THE CARBON AND NITROGEN STABLE ISOTOPE GEOCHEMISTRY OF TWO LUNAR METEORITES: ALHA-81005 AND Y-86032

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Abstract: The carbon and nitrogen stable isotope geochemistry of two lunar meteorites, ALHA-81005 and Y-86032 has been compared with that of an Apollo 16 regolith breccia, 60016. Although much of the carbon present in all three samples is terrestrial organic contamination, the meteorites have higher carbon abundances and lighter isotopic compositions than 60016. The non-contaminant carbon in ALHA-81005 and Y-86032 occurs as two distinct components, combusting between 550–700°C and 900–1100°C. Since these components are absent from the pristine lunar breccia, they must have been added (i) from the impactor which ejected the meteorites from the Moon; (ii) in the Antarctic or (iii) be representative of a lunar environment not sampled by Apollo missions. At temperatures over 1100°C, spallogenic carbon combusts, with elevated $\delta^{13}C$, greater than 0‰.

Nitrogen systematics are less-well resolved than carbon, partly due to the lower amounts of nitrogen gas liberated by the meteorites. Nitrogen abundance of ALHA-81005 and Y-86032 fall in the range of values from lunar breccias and $\delta^{15}N$ values follow the heavy-light-heavy pattern characteristic of such samples. Spallogenic carbon and nitrogen are more abundant in ALHA-81005 than Y-86032, in keeping with its longer exposure age. Nitrogen data are consistent with identification of ALHA-81005 and Y-86032 as lunar highland breccias compacted from immature regolithic material.

1. Introduction

The first lunar samples were thought to be returned to Earth by the Apollo 11 mission in 1969. However, with the discovery by the 1981 U. S. Antarctic meteorite recovery team of Allan Hills (ALH) A-81005, it became apparent that fragments of the Moon had reached the Earth many years earlier. Since the recognition of ALHA-81005 as a lunar meteorite (MASON, 1982), a further five specimens (Yamato (Y)-791197, Y-793274, Y-82192, Y-82193, and Y-86032) have been found in the Yamato Mountains by the Japanese Antarctic Research Expeditions (TAKEDA *et al.*, 1988). Even more recently, the 1988 U. S. Ansmet team returned two lunar meteorites (one weighing approximately 700 g) from the MacAlpine Hills (SCORE *et al.*, 1989). Hence, there are now eight known lunar meteorites, totalling approximately 1.5 kg in weight. This compares with almost 382 kg returned by the Apollo and Luna missions (which sampled only *ca.* 4.7% of the Moon's surface).

Of the eight lunar meteorites, five have been studied in detail. Three of the

Japanese specimens (Y-82192, Y-82193 and Y-86032) are paired (Warren et al., 1989); the two MacAlpine Hills meteorites are also paired, therefore the eight samples represent, at most, five ejections from the Moon. Excluding the most recent finds from MacAlpine Hills, which have not yet been released to the scientific community for research, the remaining four individuals seem to be derived, on the basis of several geochemical criteria, from at least three separate craters (Dennison et al., 1987; Warren et al., 1989; Eugster and Niedermann, 1988). It follows that the meteorites' presence on Earth is the result of several discrete impact events, and not a single impact with subsequent break-up during Earth-Moon transit. Indeed, the meteorites record differing ages—terrestrial residence time plus Earth-Moon transit time: ALHA-81005 was ejected from the Moon long after the paired meteorites Y-82192/3/86032 (Warren and Kallemeyn, 1988).

Lunar meteorites have been compared with Apollo samples; major, minor and trace element compositions are most similar to anorthositic highland material (Verkouteren et al., 1983; Warren et al., 1983, 1989). More specifically, ALHA-81005 and Y-82192/3/86032 have been likened to the mature regolith breccias returned from the Apollo 16 landing site (Warren et al., 1983), particularly those collected from station 10, half-way between the North and South Ray craters (Takeda et al., 1986). However, there are sufficient differences in chemistry between lunar meteorites and Apollo material to infer that the meteorites are not from the same region of the Moon (the central nearside) that was sampled by either the Apollo or Luna missions, and probably derive from an area quite removed from the central nearside. Indeed, it has been suggested by several authors that the meteorites in fact originate from either the farside of the Moon or its NE limb (Pieters et al., 1983; Ryder and Ostertag, 1983; Warren and Kallemeyn, 1987).

