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Nitrogen, Carbon, and Noble Gases in Apollo Lunar Samples

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Abstract

A suite of five powdered lunar basalt samples have been analysed for nitrogen, carbon, helium, neon, and argon, using a high-sensitivity stepped combustion mass spectrometer system at the Open University, UK. Preliminary results indicate the presence of cosmogenic nitrogen and carbon, released in small amounts at high temperatures, as well as small amounts of cosmogenic neon and argon (mixed with a trapped non-cosmogenic component). Low temperature steps are dominated by contamination release, although 15555 displays an unusually abundant, isotopically light carbon component, released at 500 °C.

1. Introduction

In recent years, the search for lunar volatiles has attracted renewed interest; new analyses of lunar glasses and apatite crystals suggest initial magma volatile contents (prior to degassing) many times higher than previously reported [1], with some possibly reaching terrestrial-like volatile abundances [2]. Alongside these discoveries, several spacecraft have carried out remote experiments on the lunar surface, with equally encouraging results. The Moon Mineralogy Mapper (M3) spectrometer on-board Chandrayaan-1 detected absorptions of wavelengths associated with the presence of either OH or H2O groups within the upper layers of the lunar regolith [3]. Most recently, the LCROSS mission documented water and other hydrocarbons and volatiles within impact ejecta near the lunar south pole [4]. In light of this, and given the advancements in analytical techniques made in the decades since the Apollo missions returned lunar samples to Earth, it seems timely to reassess the volatiles in lunar samples, to better constrain their likely source(s) and abundances.

Using The Open University's custom-built high-sensitivity mass spectrometer system ('Finesse'), stepped combustion analyses have been carried out on a range of lunar basalts. Stable isotope data for carbon, nitrogen, helium, neon, and argon has been collected for each combustion step, and the preliminary results are presented herein.

1.1 'Finesse' Mass Spectrometer System

Finesse is a custom-built, automated stable isotope machine, located at the Open University, UK. It consists of three static-mode mass spectrometers (one for carbon, one for nitrogen, and a quadrupole for noble gases), all linked to a common sample inlet/extraction furnace system, and operating under high vacuum [5]. Very low blank levels associated with Finesse make it ideal for the analysis of low-abundance volatiles typically found in lunar samples.

2. Methods

Five powdered lunar basalts were selected for initial analyses, one each from Apollo 11, 12, 14, 15, and 17. For each sample, 5 mg of basalt powder were measured out and placed into handmade platinum foil 'buckets' (previously cleaned to remove contamination), which were then crushed to form spheres for ease of sample introduction. Empty Pt foil buckets were used to measure machine blank levels.

Samples were dropped into the furnace and combusted (in 100 °C steps, from 200 °C to 1400 °C); the gases released at each temperature step passed through a series of cold fingers, cryotraps, and molecular sieves to separate and purify them, before they being sequentially fed through into the relevant mass spectrometer. In these initial analyses, data were collected for N_2, CO_2, He, Ne, and Ar.

3. Preliminary Results

3.1 Nitrogen

Most of the nitrogen in the samples analysed so far was released at lower temperature steps (typically < 500 °C), and was associated with $\delta^{15}N$ values of ± 10 ‰ or less. Mid-temperature nitrogen (600-900 °C), while much less abundant, has similar $\delta^{15}N$ values of between -10 ‰ to +40 ‰. However, at temperatures above 900 °C, the nitrogen released is at, or is below, blank levels, with $\delta^{15}N$ values of +500 ‰ to +1000 ‰.

3.2 Carbon

As with nitrogen, the majority of the carbon in the basalts is released at temperatures below 500-600 °C, associated with $\delta^{13}C$ values of -35 ‰ to -9 ‰. Very little carbon (only just above blank levels) is released above 600 °C, although, similar to nitrogen, the carbon becomes isotopically heavier at the higher temperature steps (+ 900 °C), peaking at slightly positive $\delta^{13}C$ values of between +2 ‰ and +6 ‰.

In 15555, a distinct carbon component is released between 500-600 °C, with a much lighter isotopic signature of -46 ‰. This light carbon component is present in far greater abundance than seen in other samples, at around 5200 ng, and compared to other low-temperature carbon components in the same sample, at around 500 ng (Figure 1). Apart from this light component, the isotopic values for carbon in 15555 at other temperature steps match well with published stepped combustion data for this sample [6].

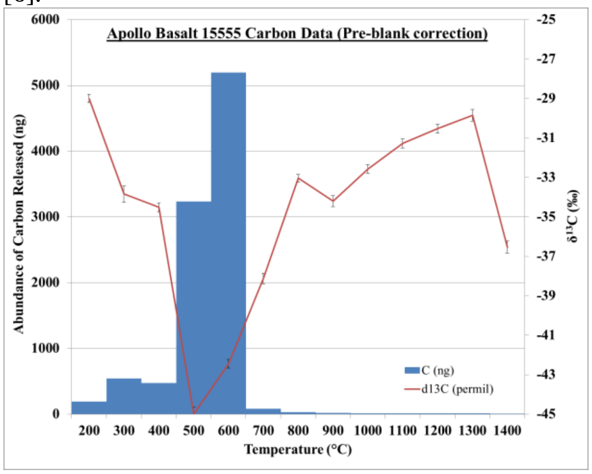

Figure 1: Step plot for carbon released from powdered basalt sample 15555.

3.3 Noble Gases

Initial results indicate an excess of neon and argon in the basalt samples analysed so far; both neon and argon display mixing between a minor cosmogenic component, and a more abundant non-cosmogenic trapped component. ^{4}He is released in the 500 °C step, and is correlated with a release of ^{20}Ne.

4. Summary

From these preliminary results, a striking feature is the high-temperature release of isotopically very heavy nitrogen in the samples analysed so far. Such isotopically heavy nitrogen, present in almost blank-level amounts, suggests spallation processes are the most likely source for such high-temperature nitrogen; the heaviest isotopic composition recorded for nitrogen is in 10017, with the greatest exposure age (at 480 My [7]). Carbon displays a similar enrichment in the heavy isotope at high temperatures, although not to the same extent. Furthermore, cosmogenic neon and argon are also present in these samples.

The trapped noble gas components seen in the samples do not seem to be from a solar wind source.

The variable nature of the isotopic signatures of the volatiles released below 500-600 °C, and the relative abundance of gas released at these temperatures, indicates a mixing of different terrestrial contaminants, loosely bound to the samples.

Further analyses of lunar basalt chips, and the analysis of more pristine samples (i.e. those with < 50 My exposure ages) are planned, to better identify and characterize indigenous lunar carbon, nitrogen, and noble gas components.

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