Physical Properties of Lunar Samples

by

S. Baldridge, D. H. Chung, K. Horai,
G. Simmons\(^{ab}\), T. Todd, H. Wang, D. J. Weidner,
and W. B. Westphal

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

a. Presently at the Manned Spacecraft
   Center, code TA, NASA, Houston, Texas

b. Speaker
A. **Thermal Expansion**

Thermal expansions of lunar rocks measured on centimeter-sized specimens over the range -100°C to +200°C with a dilatometer are the following:

| Sample  | $\alpha|_{25^\circ C}$ $(10^{-6} \text{ } ^\circ\text{C}^{-1})$ | $\partial \alpha/\partial T$ $(10^{-9} \text{ } ^\circ\text{C}^{-2})$ |
|---------|-----------------------------------|-------------------------------|
| 10057   | 7.5                               | 6                             |
| 12022   | 5.6                               | 3 1/2                         |
| 10020   | 5.0                               | 4                             |
| 10048   | 3.5                               | 8                             |

Where the value of $\alpha$ is given at +100°C and $\partial \alpha/\partial T$ is valid over the range +100 to 200°C. Smoothed data of Kozu and Takane (1929) for quartz parallel to c-axis were used for the calibration of the dilatometer.

No permanent strains in the lunar samples were observed over the temperature range -100 to +200°C.

Several possible models of density in the lunar interior, based on these data and previously measured values of compressibility, are reported.

B. **Thermal Diffusivity**

The thermal diffusivity of 12002 and 12022 was measured in the temperature range between 130°C and 410°C by a modified Angstrom method. Both specimens are crystalline igneous rocks (olivine dolerite) and exhibit almost identical variation of thermal diffusivity with temperature. The empirical formula obtained by least-squares from the combined data for 12002 and 12022 is

$$k^{-1} = (0.58 \pm 0.05) \ t - (9.0 \pm 12.5)$$

where $k$ is the thermal diffusivity in cm$^2$/sec and $t$ the temperature in °K. The trend shows that the thermal diffusivity of
of Apollo 12 olivine dolerite is more temperature dependent than that of Apollo II type A crystalline rocks.

C. Dielectric Properties

Presented first in this paper are measurements of apparent dielectric constant and dissipation factor of Apollo 12 lunar samples 12002(58), 12022(60), and 12022(95), over a range of frequencies from 100 Hz to 10 MHz and temperatures from 196°C to +200°C. The dielectric properties determined on earth basalts and simulated lunar materials with the composition of Surveyor V analyses, along with the corresponding properties measured on Apollo II lunar samples, are used to characterize the dielectric properties of these lunar samples. Next, with these data applied to two major models (wet and dry) of lunar depth variation in the complex dielectric constant, the electro-magnetic probing of the moon (at a few kHz frequency) on a horizontal scale of about 100 km is investigated on the basis of a stratified medium consisting of N electromagnetically linear, isotropic, homogeneous layers. We conclude that:

1. The lunar samples have higher values of dielectric constant than earth materials of similar chemical compositions, an effect due probably to high conductivity materials present in the lunar samples. The high frequency dielectric constant of the lunar igneous samples is about 7 to 14 at room temperature, and increases slightly with increasing temperature.

2. The lunar samples show greater dielectric losses than earth basalts. The high frequency losses for the lunar samples range from 0.03 to 0.2 at room temperature, and they are temperature-dependent.

3. The lunar samples show a temperature-dependent low frequency dispersion, a characteristic of excessive impurity charges present in these lunar samples.

4. If a wet model of the moon is adopted, one arrives at the result that a transverse magnetic surface wave mode will be present on the moon; the surface wave mode will be sensitive to the depth of the ice-water transition (expected at about 1 km
depth) and to lunar dielectric properties between the transition depth and the surface. If the moon is dry, as it seems at present, a thermally activated region of a conductive basement is expected at about 100 km, and the surface wave will be sensitive to dielectric properties of this region.

D. Elastic Properties

Compressional and shear velocities in samples 12002, 54 and 12022, 60 were measured in three orthogonal directions by the standard Birch pulse transmission method to 6.5 kb. Both P and S-wave velocities doubled over this pressure range and both showed less than 3% anisotropy which is about the experimental error. Average five kilobar values are given below:

<table>
<thead>
<tr>
<th>Sample</th>
<th>( \rho (g/\text{cc}) )</th>
<th>( V_p (\text{km/sec}) )</th>
<th>( V_s (\text{km/sec}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12002, 54</td>
<td>3.21</td>
<td>7.2</td>
<td>3.7</td>
</tr>
<tr>
<td>12022, 60</td>
<td>3.21</td>
<td>7.6</td>
<td>4.2</td>
</tr>
</tbody>
</table>

These velocities are similar to those obtained on Apollo 11 samples. The ratio of output signal amplitude to input signal amplitude is about the same as terrestrial basalts which we interpret to mean that the attenuation in lunar igneous rocks is about the same as that in dry terrestrial igneous rocks. The velocities as a function of pressure give a travel time curve consistent with data obtained from the Apollo 13 SIV-B impact. Current petrologic models indicate that below depths corresponding to a pressure of 10 kb, compositional changes would occur so that the present velocity data are probably applicable to this depth only.