Light element (viz. carbon and nitrogen) geochemical analyses of Apollo samples have played an important role in furthering the understanding of the Moon's exposure history (e.g., Pillinger, 1979). There is a variety of carbon- and nitrogen-bearing components in lunar materials. Soils and mare regolith breccias contain the highest concentrations of these elements, an over-abundance mainly due to exposure to the solar-wind while on the lunar surface (Pillinger, 1979). Lunar highland breccias, by comparison, are depleted in carbon and nitrogen, but still contain significant quantities of the elements. In the case of nitrogen, it may be possible to distinguish contributions from ancient and modern solar-wind, due to differences in isotopic composition (Becker and Clayton, 1975; Kerridge, 1980; Thiemens and Clayton, 1980). Lunar samples ought also to contain a component derived from impacting meteorites, however, any such carbonaceous material has never adequately been resolved from background contributions.

The potential for studying lunar materials has been extended greatly by the discovery on Earth of meteorites from the Moon, not least by giving access to fresh sampling areas for investigation. The aim of this particular carbon and nitrogen stable isotope study is to make a preliminary comparison between two lunar meteorites and an appropriate lunar sample, Apollo 16 breccia 60016. The applicability of 60016 is based entirely on its major element chemistry, since the similarity of lunar meteorites to authentic lunar highland breccias from the Apollo 16 site breaks down once trace

elements such as Ni, or Au/Ir ratios are considered (WARREN *et al.*, 1989).

2. Experimental

Carbon and nitrogen analyses of two lunar meteorites ALHA-81005 and Y-86032, plus carbon analysis of Apollo 16 breccia 60016, were carried out in order to determine the abundance and isotopic composition of the elements in these samples. For the two meteorites, C and N measurements were made on separate aliquots derived from a 30 mg reservoir of crushed (*ca.* 50 μm) whole-rock meteorite. The 60016 material was a specimen allocated to the European Lunar Consortium in 1974. For all experiments, sample sizes were between 2 and 3.5 mg.

The samples were combusted in steps (generally increments of *ca.* 50°C) from room temperature to 1200°C; a full procedural protocol has been published elsewhere (BOYD *et al.*, 1988; ASH *et al.*, 1990). Carbon was analyzed as carbon dioxide gas; yields were measured on a capacitance manometer to ± 0.2 ng. Isotopic composition was determined on a static, noble gas-type mass spectrometer to $\pm 1\%$ for quantities of gas containing greater than 10 ng of carbon (CARR *et al.*, 1986). Nitrogen isotopes were measured, using nitrogen gas, to $\pm 0.5\%$ (WRIGHT *et al.*, 1988a); quantitative information was acquired by previous calibration of the mass spectrometer ion-beam current (± 0.5 ng). Isotopic compositions are quoted relative to the PDB standard for carbon and AIR for nitrogen.

