
This paper reports on laboratory measurements of the internal friction quality factor Q and velocity on lunar and analogs of lunar rocks to aid in the interpretation of seismic Q versus depth profiles which seismologists\(^1,2\) are now deriving for p and s waves. These profiles are having considerable impact on current models of the structure,\(^1,2\) evolution,\(^3\) and present thermal state\(^4\) of the moon. In the past, laboratory measurements\(^5\) of Q were applicable to a crustal layer of only limited thickness corresponding to competent rock at zero-confining pressure and temperatures near 300K. In order to obtain a more accurate and fuller interpretation of the lunar seismic data in particular and future planetary seismic data in general, we have begun to extend our laboratory measurements to include rock under confining pressure and at high temperatures representing bed rock at some depth. Here we report on the feasibility of obtaining Q in the 50 Hz range with the rock under hydrostatic confining pressure and present apparently the first measurements anywhere of Q while increasing hydrostatic pressure and temperature simultaneously. Also, to better understand the dramatic effect of H\(_2\)O on Q we have carried out measurements with other volatiles and studied the effect of one of these on the temperature dependence of Q. These and other data have given us valuable clues about the nature of the attenuation mechanism.

(1) Seismic Q Measurements Under Hydrostatic Pressure

In an effort to explore the feasibility of operating our low frequency apparatus in a gas pressure vessel we have modified the sample fixture to reduce the air drag and to allow measurements on a Cu sheathed sample. Air drag calibration measurements at 50 Hz on a metallic rod gave less than 5% reduction in Q at 2000 psi He gas pressure. Tests on a terrestrial analog of lunar basalt with a 2 mil Cu sheath gave increases in Q and velocity with confining pressure qualitatively similar to those observed at 10 kHz under similar outgassing conditions. These tests would appear to open the door for laboratory measurements of seismic Q on rock under conditions corresponding to the interior of the lunar crust.

(2) Q\(_p\) Measured With Increasing P and T

An Aminco pressure vessel was modified to serve as a fluid cooled pressure vessel for an internal furnace for operation at temperatures T and confining pressures P as high as 400°C and 20 ksi. The objective is to begin measurements of Q\(_p\), Q\(_s\), V\(_p\), and V\(_s\) while changing P and T along a lunar profile. Table I shows some initial data obtained on a terrestrial analog of lunar basalt (Amboy Crater, California) encapsulated in a vacuum of 10\(^{-6}\) Torr after strong outgassing. The data were obtained at 10 kHz with the sample vibrating in the extensional (Young's modulus) mode. Q is seen to increase dramatically with increasing P/T - more than was observed with increases of P or T alone. This trend suggests that high Q values are also concomitant with hot dry rock deeper in the lunar crust.

(3) Influence of Volatiles on Q of an Analog of Lunar Rock at 50 Hz

In our studies of the effect of volatiles on seismic Q we have not yet
found one that decreases Q as much as H$_2$O. The next most effective after H$_2$O was found to be CH$_2$Cl$_2$ (Dichloromethane) with similarly high dipole moment (1.60 Debye as compared to 1.82 Debye for H$_2$O). Since our previous measurements of Q versus temperature had revealed striking features we also explored the temperature dependence for various partial pressures of CH$_2$Cl$_2$ at one atmosphere total pressure with dry N$_2$ as diluent. The Q data, normalized to 700 Torr N$_2$ (0 Torr CH$_2$Cl$_2$) showed strong decreases in Q with increases in partial pressure CH$_2$Cl$_2$ at low temperatures ~20C and at high temperatures ~250C. This behavior is qualitatively similar to that observed with H$_2$O and provides valuable clues for understanding the mechanism by which volatiles lessen the Q.

(4) Model for Absorption Mechanism

We propose a model for the absorption mechanism which involves changes in the bonding, structure, and coverage of the molecular, physisorbed and chemisorbed H$_2$O at the crack and grain boundaries. Key to the mechanism is the strong bonding - as high as 50 Kcal/mole - between the OH groups and SiO$_2$ groups present on the surfaces of silicates, such as the feldspars. The passage of the seismic wave is thought to create local perturbations particularly at crack tips, grain contacts, asperities and other zones with high mechanical advantage. In these zones even the small seismic strains can exert strong forces on the adsorbed H$_2$O species causing lateral displacement and the breaking of bonds with the resultant removal of energy from the waves - energy ultimately lost as small amounts of heat. Our theoretical approach is to model the process in terms of a thermally activated process with a distribution of activation energies representing a range of bonding energies depending on the nature of the surfaces and their coverage. This model predicts a strong decrease in damping at low temperatures (below 270K) in good agreement with our observations.

<p>| TABLE I |
| Q and $v$ Along Lunar Temperature/Pressure Profile |</p>
<table>
<thead>
<tr>
<th>Temperature ($^\circ$C)</th>
<th></th>
<th>$Q_y$</th>
<th>$v_y$</th>
</tr>
</thead>
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<tr>
<td>22$^\circ$</td>
<td>0</td>
<td>750</td>
<td>8.740</td>
</tr>
<tr>
<td>25$^\circ$</td>
<td>3.65</td>
<td>630</td>
<td>9.691</td>
</tr>
<tr>
<td>50$^\circ$</td>
<td>7.30</td>
<td>1211</td>
<td>10.205</td>
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</tbody>
</table>
SEISMIC Q & VELOCITY AT DEPTH

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REFERENCES


