THE ISOTOPIC SIGNATURE OF RECENTLY IMPLANTED SOLAR NITROGEN IN 68815

J.S.Kim*, Y.Kim, K.Marti & J.F.Kerridge, Dept.Chemistry 0317, UCSD, La Jolla, CA 92093.
* Present address: Div.Chemistry & Radiation, KRISS, P.O.Box 102, Yusong Taejon, Korea 305-600

Analysis of N, Xe and Ne in a surface fragment of 68815 has yielded (1) a value of +38‰ for $\delta^{15}N$ in the recent solar radiation, (2) a trapped N/Xe ratio somewhat lower than that in typical regolith but still enhanced relative to the "solar" value, and (3) a N surface concentration corresponding to an exposure duration of about 10^5 yr. These findings lead to the following conclusions: (a) The long-term variation in $^{15}N/^{14}N$ is more complex than previously thought; (b) Any mixing-model interpretation of the long-term trend must invoke a minimum of three isotopically distinct components; (c) There is still no clear evidence for major nonsolar N in the lunar regolith; (d) Erosion of the lunar surface limits the lifetime of the solar-wind-implanted layer to about 10^5 yr.

After twenty years of intensive study, nitrogen isotope systematics in the lunar regolith continue to generate exciting new questions. In order to shed light on some of these questions, we have analysed a piece of the exposed surface of rock 68815 which was emplaced on the lunar surface 2Myr ago by the South Ray Crater impact. The exposure history of this rock is well documented [1-3]; it appears to have had the simplest, and most recent, surface exposure known for an Apollo sample. In particular, the opportunities for this material to have acquired nonsolar N are substantially reduced compared with regolith material, and it is also unlikely that its trapped gas could have been implanted prior to 2Myr ago. Consequently, we believe that this sample can yield the isotopic signature of recently implanted solar radiation, thereby defining one end of the long-term trend in $^{15}N/^{14}N$, and providing a constraint on models that invoke an invariant isotopic composition for solar N.

A piece of 68815 was carefully cleaved to give two fragments yielding about $0.1 cm^2$ and $0.64 cm^2$, respectively, of pitted true surface, and a subsurface fragment to serve as a control. The smaller surface fragment was analysed first, for N and Ne, to establish optimum experimental conditions for the larger fragment, which was analysed in 9 temperature steps for N and Ne. Xe was analysed in 5 steps, all of which yielded the signature of solar Xe. Results from analysis of the subsurface fragment were used to calculate contributions due to terrestrial contamination, cosmic-ray spallation and indigenous N which were then subtracted from the data for the surface fragments. For the larger surface fragment, that subtraction amounted to 26% of the measured ^{14}N content. Key features of the resulting data are summarised in Table 1; the N isotopic release pattern is given in Fig. 1. Major findings are the following:

Table 1

	N ng/cm^2	$\delta^{15}N$‰	$^{132}Xe \times 10^{-12}$cc/cm^2	$^{20}Ne \times 10^{-6}$cc/cm^2
Large surface fragment	417	+23.5	108.0	6.5
Small surface fragment	651	+31.7	-	9.5

The trapped N/Xe ratio of 68815 is 3.0×10^6, intermediate between the (interpolated) "solar" values of 1.5×10^6 [4] and 2.5×10^6 [5] and those characteristic of lunar regolith, which range upwards from 4×10^6 [6]. The fact that regolith N/Xe ratios are somewhat higher than that of 68815, which has not had a regolith history, may lend some support to the idea that lunar regolith contains excess, nonsolar N, though greater loss of Xe during regolith processing seems equally plausible as an explanation. (We note that recent closed-system stepwise-etching data appear inconsistent with significant loss of the heavy noble gases [7].)

Unlike virtually all previously analysed lunar samples, 68815 does not show the characteristic decrease in $^{15}N/^{14}N$ of trapped N with increasing release temperature, Fig. 1. If the normal variation of $^{15}N/^{14}N$ with temperature is attributed to trapping of isotopically distinct components at different depths depending upon implantation energy [8], the 68815 data imply either the near-absence of one or more components, of which the small, isotopically light release at 1050°C might represent a vestige (though the distribution of N as a function of release temperature seems typical for regolith material), or a lack of isotopic distinction between the components. Interestingly, there is some evidence that that isotopic distinction has been decreasing with time and could conceivably have vanished in recently exposed samples [8].