3. Results

3.1. Carbon

Figure 1 shows the stepped combustion profiles of the two lunar meteorites and Apollo 16 breccia 60016; data are summarized in Table 1. It has long been recognized that lunar and meteorite samples are prone to terrestrial organic contamination, even when great care is taken with their handling, although Antarctic meteorites are "cleaner" than most other meteoritic samples (SWART *et al.*, 1983). Contamination by terrestrial debris is most significant in samples with a low indigenous carbon content, a category into which lunar materials fall. However, organic contaminants combust at low temperatures, and may generally be characterized during stepped combustion analyses by a release of carbon below 450°C, with δ^{13}C between -30% and -20% (DESMARAIS, 1978; SWART *et al.*, 1983). Therefore, in the following discussions, it will be assumed (given the lack of evidence for indigenous lunar organic compounds) that the carbon released below 450°C during stepped combustion is due to terrestrial organic contamination. In the Apollo 16 material, a strong case can be made for the terrestrial contamination continuing to burn up to 500°C. This temperature increment is therefore used as the cut-off between combustion of contaminant and indigenous carbon in 60016. The contaminant carbon in 60016 is only 104 ppm, even though the material has been stored for 15 years. The difference between 104 ppm and the 576 and 292 ppm liberated from ALHA-81005 and Y-86032 respectively represents the contamination acquired in the Antarctic environment and/or accumulated by storage elsewhere.
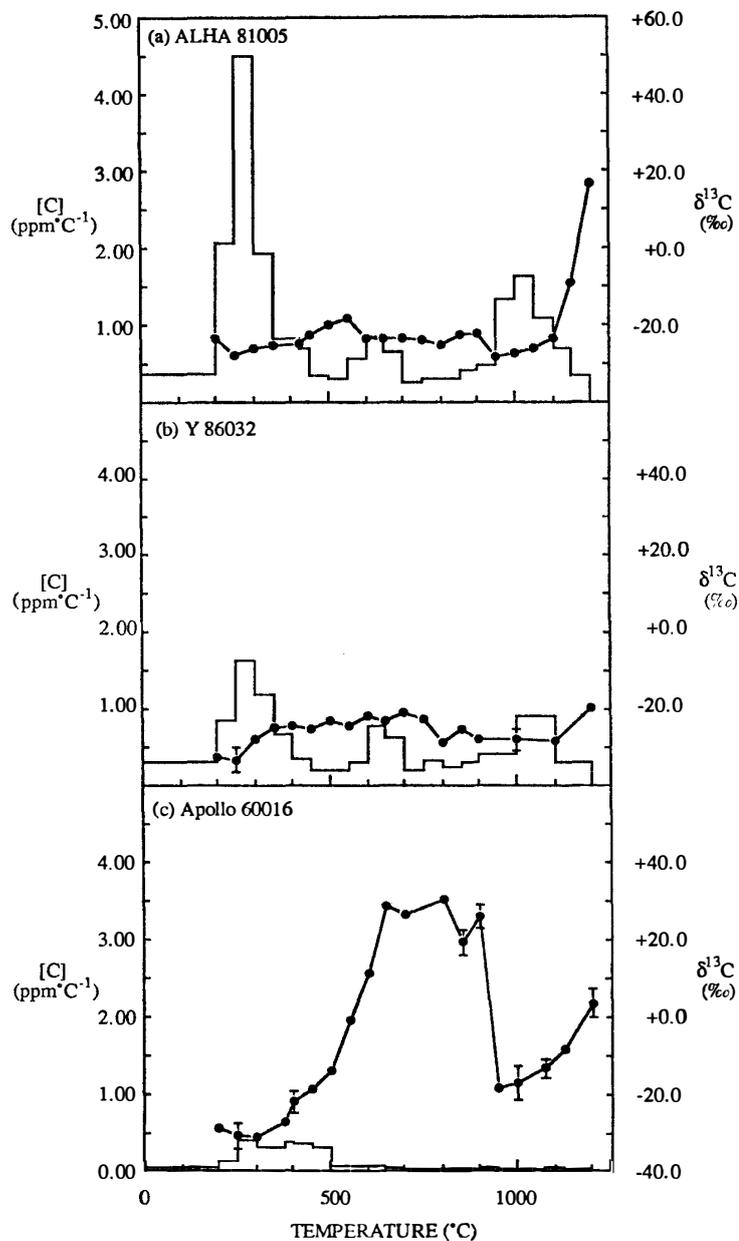
Fig. 1.   Carbon released on stepped combustion in increments from room temperature to 1200°C
is shown as a histogram for (a) ALHA-81005, (b) Y-86032 and (c) Apollo 60016. Errors
(±1σ) in $\delta^{13}C$ (—●—) are less than the size of the symbol, unless shown otherwise.

Table 1.   Summary of carbon and nitrogen data from stepped combustion of lunar meteorites
ALHA-81005, Y-86032 and Apollo regolith breccia 60016.

