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Scattering of Seismic Waves and Lunar Seismograms

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A preliminary report of LATHAM et al. [1970] of the lunar seismic experiments contains a—unfortunately very small—reproduction of the seismogram owing to the impact of Apollo 12 ascent stage. The cited authors interpreted the form of the seismogram, especially the long duration of the oscillations and the lack of discrete phases, as due to a scattering mechanism of seismic energy in a highly heterogeneous medium. BERCKHEMER (personal communication) verified this hypothesis by means of a model seismic experiment.

Thus stimulated, the author tried to use his formalism [STROBACH 1964] which was deduced to describe the statistics of superposition of random phased sinoidal microseismic waves, for calculation of the envelope of the lunar seismogram by simple transcription of the included quantities. Assuming two-dimensional wave transmission, it is only necessary to interpret the elements $e^{-i\varphi_k}$ of the author's paper as vectorial free path elements of the scattered seismic energy quantums. If their lengths are not unity, but σ, we only have to multiply the sum of the $e^{-i\varphi_k}$, i.e. the resultant path $\vec{r}$, by σ (see Fig. 1). The sum is obtained by formula (7) in [STROBACH 1964]

$$w_N(\vec{r}) = \frac{1}{\pi N} e^{-\frac{r^2}{N}}, \tag{1}$$

where $w_N(\vec{r})$ is the probability density for the event of the vector $\vec{r}$, and N the number of the paths of unity length which are equal distributed relative to azimuth angle. Now we find that N paths of length σ are transmitted by waves of velocity v in the time $t = \sigma N / v$. By this we obtain from (1)

$$w(t \mid \vec{\Delta}) = \frac{\sigma}{\pi t v} e^{-\frac{\Delta^2}{t v \sigma}}, \tag{2}$$

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i.e. the probability density for the arrival of an energy quantum at the position $\vec{\Delta}$ after the travel time t, $\vec{\Delta}$ now being a constant spatial vector marking the seismometer's position. The underlying idea of the mechanism expressed by formula (2) is that a seismic energy quantum, after each transmission of a free path of constant length σ, is scattered randomly, i.e. into an arbitrary direction, and without energy loss.

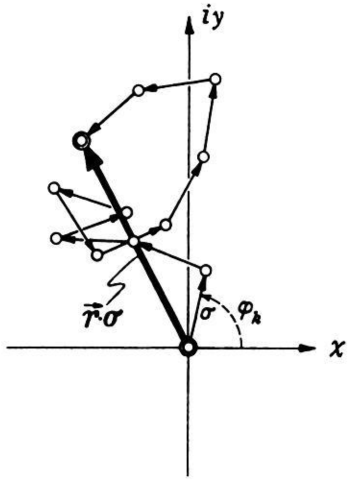

Fig. 1: The spatial vector $\vec{r}\,\sigma$ as the sum of the free path elements σ of the scattered seismic energy quantums.

Otherwise, if we have energy dissipation, we assume that only the proportion q $(0 < q < 1)$ of the instantaneous energy is transmitted to the next path after each scattering process. Thus we obtain from (2)

$$w(t\,|\,\vec{\Delta}, q) = q^{\frac{tv}{\sigma}} \cdot \frac{\sigma}{\pi t v} \cdot e^{-\frac{\Delta^2}{tv\sigma}}. \tag{2a}$$

Changing from energy quantums to amplitudes we have to calculate the square root of (2a). Thereafter this expression describes the envelope of a theoretical lunar seismogram in arbitrary amplitude scale.

The formula was treated for various values of σ and q, using the known data $\Delta = 75{,}9$ km (distance seismometer/LM impact) and $v = 3{,}23$ km/sec (after LATHAM et al. [1970]) and was then compared with the actual seismogram. Excellent agreement is obtained for free path length $\sigma = 2{,}0$ km and transmission rate $q = 0{,}99895$ (see Fig. 2). Thus, as to the observed frequency of 1 hz, we get a quality factor $Q = 1850$ which accords with the behavior of the lower mantle of the earth. The quantity σ may be interpreted as the *mean* free path length and should correspond with the mean diameter of the blocks or units which are supposed to cause the scattering pıo-cesses. Agreeing with Berckhemer's model seismic experiment, we can assume the block-like structure to consist of a system of fissures, each with a limited extension in such a way that the seismic energy quantums find bridges to pass from one block to the next. It is possible that a structure of this nature and with dominant vertical cracks

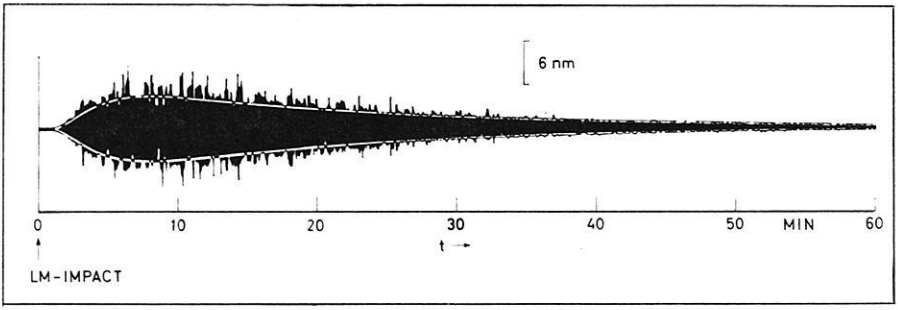

Fig. 2: Lunar seismogram of impact of Apollo 12 ascent stage and the theoretical envelope under the assumptions of $\sigma = 2.0$ km and a quality factor $Q = 1850$.

could be formed by meteor impacts and/or cooling fissures. As, following Latham et al. [1970], lunar tectonics may be very low, the moon's outer shell should be in such a condition that the extreme surface temperature variations effect the blocks as extending and contracting *units*, because the disruption has reached a state which no longer gives rise to new fracture. But this is only possible if the fissures are not healed up; and *if* they are not, seismic waves must be scattered and cannot penetrate the structure on a direct path.

An important quantity which could offer the possibility to cheque the scattering hypothesis would be a frequency distribution of the amplitudes of all single oscillations, after rejecting the effect of varying envelope. This distribution should agree with the random walk distribution published in Fig. 1 in [Strobach 1964]. For want of a seismogram of sufficient time resolution this could not be done till now.

I have to thank Mr. A. Jensch who wrote the computer program and accomplished the calculations.

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