Given a solar-wind proton flux that has been shown to be close to the present value over the exposure lifetime of 68815 [3], a solar N/H ratio of about 10^{-4} [4,5], and 100% N implantation efficiency, the surface

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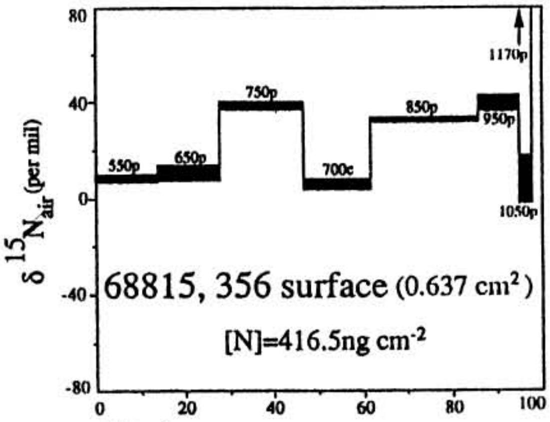

Fig. 1

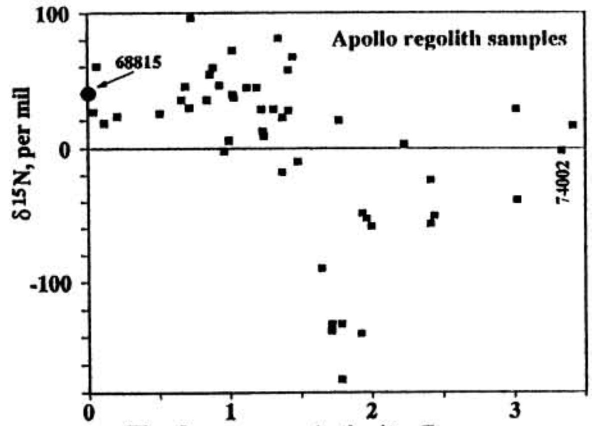

Fig. 2

Fig. 1. Nitrogen isotopic signatures in stepwise release from a surface sample of 68815. The isotopically uniform release from the 750, 850 and 950°C pyrolysis (p) steps is identified as recently implanted solar N. The dip in the 700°C combustion (c) step and the peak above 1050°C are attributed to incomplete correction for terrestrial contamination and spallogenic N, respectively. Fig. 2. Whole-rock values of $\delta^{15}N$ as a function of antiquity for lunar soils and regolith breccias plus the data for 68815. Note the apparent decrease in $\delta^{15}N$ over the past ~1Gyr

concentration of N in 68815 corresponds to an exposure duration of about 10^5 years, significantly less than the 2Myr surface history of the rock. This is likely due to erosion of the 68815 surface either on the lunar surface or possibly subsequent to collection. If this reflects stochastic erosion by micrometeorite bombardment, estimated by Rao *et al.* [3] to yield a time-integrated rate of 1mm/Myr, the 10^5 yr period corresponds to the area-averaged interval since the last micrometeorite impact. Alternatively, if the erosion of 68815 has been by the continuous action of solar-wind sputtering, a 10^5 yr duration is broadly consistent with the sputtering rate of 0.0024A/yr calculated independently for the lunar regolith [9].

Based on the essentially uniform release during pyrolysis at 750, 850 and 950°C, nitrogen trapped on the lunar surface during the past 2Myr, or more probably 10^5yr, is apparently characterised by a well-defined $\delta^{15}N$ value of +38‰. This is distinctly lighter than most previous estimates of recent solar N [10,11] but is not inconsistent with the long-term trend in $^{15}N/^{14}N$, Fig. 2. However, because the heavier $\delta^{15}N$ values in Fig. 2 represent measurements of *bona fide* lunar regolith samples, it follows that the long-term trend should now be seen as including a decrease in $\delta^{15}N$ during the past ~1Gyr or so, following an increase of about 40% during the previous ~1Gyr.

Assigning a value of +38‰ to recently implanted solar N imposes a new constraint on models that seek to explain the lunar N systematics in terms of mixing an invariant solar-wind component with some hypothetical nonsolar N [e.g., 12,13]. Because the lunar N database contains $\delta^{15}N$ values both heavier and lighter than +38‰, a minimum of three components is now required, further exacerbating the problem that such models have in explaining the essentially constant proportion of N to solar-derived noble gases [8].

In summary, our analysis of the surface of 68815 has improved our understanding in a number of aspects of lunar N systematics, notably by providing a largely model-independent measure of $^{15}N/^{14}N$ in the recent solar radiation, and by establishing further complexity in the long-term variation in $^{15}N/^{14}N$.

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