Sample		[C] (ppm)	$\delta^{13}C_{PDB}$ (‰)	wt (mg)	[N] (ppm)	$\delta^{15}N_{AIR}$ (‰)	wt (mg)
ALHA-81005	(Total)	1055	−23.9	2.667	53	+29.1	3.557
	(T>450°C)	479	−21.9		43	+32.9	
Y-86032	(Total)	612	−26.7	1.929	31	+ 7.7	2.351
	(T>450°C)	320	−25.2		10	+10.6	
Apollo 60016	(Total)	127	−18.1	2.348			
	(T>500°C)	23	+ 9.9				

Ignoring the contribution from terrestrial contamination, the carbon contents of ALHA-81005 and Y-86032 are 429 and 320 ppm, respectively, much greater than values measured for any breccia (12–198 ppm), or soil (23–180 ppm) returned by the Apollo program (KAPLAN *et al.*, 1970, 1976; KERRIDGE *et al.*, 1975, 1978; MOORE *et al.*, 1973, 1974; PETROWSKI *et al.*, 1974; summarized in PILLINGER, 1979). The sample of 60016, considered as a good analogy to ALHA-81005 and Y-86032, and analyzed herein, has only 23 ppm indigenous carbon, and falls at the low end of the regolith breccia spectrum, highlighting the difference between the meteorites and authentic lunar materials. Summed $\delta^{13}C$ values ($-21.9‰$ for ALHA-81005; $-25.2‰$ for Y-86032) are within the range exhibited by lunar breccias ($-30.1‰$ to $+9.2‰$; KAPLAN *et al.*, 1970; PETROWSKI *et al.*, 1974), although most lunar breccias, including the more mature regolith samples, fall towards the heavy end of this range—it is believed (KERRIDGE *et al.*, 1978) that most of the spread in $\delta^{13}C$ derives from incomplete removal of terrestrial organic contamination, and that the positive numbers represent the true values for $\delta^{13}C$ of lunar samples. Indeed, the results for 60016 bear this out: $\delta^{13}C$ above 500°C is $+9.9‰$, whereas the total $\delta^{13}C$ (including contamination) is isotopically much lighter, at $-18.1‰$.

Examination of the stepped combustion profiles in Fig. 1a, b shows that the two lunar meteorites are remarkably similar in their carbon combustion patterns. Both have three clear peaks of carbon release, signifying three discrete carbonaceous components, whose characteristics are summarized in Table 2. The first component, which combusts below 450°C, has already been ascribed to terrestrial organic contamination. It accounts for approximately 50% of the total carbon abundance in each meteorite, and has $\delta^{13}C$ between $-25‰$ and $-28‰$, an isotopic signature typical of terrestrial organics (SWART *et al.*, 1983). There is approximately twice as much contamination in ALHA-81005 than Y-86032, a factor which might be related to its greater storage age. At intermediate temperatures (550–750°C), approximately similar amounts of carbon combust (115 ppm in ALHA-81005 *vs.* 95 ppm in Y-86032), component A; the measured $\delta^{13}C$ is slightly heavier than that of the terrestrial contaminant, at $-23.4‰$ in ALHA-81005 and $-22.2‰$ in Y-86032. The third component (component B) indicated in the yield histogram combusts between 900 and 1100°C. It accounts for 226 ppm and 146 ppm carbon respectively, thus is 50% more abundant in ALHA-81005, and has $\delta^{13}C$ between $-26.1‰$ (ALHA-81005) and $-28.2‰$ (Y-86032). A fourth component, whilst not apparent in the yield pattern, is indicated by a rise in

Table 2. *Abundance and isotopic composition of individual carbon-bearing components in ALHA-81005 and Y-86032.*

Component	Combustion temperature (°C)	ALHA-81005			Y-86032		
		% of total C	[C] (ppm)	$\delta^{13}C$ (‰)	% of total C	[C] (ppm)	$\delta^{13}C$ (‰)
Organic contamination	<450	55	576	−25.5	48	292	−28.4
A	550–750	11	115	−23.4	16	95	−22.2
B	900–1100	21	226	−26.1	24	146	−28.2
Spallogenic carbon	>1150	—	—	>0	—	—	>0

Table 3.   Abundance and isotopic composition of individual components in Apollo 60016.

