

RETENTION OF SOLAR WIND-IMPLANTED ELEMENTS IN LUNAR SOILS.

D. J. DesMarais, J. M. Hayes*, and W. G. Meinschein, Department of Geology, Indiana University, Bloomington, Indiana 47401. *Also Dept. of Chemistry.

Previous reports from this laboratory (1,2) have given the amounts of carbon released by pyrolysis (to 1300°C, He atmosphere) of a number of different soil samples. Table 1 extends these analyses to hydrogen released by pyrolysis. In addition, we have determined the amounts of hydrogen released

Table 1. Hydrogen abundances (cm³ STP/g) in lunar materials.
(For detailed sample identification see reference 1.)

15001,166	0.47	15002,308	0.58	15004,164	1.03	15005,232	0.69
15012,7	0.78	15012,8	0.81	15013,8	0.76	15080,5	0.71
15100,9	0.50	15301,24	0.56	15401,13	0.15	15415,44	0.02
15426,31	0.13	61221,3	0.39	61241,19	0.73	62440,6	0.88
63320,10	0.71	63340,10	0.56	63500,6	0.55	67481,24	0.35
68501,37	0.83						

by specific particle types and find the following results (149-250 μm size fraction): plagioclase grains 0.067, glasses 0.24; light breccia 0.21, dark breccia 0.71, and agglutinates 1.2 cm³ H₂ STP/g (for sample numbers and fraction descriptions, see Table 1, ref. 1). This distribution parallels that observed for carbon; indicating that, like carbon, hydrogen is retained in significant amounts during the processes of agglutinate- and breccia-formation. Thus, like carbon, hydrogen should eventually accumulate a significant volume-correlated component (2).

Following our earlier work (1,2), we have resolved surface- and volume-correlated components for various elements by fitting the results of the analyses of particle size fractions to the expression

$$[X]_r = [X]_b + 3S_x/r\rho$$

where $[X]_r$ is the total abundance of element X in some size fraction, r (X/mass of sample); $[X]_b$ is the volume-correlated component (X/mass of sample); S_x is the "surface concentration" (X/cm²); r is the avg. particle radius (cm); and ρ is the particle density (arbitrarily set at 3 g/cm³ in these calculations). We denote the total concentration of element X in a given soil as ΣX (X/mass of sample). The calculated "surface concentration" is, of course, not genuine because the particles have been assumed to be smooth spheres. It serves well, however, for interelement comparisons in soils of equivalent maturity. Applying this method of data reduction to our own analyses of hydrogen in various particle size fractions, we obtain the results shown in Table 2. As noted above, the existence of a sizable volume-correlated component is preordained by the observation that composite particles are relatively rich in hydrogen.

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Table 2. Distribution of hydrogen with respect to grain size.

Sample	S_H , cm ³ H ₂ STP/cm ²	$[H]_b$, cm ³ H ₂ STP/g	ΣH , cm ³ H ₂ STP/g
15012,7	$(0.85 \pm 0.13) \times 10^{-3}$	0.41 ± 0.06	0.78
15080,5	$(1.14 \pm 0.15) \times 10^{-3}$	0.37 ± 0.07	0.71
15401,13	$(0.50 \pm 0.06) \times 10^{-3}$	0.06 ± 0.03	0.15
61221,3	$(0.30 \pm 0.04) \times 10^{-3}$	0.16 ± 0.03	0.39
68501,37	$(0.69 \pm 0.11) \times 10^{-3}$	0.53 ± 0.08	0.83

(indicated uncertainties are \pm one standard deviation)

We have similarly resolved surface- and volume-correlated components of the following solar wind elements using data in the references noted: N (3), ⁴He, ²⁰Ne, ³⁶Ar, ⁸⁴Kr (4-7). Do these elements follow carbon and hydrogen in accumulating significant volume-correlated components, or are they lost during agglutinate- and breccia-formation? It might be expected that the rare gases, in particular, could be evicted from their precarious surficial perches by the energetic events of soil cycling. We can note that Baur *et al.* (8) have already shown that the agglutinates are relatively poor in rare gases. We have further explored the question by defining a (percentage of volume-correlation) = $100([X]_b / \Sigma X)$. Percentages of volume-correlation for a number of solar wind-implanted elements are given in Table 3. To rank these elements in order of decreasing percentage of volume-correlation is to rank them according to their degree of retention during soil-cycling (breccia- and agglutinate-formation).

To obtain a fuller understanding of the retention of solar wind-implanted elements in lunar soils, we divide the integrated input of a particular element into four fractions, two of which are lost, and two of which are retained. By $R_v(X)$ and $R_s(X)$ we denote the retained volume- and surface-correlated components of element X. Losses are viewed as occurring by two distinct mechanisms, with a fraction $L_d(X)$ being lost by diffusive escape from grain surfaces, and with a fraction $L_c(X)$ being ejected from the grains by the energetic events of soil-cycling. By definition, $R_v(X) + R_s(X) + L_d(X) + L_c(X) = 1.0$. The eventual resolution of all four components will furnish a rather complete view of the retention problem.

For the moment, however, we will note that the relative magnitudes of $[R_s(X) + R_v(X)]$ can be determined from overall relative retentions. Among the elements listed, it turns out that nitrogen is generally present in the highest amount in proportion to its solar abundance when a representative set of mature soils is considered. Reference to average elemental abundances in soils and to solar abundances allows calculation of the relative overall retentions reported in Table 3. Hydrogen appears most strongly depleted overall, yet is highest in percentage of volume-correlation. Apparently its chemically reactive nature facilitates hydrogen-retention during cycling, although the great majority of input atoms is lost by hydrogen-stripping. Comparison of nitrogen and carbon

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Table 3. Percentage of volume-correlation and relative overall retention of solar wind-implanted volatile elements.

Element	Percentage of Volume-correlation	Relative overall Retention
N	33	1.0
C	49	0.65
⁸⁴ Kr	21	0.21
³⁶ Ar	21	7.1×10^{-2}
²⁰ Ne	15	2.6×10^{-2}
⁴ He	12	1.9×10^{-3}
H	55	1.6×10^{-3}

is also interesting. Interaction of these two elements with the solar wind hydrogen flux produces methane and almost certainly ammonia. Methane is very volatile and escapes readily during heating and cruching experiments, whereas ammonia is so well-retained that its presence cannot be demonstrated. Therefore, the higher overall retention of nitrogen relative to carbon is probably explained by the relatively great loss of methane compared to ammonia.

In conclusion, we have resolved two distinct mechanisms of volatile element loss: (1) diffusive escape, and (2) eviction during cycling. In addition, we have roughly determined the extent to which each mechanism affects H, N, C, and the rare gases.

References

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