
We are determining the low frequency velocities and damping factors of acoustic waves in rock powders in vacuo with a view to understanding the lunar seismic signals, which are clearly so different from the earth's.

Many features of the lunar seismic signals can be understood in terms of the Gold-Soter model,\textsuperscript{1,2} in which the outer layer of the moon is largely composed of rock powder the compaction of which increases in some manner with depth. The long rise and fall times of the lunar seismic signals would result from the diffusion of acoustical energy through the powder where the scattering mechanism would arise from inhomogeneities such as the undulating lunar surface and powder density fluctuations. The energy would be confined to such a powder layer by what is essentially total internal reflection, the increasing compaction with depth providing the necessary increase in velocity with depth.

The diffusion process results in long path lengths which can only result in the observed large signals at long delays if the acoustical damping factor $n(=1/2\zeta)$ is small. This factor thus emerges as the crucial rock powder parameter, though the severity of the constraint that it be small is eased by the low wave propagation velocities that occur in rock powders. It would seem that to satisfactorily account for the lunar seismic signals $Q$ need not exceed 2000, and it could be less.

Measurements by Hunter et. al.\textsuperscript{3} at frequencies above 7 kHz give values of $Q \sim 5$. We did not consider this a discouraging result because most of the energy in the lunar seismic signals is near 1 Hz, at which frequency, for a given wave amplitude, the particle strain is about a factor of $10^7$ less than that at $10^8$ Hz, which could result in much lower damping at the lower frequency. A result by Schmidt at 20 Hz\textsuperscript{4} also gave a $Q$ value $\sim 5$ but in this case adequate precautions against container damping had not been taken. None of this earlier work had been done in vacuo.
We are therefore measuring Q in vacuo and as close to 1 Hz as is convenient, which at present is at about 10 Hz in well settled powder. The lowest limit is imposed upon us by the size of the laboratory and is about 6 Hz. We set up longitudinal standing waves in a horizontal trough of rock powder and observe the free decay. This trough is very compliant horizontally, is of low mass, and is very lightly supported by fine wires on low loss supports. Any residual support system effects can only decrease Q, therefore any result we obtain may be a lower limit on Q of the powder. From measurements performed on the system we estimate that the support system probably limits values of Q observed in vacuo to an absolute minimum of 1000. To test for support system effects we have worked with 2 different masses of powder in the trough and the results were essentially the same in each case. We are therefore not yet being limited by damping in the support system. Our results are summarized overleaf.

The best value of Q obtained so far, 120 in as yet imperfect conditions, gives support to the model in which the observed seismic signals result from propagation through variously compacted layers of rock powder. We think it possible that when fluids are removed more thoroughly from the powder then values of Q in excess of 1000 can occur, especially when the powder has been pre-compacted.

Low frequency acoustic compressional waves in the rock powder at the lunar surface travel at about 50 m/s and measurements exist that indicate that the overburden weight alone can increase this velocity to 3000 m/s at a depth of about 5 km, at which depth the material would still be essentially a powder. Little energy put in at the surface could penetrate such a layer. Data from first arrival times of seismic energy on the moon in fact correspond to propagation velocities of about 3000 m/s.

MEASUREMENTS OF THE ACOUSTICAL PARAMETERS OF ROCK POWDERS, AND THE GOLD-SOTER LUNAR MODEL.

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Summary table of results on acoustic wave propagation in powdered basalt

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effect on Q</th>
<th>Effect on c</th>
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<tbody>
<tr>
<td>Powder support system.</td>
<td>Negligible at intrinsic powder Q values below 1000.</td>
<td>Negligible.</td>
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<tr>
<td>Ageing: settling and partial removal of fluid films.</td>
<td>6x increase, at least.</td>
<td>50% increase at least.</td>
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<tr>
<td>Frequency.</td>
<td>&lt; 5% change over first 3 modes at least.</td>
<td>&lt; 1% change over first 4 modes at least.</td>
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<tr>
<td>Amplitude.</td>
<td>2x increase between 100μm and 10μm, thereafter &lt; 5% down to at most 0·01μm.</td>
<td>Negligible.</td>
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<tr>
<td>Ambient air pressure.</td>
<td>2x increase between 760 Torr and 0·1 Torr, thereafter &lt; 5% increase down to 0·03 Torr.</td>
<td>Negligible.</td>
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Result at low amplitudes on aged powder at < 0·1 Torr pressure:

- density = 1·34±0·01 gm/cm³, (c.f. 1·7±1·9 gm/cm³ for the lunar surface).
- longitudinal wave velocity = 47·3±0·5 m/s, (c.f. 45 m/s for the surface layer at Surveyor sites).
- $Q = 118±5$