Component	Combustion temperature(°C)	% of total C	[C] (ppm)	$\delta^{13}C$ (‰)
Organic contamination	<500	81	103	−24.0
Solar-wind/Elemental ?	550–900	10	13	+23.8
C in iron metal ?	900–1075	3	4	−16.6
Spallogenic carbon	>1150	—	—	>0

$\delta^{13}C$ at high temperature. This is most obvious in ALHA-81005, for which $\delta^{13}C$ approaches +20‰ at 1200°C, and presumably is evidence for the presence of trace amounts of spallogenic carbon, so highly enriched in ^{13}C that even in low quantities it exerts a significant influence on isotopic composition. The spallogenic component is much more abundant in ALHA-81005 than Y-86032, in keeping with the longer exposure age of ALHA-81005 compared to Y-86032 (580 Ma vs. <11 Ma respectively, Eugster et al., 1986; Eugster and Niedermann, 1988).

Whilst the carbon isotopic and abundance patterns for ALHA-81005 and Y-86032 match each other so well, they are very different from the data for the lunar regolith breccia 60016 (Fig. 1c), selected for analysis due to its apparent similarity to the lunar meteorites (Takeda et al., 1986). Two of the four components present in the yield histograms of ALHA-81005 and Y-86032 are not seen in that of 60016 (Table 3). Rather, the histogram is dominated by a single component, terrestrial contamination, which has $\delta^{13}C$ ca. −24.0‰, and accounts for some 81% of all the carbon present. Above 550°C, carbon combusts in decreasing quantities to 900°C, where there is a second peak in the histogram. Between 550 and 900°C, 13 ppm of carbon combusts, ca. 10% of the total; $\delta^{13}C$ is high, reaching +30.3‰ between 700 and 800°C, but summing to +23.4‰. Between 900 and 1075°C, a further 4 ppm carbon combust, 3% of the total, with $\delta^{13}C$ decreasing to −16.6‰. Above this temperature, $\delta^{13}C$ starts to rise again, presumably as spallogenic carbon combusts.

3.2. Nitrogen

Figure 2 shows the nitrogen stepped combustion profiles of (a) ALHA-81005 and (b) Y-86032; data are summarized in Table 1. As for carbon, the nitrogen released below 450°C is ascribed to terrestrial organic contamination. For both the samples, the abundance of nitrogen released above 450°C (43 ppm in ALHA-81005 and 10 ppm in Y-86032) and isotopic composition (+32.9‰ and +10.6‰ respectively) fall in the ranges reported for lunar breccias (4–70 ppm; $\delta^{15}N$ ca. −65 to +74‰; Becker and Clayton, 1975; Kaplan et al., 1976; Fourcade and Clayton, 1984). The very low nitrogen abundance in Y-86032 is as expected on the basis of noble gas data from its partners Y-82192/82193, which suggests a negligible solar-wind exposure (Bischoff et al., 1987). Ignoring nitrogen released below 450°C, the stepped combustion data for nitrogen may be interpreted generally as if ALHA-81005 and Y-86032 were typical lunar breccias, always bearing in mind that the amounts of nitrogen released were low, and thus step sizes were necessarily large. Fluctuations in $\delta^{15}N$ point to there being several different components present, with the classic heavy-light-heavy pattern of lunar breccias seen (e.g., Thiemens and Clayton, 1980; Carr, L. P. et al., 1985), particularly in ALHA-81005. In this context, the isotopically light component is believed to rep-
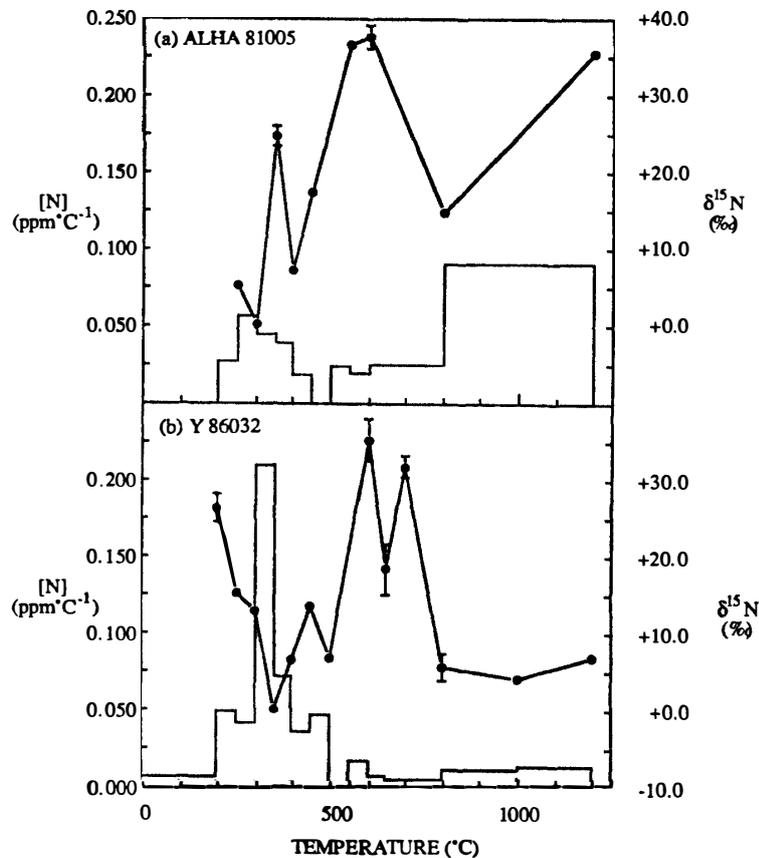
Fig. 2. Nitrogen released on stepped combustion in increments from room temperature to 1200°C is shown as a histogram for (a) ALHA-81005 and (b) Y-86032. Errors ($\pm 1\sigma$) in $\delta^{15}N$ (—●—) are less than the size of the symbol, unless shown otherwise.

