NITROGEN ISOTOPES IN LUNAR REGOLITH: A CONTINUING PUZZLE
John F. Kerridge, Institute of Geophysics, UCLA, Los Angeles, California 90024

In order to celebrate the tenth anniversary of the discovery of a secular increase in the $^{15}$N/$^{14}$N ratio of N trapped within the lunar regolith [1, 2], it seemed appropriate to discuss the plausibility of some recent interpretations advanced to account for this effect. Those interpretations have tended to invoke processes indigenous to the lunar surface, rather than a secular change in composition of the solar wind [e.g., 1]. Such "lunar" models avoid the real difficulties associated with manufacture of sufficient quantities of $^{15}$N in the solar wind reservoir [3], but suffer from defects of their own. I argue here that those defects are sufficiently serious to cast doubt on the ability of such models to explain the observational data. Those data still appear to require a secular change in solar wind composition, though the mechanism responsible for generating that change remains obscure.

A common feature of most recent theories is that they invoke a secular variation in the mixing ratio of two isotopically distinct components on the lunar surface. In the 1982 model due to Ray & Heymann [4], the "light" component is identified as directly implanted solar wind ($^{15}$N hypothesised to be about $-220^\circ/_{oo}$). The "heavy" component, of which both the proportion and $^{15}$N/$^{14}$N ratio are postulated to have increased with time, is identified as lunar atmospheric material, outgassed from previously irradiated regolith, followed by isotopically selective loss from the lunar atmosphere and reimplantation. A major problem with this interpretation is that it should lead to a change in regolith $^{13}$C/$^{12}$C correlating with that in $^{15}$N/$^{14}$N and of comparable magnitude, whereas this is not observed [5].

In a comprehensive treatment of the N isotopic distribution in the solar system, Geiss & Bochsler [3] showed that the entire suite of N isotopic data could be interpreted in terms of two components of nucleogenetic origin. This model is in good agreement with most planetary (including meteoritic) data, but application to the lunar regolith data may not be so successful. The "heavy" component in this model is the solar wind ($^{15}$N taken to be $+120^\circ/_{oo}$), whereas the "light" component is identified as indigenous lunar N ($^{15}$N hypothesised to be below $-230^\circ/_{oo}$), whose outgassing from the lunar interior, and hence mixing ratio in the lunar regolith, have decreased with time. This model therefore predicts that ancient samples should contain substantial quantities of a $^{14}$N-rich component whose presence would perturb the correlation between N content and solar wind exposure. Such a perturbation is not, however, consistent with the data [6] so that, barring excessive uncertainties in the exposure data [3], it seems that this model is not in complete agreement with observation. Nonetheless, it must be stressed that models which invoke a single, solar wind, source for regolith N are complicated by an apparent substantial enrichment of N [7-9], relative to noble gases, compared with nominal solar values [10]. This has led to suggestions that a substantial non-solar-wind component is present in regolith N [8] but the observational evidence still seems to preclude that such a hypothetical component could be responsible for the variation in $^{15}$N [6].

Norris et al. [11] interpreted their lunar N data as supporting a model in which "light" indigenous lunar N was mixed with "heavy" solar wind on the lunar surface, but they also suggested [12] that the "light" component might be of meteoritic origin. Evidence has been found [13] for N with a $^{15}$N value below $-326^\circ/_{oo}$, associated with refractory carbonaceous material in some meteorites. Because of the refractory nature of its host phase, it was suggested that such N could have survived impact-vaporisation and would therefore have contributed to the N inventory in the lunar regolith. The variation in regolith $^{15}$N was
thus interpreted in terms of a secularly decreasing flux of such carbonaceous material onto the lunar surface, resulting in a decreasing mixing ratio of the "light" component with time [12]. However, both interpretations are in conflict with the observation that low-δ15N regolith samples do not, as predicted, contain excess, i.e. non-solar-wind, N [6] and, in addition, the second interpretation leads to a prediction that those low-δ15N samples should contain substantial amounts of meteoritic C, which, again, is not observed [14].

In general, observational constraints, such as those invoked above, make a lunar surface mechanism appear unlikely as the cause of the regolith N systematics. A feature of those constraints is that they tend to involve predictions of chemical variations associated with the N isotopic variations and in the same regolith samples. Such a direct association makes them very strong constraints. By contrast, evidence against theories invoking a secular change in solar wind composition have tended to be indirect, e.g. constraints imposed on the "solar spallation" model by solar nuclear gamma radiation [3,15], the solar flare particle track record [3], or the solar B abundance [1,3,15]. More direct tests used so far, e.g. solar-spallation-based predictions of an increase in solar wind 13C/12C ratio correlated with the increase in 15N/14N, but at about a tenth of its magnitude [5], have been indecisive [5,16,17]. However, it must be admitted that the cumulative effect of these various constraints makes the "solar spallation" model seem quite implausible [3], and it is probably necessary to seek a non-nuclear process capable of achieving the required compositional change in the solar wind reservoir.

In summary, recent attempts to explain the lunar regolith N data in terms of various lunar surface processes seem unsuccessful. Consequently, it still appears that the variation in 15N/14N is due to a secular increase in the proportion of 15N in the solar wind. Given the major obstacles to direct production of enough 15N in the solar convective zone, it may be desirable to investigate further models which invoke a change in mixing ratio of distinct components within the solar wind reservoir. Evidence for significant isotopic differences between solar flare Ne and that in the solar wind [18] may be suggestive in this regard.

REFERENCES