THE PRESENCE, TRANSPORT AND ORIGINS OF VOLATILES IN THE LUNAR
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We report the first results of measurements of volatiles extracted from
Apollo 17 deep drill core (DDC) sections. Experimental considerations due to
the small amounts mobilized and some implications regarding sources and trans-
port are discussed.

Elements such as Hg, Cl, Br have appreciable vapor pressures even at 250°K
which is the temperature in the near subsurface (from \(\approx\) 10 cm to a few meters)
of the moon. Above this cold zone diurnal heating raises the surface tempera-
ture to 130°C and below there is a gradual temperature increase due to inter-
nal heat. Gases from the interior must pass through this cold-trap zone while
atmospheric gases diffuse down to this zone. We have presented evidence for
the latter effect in the concentration gradients of Hg and Br in response to
the temperature gradient in the top 10-12 cm from the surface (1). The pro-
blem of establishing migration from the interior of the moon is complicated by
cratering which buries surface layers by inverting or blanketing. Thus,
deposits percolated up from depth, if present, must be resolved from those
already present.

Atmospheric gases may be lost from the moon by nonthermal mechanisms
and/or thermally if introduced into the atmosphere as the result of the heat
produced in an impact. They must then be replenished since they continue to
be present at the lunar surface. Parentless \(^{40}\)Ar, excess fission Xe, and Hg
are examples which have been found in soils, and Ar and Rn have been observed
in the lunar atmosphere. Replacement may occur either through 1) venting
along pipes or deep fissures; possibly volcanic, or 2) diffusion through
micro- and macro-pore structures in the more fractured outer zones, and grain
boundary or volume diffusion at higher temperatures (at greater depths).

A possible test of these two mechanisms for replenishment of volatiles is
to measure elements volatilized at low temperatures from samples taken at a
depth below that at which diurnal heating may control the surface concen-
tration.

The results described below may not necessarily be extrapolated to lower
temperature without ascertaining whether the trace concentrations and surface
areas are such that monolayers may exist allowing only for adsorption consid-
erations or multilayers permitting vapor pressure arguments to be applied.
Our previous measurements have usually been on < 100 mg of samples at temper-
atures of \(\geq\) 75°C. Structure has always been observed in release curves during
stepwise heating. Time dependent release during isothermal heating at 130°
and 175° has also been observed. Possibly, thermal decomposition of molecular
species and migration from cracks or pores could account for these effects.
Volatiles released at lower temperatures may be more exclusively surface
deposited. Large amounts of sample are needed for low temperature measure-
ments since even at \(\geq\) 100°C ppb and sub-ppb amounts of halogens and Hg are
released. An opportunity to measure large samples is being provided by the
Horai thermal conductivity experiments. An earlier room temperature measure-
ment of volatile Hg was made during the opening, by puncture, and pumping of
the sealed Apollo 16 and 17 ALSRC's (rock boxes) (2).
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The Horai experiment is designed to determine the thermal conductivity in the regolith by measuring that of fines in drill stems and drive tubes i.e., in relatively undisturbed stratigraphic columns containing 200-1000 gms of soil. During evacuation of a drill stem the gases and volatiles are pumped through a section of the vacuum system containing an Au mesh to trap Hg and through a cold trap to condense volatiles which are later adsorbed on silica gel in a cold finger.

We report here data on two drill stems, 70002 (H-1) and 70006 (H-2). Aliquants of the samples and the blank were irradiated in a high flux reactor. Cl, Br, and I were measured in hot water leach solutions and Hg was volatilized from the Au at ~ 450°C and ~ 970°C. The downstream Au mesh was taken to represent the Au blank, hence the Hg results may be lower limits.

Halogen results for the two drill stems are given in Table 1. Only 70002 Hg has been determined and is given in Table 2 with previously reported Apollo 17 data. The concentrations corrected for the SiO2 blank and the downstream Au-Hg are taken as those present on soil surfaces. For comparison purposes two other sets of data on surficial deposits are given in Table 1--the amounts of Cl, Br and I leached by hot water from samples from drill stems 70002, 70005 and 70006 and from three basaltic soils and a soil breccia collected at the surface. Some observations are: 1) On the basis of the DDC samples only one part in 100-1000 of the total halogens on surfaces volatilized at room temperature (R.T.). 2) The halogen ratios for leached core samples are on the average systematically higher than those for halogens volatilized at room temperature. In the leached samples the relative enrichment of Cl is greater, followed by Br and then I. Either two different deposits are present or the laboratory a reverse order volatilization occurred from a single deposit, i.e., I > Br > Cl, to yield lower ratios in the room temperature fractions. 3) Among the surface soils one, 71501, has the same interhalogen ratio as the DDC leached samples. The other samples, including reference soil 70181, have variable ratios caused by a relative excess Cl and/or depleted I. This latter observation may reinforce the reverse order volatilization in 2) above. The picture is complex. For instance, the relatively uniform interhalogen ratios in the DDC leach samples are not easily understood since gardening should have exposed all the soils to the surface at some time leading to the variations seen among present surface soils.

It is of interest that the Cl/Br ratios of ~ 37 and ~ 78 in the DDC R.T. and leach samples, respectively, are the ratios we have seen most frequently in (~ 100) lunar samples (3). Vapor clouds were proposed to account for these ratios and it was noted that the ratio of ~ 40 is near cosmic. This then may be evidence for an unfractonated interior source.

The Hg released from 70002 is 4.7 x 10^-12 g/g of core sample and is not inconsistent with that found in the Apollo 17 ALSRC (3.1 x 10^-11 g/g). We will not know whether the difference is significant until more DDC sections have been measured. In general, the need for a continuous supply of Hg to the surface exists as discussed previously (4).

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Table 1: Halogens Removed by Volatilization and H₂O Leaching from Apollo 11 Deep Drill Stems and Surface Soils (ppm, Cl/Br = 27)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Br</th>
<th>Cl</th>
<th>I</th>
<th>Br/Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>70002</td>
<td>0.0070</td>
<td>0.0077</td>
<td>0.078</td>
<td>0.041</td>
</tr>
<tr>
<td>70006</td>
<td>0.0070</td>
<td>0.0077</td>
<td>0.078</td>
<td>0.041</td>
</tr>
</tbody>
</table>