NITROGEN ISOTOPES IN THE LUNAR REGOLITH; RESULTS FROM DOUBLE DRIVE TUBE 79002 / 79001

J. Stone and R.N.Clayton*, Enrico Fermi Institute, University of Chicago. *Also Department of Chemistry and Department of Geophysical Sciences.

The isotopic composition of nitrogen trapped in lunar soils and soil breccias varies from 22% depleted, to 12% enriched in ^{15}N relative to air N (1,2). Stepwise extraction from single samples commonly yields N covering a large fraction of this range. Whether this isotopic diversity reflects a secular increase in solar wind (SW) $^{15}N/^{14}N$ ratio, sampled by soils exposed at different times on the lunar surface (3), or admixture of (isotopically heavy) SW nitrogen and an (isotopically light) component of lunar origin (4), remains uncertain. Investigation of covariation between N isotopic compositions, cosmic ray exposure ages and soil maturity indices, in samples containing both the light and heavy N components should provide some constraint on these hypotheses. Such data should also afford local stratigraphic information, elucidating lunar surface processes.

SAMPLES: Soils and soil breccias for N analysis were obtained from the 79001/79002 drive tube. The core contains four stratigraphically distinct units (5); the uppermost appears to represent recent (1.6Ma; (6)) ejecta from Van Serg crater (7). Breccia 79035, containing the lightest N yet observed in a lunar sample (8), was collected a few metres from the drill site.

RESULTS: Data from six soil and three breccia samples are set out in figs. 1-5. Stepwise extraction (figs.1a,b) of all samples yields the U-shaped isotopic release pattern typical of lunar materials, reflecting the presence of two trapped components, and spallation N released at high temperature (1). Figures 2 - 4 illustrate variations in **bulk** properties of the samples.

Sample N and He abundances correlate strongly (fig.2), but at a He/N ratio 400-fold lower than that at the solar surface (9). On this basis, the spread of gas contents most likely represents mixing of mature (gas-rich) and immature materials, rather than differing degrees of SW irradiation. Bulk soil isotopic composition and reciprocal N content correlate roughly (fig. 3; sample 79001-2154, containing abundant (gas-poor) rock fragments excluded); indicating that the mature and immature end-members of the N-He correlation are characterised by (somewhat variable) bulk isotopic compositions, of $\delta^{15}N$ <-130‰ and >-10‰ respectively. Samples from the light and dark stratigraphic units, considered as separate groups, define better mixing trends than the sample set as a whole. The materials mixed to generate data arrays pertaining to these units appear isotopically similar, but need not be identical. The variation of cosmogenic ^{15}N abundance with N content (fig. 4) implies a substantial difference in regolith residence times (and/or shielding histories) between the two end-members.

DISCUSSION: Regolith History, Mixing and Core Stratigraphy: The mature fraction of these samples is identifiable with dark, heavily pre-irradiated (nominal $^{15}N_c$ ages >2Ga; cf $^{21}Ne_c$ ages up to 800Ma (10)) fragmental material excavated by the Van Serg impact. Soils uppermost in the core are not "gardened" equivalents of those beneath. They may consist largely of comminuted breccia material, as suggested by McKay et al. (11). The processes by which similar material has become incorporated into soils underlying the Van Serg ejecta cannot be specified, however.

$^{15}N_c$ contents vary erratically down the core and bear no resemblance to the depth-dependence of cosmogenic N production (12). Assembly of the core stratigraphy must have occurred rapidly in comparison to the (2-300Ma) timescale on which $^{15}N_c$ accumulation becomes apparent in samples of this nature. Cosmic ray exposure of these materials relates principally to a prior history, elsewhere in the regolith.

Nitrogen Components: Isotopic variation with stepwise N release (fig. 1) implies the presence in these samples of two or more trapped components. The **combined** abundance of these components varies in proportion to maturity, hence integrated SW exposure, irrespective of sample isotopic composition (3). By contrast, the abundance of a "solar-wind" component of fixed isotopic composition ($\delta^{15}N$ = +120‰ ; abundance deduced by isotopic balance against a light N component set at $\delta^{15}N$ = -220‰ ; see (4)), correlates poorly with He and Ar

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concentrations (cf (13)). A variable SW $^{15}N/^{14}N$ ratio and a SW origin for the **total** trapped N in these samples seems most plausible (3,8,13). This conclusion follows regardless of the fact that isotopic variation in the samples arises through a binary mixing process - both end-members must be characterised by N contents proportional to their maturity, yet differ isotopically by more than 120‰.

The time at which materials comprising these soils acquired their SW gases cannot be specified on the basis of the available data. Provided that the regolith is well mixed over cosmic-ray attenuation depths on a timescale shorter than the $^{15}N_c$ exposure ages of the samples, it is probable that those which have resided there longest will also carry evidence of earliest SW irradiation (3,8,13). Fig. 5 indicates that the light N component, concentrated in the mature soils and breccias, may have been implanted as much as ~2Ga prior to the present day.

Though difficult to reconcile with models of the solar wind source region (3,4), secular increase of the SW $^{15}N/^{14}N$ ratio remains the most plausible explanation of isotopic variation in lunar materials. Grain surface etching experiments, and a study of the grain-size dependence of N content in light-N-enriched breccias, would further test this conclusion.

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