resent nitrogen from ancient solar-wind, added to the sample during exposure on the lunar surface before lithification. The more ^{15}N-enriched material combusting at lower temperatures may be a more recent sample of solar-wind nitrogen (and hence more loosely-bound, due to a nearer grain-surface location). Spallogenic nitrogen, as evidenced by increasing $\delta^{15}N$ at high temperatures occurs, and, like spallogenic carbon, is more abundant in ALHA-81005 than Y-86032.

4. Discussion

The carbon chemistry of lunar materials is fairly well-understood: most carbonaceous components are not indigenous to the Moon, but have been added over time, from the solar-wind and possibly from meteoritic debris. The abundance of carbon in lunar materials is therefore related to their exposure on the lunar surface. Soils contain the highest quantities of extra-lunar carbon, whilst igneous rocks excavated from depth below the surface give the best estimate of indigenous "lunar" carbon. Regolith breccias may be considered as fossil soils which became closed to exogenous influences after compaction. Contributions of carbon from meteoritic sources to soils and breccias is poorly defined—much of the meteoritic carbon must have been lost

during impact; how much is retained, if any, and what form it takes is not clear.

The data obtained here for Apollo 60016 indicate that this rock is a fairly typical lunar breccia, in terms of its carbon chemistry. Almost all of its indigenous carbon is released between 550–900°C with $\delta^{13}C$ ca. $+23.8‰$. This is consistent with compaction from an immature regolith having surficially implanted carbon atoms, inherently enriched in ^{13}C, or preferentially sputter-fractionated to increase the relative abundance of the heavier isotope. Little carbon from the parent soil has been incorporated in exposure-produced iron metal. In contrast, carbon analyses of the two lunar meteorites are completely different from 60016, and show none of the characteristics typical of lunar breccias.

High resolution stepped combustion analyses were not a regular feature of lunar studies carried out during the 1970's, therefore it was necessary to conduct the comparable experiment as part of the current investigation. As has already been stated, there is no resemblance between 60016 and the lunar meteorites for carbon, except on minor details: all the samples exhibit substantial contamination, as would be expected, and they also contain spallogenically produced ^{13}C from cosmic-ray exposure. A feature which might have been apparent in lunar meteorites, i.e. a small quantity of ^{13}C-enriched carbon burning over the temperature regime appropriate for surficially implanted carbon atoms, is either not present in the meteorites, or has been obscured by the co-occurrence of copious amounts of carbon from other sources. Both the meteorites contain two components of carbon, noncommittally called A and B, which contribute to total carbon contents far in excess of anything observed previously for lunar samples. Component A is found in approximately similar amounts in the two meteorites (ca. 100 ppm), but component B is about a factor of 50% more abundant in ALHA-81005 than Y-86032 (226 ppm vs. 146 ppm).

