HELIUM, NEON, AND ARGON ON AN EXPOSED LUNAR SURFACE BY LASER PROBE MASS SPECTROMETRY

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We have reported previously results of analyses of He, Ne, and Ar released from 75 μm-diameter sites along a linear traverse from a shaded region to a region exposed to solar radiation (1). We will present here the results of similar analyses for a two-dimensional array of sites, all of which are on the surface of a sample nominally exposed to direct solar radiations.

The sample used is 12054,31. The surface analyzed is coated entirely with dark brown glass microscopic accretionary material usually found on well-exposed surfaces (2,3). Although the face of the rock from which 12054,31 was taken contains numerous impact pits (3), the surface was not in equilibrium with respect to crater superposition; and none of the sites discussed here was affected by the removal of material by nearby impact events. An exposure age for the surface of 1.75 x 10⁶ yr was obtained using the solar flare track method (4). Based on a reconstruction of the lunar surface orientation of 12054 using Apollo 12 mission photography and after study of a rock model and cutting and chipping photography, we judged the nominal solar wind direction toward the sun is about 100° east of north and the dip to be about 60° to 70° toward the south. This surface was not perfectly flat, and the topographic variations from this nominal plane surface are shown as a contour map in figure 1. With this configuration and orientation the direction toward the sun throughout a lunation always makes a fairly shallow angle with the exposed surface.

Absolute abundance data for ⁴He, ²⁰Ne, and ⁴⁰Ar were obtained for 101 sites and Ne and Ar isotopic data were obtained for 82 sites. Site locations were selected to be representative of the exposed surface. Microcraters, including mineral grains, vugs, broken surfaces, and areas of dust accumulation were avoided. ⁴He, ²⁰Ne, ³⁶Ar, and ⁴⁰Ar abundance maps are shown in figures 2, 3, 4, and 5, respectively. The abundances given are corrected for laser spot diameters less than the nominal 75 μm by as much as ~25%. The average value obtained for the ²⁰Ne/²²Ne ratio was 13.6 ± 2.2, and the average ³⁶Ar/³⁸Ar ratio was 4.8 ± 0.9. Both of these values are consistent with a solar wind origin for these gases. The average ⁴⁰Ar/³⁶Ar ratio was 0.6 ± 0.4. The observation that this ratio is almost always < 1 on surfaces exposed to the sun and > 1 for shaded, south-facing surfaces is discussed in our previous paper (1).

The average measured areal concentrations of gases, (17 ± factor of 3) x 10⁻⁵ cm³ STP/cm² of ⁴He, (10 ± 6) x 10⁻⁶ cm³ STP/cm² of ²⁰Ne, and (8 ± 4) x 10⁻⁷ cm³ STP/cm² of ³⁶Ar, may be compared with the amounts of these gases expected to be incident upon the surface during 1.75 x 10⁶ yr of exposure, assuming a solar wind origin and the flux obtained by the Apollo 16 solar wind composition experiment (5) and taking into account the orientation of the surface (strike = 100° east of north, dip = 65° south) and the shielding of the earth's magnetosphere (6). Measured values lower than expected values by factors of 400, 12, and 5, for ⁴He, ²⁰Ne, and ³⁶Ar, respectively, indicate that none of these gases is retained quantitatively. We interpret the measured areal concentrations to be equilibrium values, where the equilibrium is maintained between the accumulation of directly implanted solar wind gases and their removal by sputtering and/or diffusion processes. Some gas ions also may be lost initially, during the slightly inefficient implantation process.

Concentrations of ⁴He on the exposed surfaces are highly variable compared to the other gases. The reason for this difference is not understood but may be
related to the much higher mobility of $^4$He in the near-surface lunar environment.

Toward the lowermost part of the sample the slope of the surface steepens. This region is, therefore, less exposed to solar radiations, but still well-exposed to particles arriving from the south. In this region $^4$He and $^{40}$Ar abundances are significantly higher while $^{20}$Ne and $^{36}$Ar remain unchanged relative to average abundances for the exposed surface. We interpret this pattern to be the result of $^{40}$Ar and $^4$He ions arriving from the south, as well from the ecliptic plane (7), and being implanted at lower energies than $^{20}$Ne and $^{36}$Ar. If the more mobile $^4$He and the less energetically implanted $^{40}$Ar are more readily lost due to solar radiation or sputtering effects, which are greatest for surfaces exposed to ecliptic directions, then these gases will be processed more readily through the lunar "atmosphere" and preferentially collected on less exposed surfaces.

A more subtle trend in the data is the tendency toward somewhat lower levels of $^{20}$Ne, $^{36}$Ar, and $^{40}$Ar in part of the lower right quadrant of the sample. In this area the local dip is about 10° to 20° shallower than the average dip of ~65° for the entire surface. It is known from experimental and theoretical studies that the efficiency with which surface atoms are removed by sputtering is a function of the arrival angle of the incident particles (8). The precise character of this dependence is not well defined, but there apparently is a peak in this efficiency at angles of incidence between 50° and 70°. We suggest, as a hypothesis, that averaged over a complete lunation the less steeply dipping surfaces are somewhat more effectively eroded by sputtering than the average, or more steeply dipping, surfaces. Thus, the equilibrium concentrations of noble gases may be expected to be correspondingly lower on the less steeply dipping surfaces. Increased effectiveness of diffusion out of surfaces more directly exposed to solar radiations may also cause the differences in gas concentrations observed. Clearly, a large number of sites with different orientations will have to be analyzed to test these hypotheses.

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References
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Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

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