the light of these problems, we have estimated the impulse response and frequency properties of the impacts of some largest meteoroids recorded by Apollo and determined the possibility to use, in the future, the impacts to study the thickness and structure of the lunar crust.

We have analyzed the data and propose a model for the seismic source associated with an impact. This model takes into account the different parameters of the impactor (velocity, mass, density) as well as those of the impacted material. It provides us also some estimates on the source excitation process (a time-dependent stress acting downward on the surface) and takes into account the fact that part of the seismic force could be associated with ejecta material. This gives us a rough estimate of the efficiency of impacts in generating seismic waves.

Following Mc Garr et al. (1969), we assume a simple model for the seismic source function, namely, a time-dependent force acting downward on the surface of the planet during the impact f(t) = G g(t) = G g(t)*δ(t), g(t)=1+cos ω_1t for -π/ω_1 <t< π/ω_1, g(t)=0 otherwise, where g(t) is the time dependence of the source, G is used to denote the amplitude of the applied force. We introduce the time constant,τ, equal to $2\pi/\omega_1$ to denote the time-duration of the excitation process. The Fourier transform of g(t) is proportional to ω^{-3} for angular frequencies higher than the cutoff angular frequency ω_1. That is why we expect the seismic acceleration spectrum, which varies as ω^3 at low frequency for an impact, to be flat after the cutoff frequency and even to decrease due to additional effects such as attenuation.

The amplitude of the spectrum recorded at a given epicentral distance D can be written as

$$\hat{s}(\omega) = B\omega^3 \exp(-\frac{\omega t_{prop}}{2Q}) \times \hat{g}(\omega),$$

where B is a constant depending on the source impulse and epicentral distance, Q the quality factor related to attenuation.

We selected 12 spectra for the SIVB's impacts (the impacts of the upper stage of Saturn IV rocket-SIVB) and determined, by a least square fit of the logarithmic amplitudes, the best values for Q, τ and B parameters by a grid search. For τ = 0.6 sec we get a very good fit explaining practically for all the data with a 98% variance reduction and a very high quality factor. In contrast, for the seismic force as a point source (f(t)=mv δ (t) δ (x-x$_s$)) we find not only an unrealistically low Q value (700), but, moreover, a much lower variance reduction. The same fit was done for LM impacts spectra (the impacts of the Lunar Module-LM). For τ=0.45 sec we get again a high 94% variance reduction and an unrealistic Q=500 if this cutoff is not considered. The same fit was done for large meteoroids impacts (impacts on day the 13th and the 25th of January and the 14th of November 1976) (τ = 0.7, 0.8 and 1.05 sec, respectively). We get a very good fit explaining practically for all the data with 98% variance reduction and a very high quality factor. In contrast, the results with the seismic force as a point source are not satisfactory.