One may speculate on the nature and source of these two components. Given the low exposure history of the material compacted into ALHA-81005 and Y-86032, as indicated by their nitrogen contents, it would seem reasonable to assume that neither component A nor B was solar-wind related. Inevitably, since ALHA-81005 and Y-86032 have spent long periods on Earth, even though for the most part this sojourn took place trapped in the Antarctic ice, consideration must be given to the idea that A and B are terrestrial contaminants. Component A has a combustion temperature (550–700°C) appropriate for either elemental carbon or the decomposition of carbonate. Carbonates are common weathering products in Antarctic meteorites, but their $\delta^{13}C$ is much higher, at $0\pm5‰$ (Grady et al., 1989). The occurrence of carbonates in lunar materials has been proposed, but they are believed to be secondary alteration products (Gibson and Moore, 1975), and do not occur at the 100 ppm level. Whilst the presence of carbonates in lunar meteorites cannot be discounted, it should be pointed out that carbonates in other meteorites are ^{13}C-enriched—up to $+80‰$ in CI and CM chondrites (Grady et al., 1988). Martian carbonates, as determined by analyses of Nakhla and EETA-79001, reach $+15‰$ (Carr, R.H. et al., 1985; Wright et al., 1988b). The carbon isotopic composition of component A is lighter than that of carbonates in Nakhla and EETA-79001, suggesting that if both component A and the carbonate in SNC's were terrestrial weathering products, the processes involved in their formation must utilize different carbon sources. Nevertheless, if component A were an indigenous carbonate,

its $\delta^{13}C$ of -23 to $-22‰$ is highly unusual for a meteorite.

Identification of component B as a contaminant must be reconciled with its very high temperature of combustion (900–1100°C). The extraneous carbon would need to be in a form more stable than diamond, e.g. a carbide, and whilst this is not impossible, possibly coming from a cutting tool, it would necessitate very unfortunate co-incidental circumstances, since the two meteorites were collected five years apart, from different regions of Antarctica, and subsequently processed and stored at opposite sides of the globe, by teams of different nationality. Component B has the appropriate combustion temperature for carbon in solid solution in iron metal produced by preferential sputtering of lunar regolith materials (GARDINER et al., 1977). However, given the known ^{36}Ar abundance of ALHA-81005 (BOGARD and JOHNSON, 1983), and using the relationship between ^{36}Ar and hydrolyzable carbon reported by PILLINGER et al. (1974), it may be calculated that no more than 3 ppm of carbon could be in this form. Likewise, I_s/FeO data from MORRIS (1983) for ALHA-81005 suggests a carbon in iron content of less than 1 ppm (PILLINGER et al., 1978). Whilst there is a discrepancy in the two estimates, both are at least a factor of fifty times too small to explain the abundance of component B. The noble gas content of Y-86032, based on measurements made for Y-82192 (BISCHOFF et al., 1987; EUGSTER and NIEDERMANN, 1988) would imply several orders of magnitude less carbon in iron in Y-86032.

It is also difficult to appeal to influx of meteoritic debris to account for the over-abundance of carbon: trace element data indicate that ALHA-81005 has a CI1 chondritic component of up to 1.4 wt% (VERKOUTEREN et al., 1983), whilst Y-82192 (paired with Y-86032) has 2.4 wt% (DENNISON et al., 1987). The yield and isotopic profiles of the two meteorites are unlike those of any carbonaceous chondrite—or indeed of any type of meteorite at all. The $\delta^{13}C$ values are much closer to type 3 ordinary or CV/CO carbonaceous chondrites than CI1, however, if all the carbon were from meteorites of these classes, then approximately 56% (for ALHA-81005) and 96% (for Y-86032) of the lunar meteorites would be from type 3 chondrites, assuming no carbon was lost during impact. Noble gas and trace element studies have not reported similar gross enrichments, which would be almost impossible to achieve in any physically realistic situation. One is left to conclude that the carbon chemistry of lunar meteorites is unlike that of comparable lunar breccias, and presumably reflects admixture of an unusually large chondritic component into the lunar surface at the time and site of impact. In other words, the lunar meteorites are carrying with them the carbon isotopic signature of the impactor which launched them Earthwards.

Nitrogen abundance and isotopic data acquired for ALHA-81005 and Y-86032 in a stepped fashion at temperatures above 500°C are typical of that which might be expected for lunar highland breccias compacted from a regolith of low to very low exposure history or maturity. Such a conclusion may be reached without direct comparison with a genuine lunar breccia such as 60016, since ample data already exist in the literature. For example, the release and isotope profiles for both lunar meteorites resemble data measured for Apollo 16 soils (BECKER et al., 1976).

The two meteorites do not exhibit the extreme $\delta^{15}N$ variations shown in lunar breccias, which have been considered as due to a change in $\delta^{15}N$ of the solar-wind with time. Analyses of many lunar breccias reveal that the proposed ancient solar-wind

nitrogen is isotopically light, with $\delta^{15}N$ down to $-200‰$ (e.g., Clayton and Thiemens, 1980). Although $\delta^{15}N$ decreases across the temperature range 700–1000°C in the lunar meteorites, it never drops below 0‰, implying that the ancient solar-wind component is absent or, at best, present in reduced quantities in the meteorites. The dearth of ancient solar-wind nitrogen isotopic signature might be explained by invoking an alternative picture of lunar nitrogen. Geiss and Bochsler (1982) proposed that there were two components in lunar nitrogen: a solar system component, with $\delta^{15}N > 0‰$ (HLN) and a ^{14}N-enriched component, derived not from the ancient solar-wind, but an indigenous component of light lunar nitrogen (LLN), related to an even more ^{15}N-depleted planetary nitrogen component (LPN). The nitrogen budgets of ALHA-81005 and Y-86032 might therefore simply be mixtures of two components: modern solar-wind nitrogen and LLN, in which solar-wind nitrogen is present in greater abundance than the indigenous lunar nitrogen. Even after allowing for spallogenic contributions, $\delta^{15}N$ of Y-86032 is lower than that of ALHA-81005, and nitrogen concentration is also reduced. This is presumably a reflection of the higher abundance of recent solar-wind nitrogen compared to LLN in ALHA-81005 than in Y-86032, which is again in keeping with the longer, more recent exposure of ALHA-81005 on the lunar surface.

5. Conclusion

The two lunar meteorites ALHA-81005 and Y-86032 contain significantly higher quantities of carbon than comparable lunar regolith breccias. Carbon isotopic composition is also different. Carbon occurs as four components, two of which can be identified as terrestrial organic contamination and spallogenic carbon. The identification of the remaining two components is problematic: they might be elemental carbon or carbonate (component A) and carbon in iron metal or carbide (component B). One possible explanation for the distribution and $\delta^{13}C$ of carbon in lunar meteorites is that they have retained the carbon signature of the impactor which excavated them from the Moon and propelled them Earthwards.

Nitrogen systematics, in contrast, are dominated by exposure-related components: spallogenic and solar-wind nitrogen. In keeping with its much longer exposure age, ALHA-81005 has higher spallogenic and solar-wind nitrogen contents than Y-86032. Comparison of nitrogen in lunar meteorites with lunar soils and regolith breccias indicates that, if nitrogen in lunar samples can be regarded as a two-component mixture of LLN and HLN, the LLN component is absent from, or occurs in reduced quantities in the lunar meteorites. Nitrogen data are consistent with identification of ALHA-81005 and Y-86032 as immature breccias compacted from low maturity regolithic material.

There are sufficient differences in cabon and nitrogen stable isotope geochemistry between lunar meteorites and returned lunar materials to warrant the conclusion that the lunar meteorites might be sampling a region of the lunar surface which is not otherwise represented in the Earth's lunar collections.

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