THE MANTLE, CRUST AND ATMOSPHERE OF MARS AS ILLUMINATED BY THE LIGHT ELEMENT GEOCHEMISTRY OF NWA 7034.
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Introduction: The martian meteorite NWA 7034 (and its paired siblings NWA 7475, 7533, 7906, 7907 and 8114) is classified as a basaltic breccia [1]. More detailed studies describe the sample as either a monomict [2] or polymict [3] breccia consisting of multiple igneous-textured clasts, including impact melt rocks and phenocrysts set in a fine-grained clastic matrix. The breccia may be the product of its volcanic history [2] or regolith processes [3]. The first report of noble gases in NWA 7034 deduced a CRE age of between 5 and 11 Ma, depending on the assumed chemistry of the meteorite [4]. NWA 7034 differs from other martian meteorites not just in its petrology, but also in its chronological evolution: it contains ancient zircons (~ 4.4 Ga; ref. 3), but has a Rb-Sr crystallization age of ~ 2.1 Ga [2], implying a later disturbance. A difference in the volatile inventory might help to distinguish between the former and the latter origins, since one might hope to detect a component related to the surface exposure history of the meteorite in regolith material, which might be otherwise absent in a volcanic breccia.

Determination of the light element (C, N, noble gases) chemistry of brecciated meteorites (asteroidal and lunar) has enabled inferences to be drawn concerning the history of material at a parent body surface, as well as the evolutionary history of the parent prior to exposure. NWA 7034 offers the first opportunity to apply the lessons learnt from asteroid and lunar breccias to be applied to Mars.

Results: We have employed our Finesse stepped combustion-isotope ratio mass spectrometer system (SC-IRMS) to analyse a 10.6 mg matrix-rich fragment from NWA 7034. The material was heated in increments from room temperature to 1400 °C, with the abundance and isotopic composition of C, N, Ne and Ar being measured at each step. A summary of the results is given in the Table.

Discussion: The carbon results (Figure 1a) indicate that the sample of NWA 7034 was contaminated with terrestrial material. This is unsurprising: even though the recovered specimen seemed fairly fresh, it had been exposed to the Saharan environment. Most of the carbon comes from an organic component, almost an order of magnitude more abundant than in other martian meteorites, and with an isotopic composition characteristic of terrestrial material. The second most abundant component is carbon from the breakdown of calcite, with $\delta^{13}C \sim 0$ ‰. Calcite has been identified in NWA 7034, but its isotopic composition is much more akin to terrestrial carbonates than those identified as martian, which have a much more ^{13}C-enriched composition ($\delta^{13}C > +40$ ‰). There is also very little evidence for the presence of trapped martian atmospheric CO_2. For nitrogen (Figure 1b) the bulk of the material comes from terrestrial organic contamination, with almost no trapped/adsorbed terrestrial atmosphere. However, trapped martian atmospheric nitrogen, and nitrogen generated by cosmic ray interactions is released at temperatures above 800 °C, characterized by elevated $\delta^{15}N$ values. The noble gas data in the Table are in good agreement with those from [4]. Neon isotope data from individual temperature increments are shown in Figure 2a and making similar assumptions of parent-body chemistry to those of [4], we derive a CRE age of ~ 12 Ma, similar to those of Chassigny and the nakhlites [5]. Partitioning the Ne components into trapped and cosmogenic components [6] return a weighted mean of $(^{21}Ne/^{22}Ne)_c$ of 0.76, very close to the value of [4]. We are able to resolve individual contributions: at low T, very low ratios indicate terrestrial contamination, but between 500 and 800 °C high ratios occur, potentially inidcating the degassing of a Na-rich phase. At higher T, where the Martian component is observed in the nitrogen data, lower values occur again. It is clear that there is at least a minor component of trapped martian atmosphere, but cosmogenic componets show a complex history, too.

Summary: The fine-grained clastic matrix of NWA 7034 contains trapped martian atmosphere, although a better handle on nitrogen data has to be obtained before inferences about the composition (and thus evolution) of the atmosphere can be drawn. Secondary alteration products (carbonates) occur, but are more likely to have formed in North Africa than on Mars, so we are unable (yet) from these data to infer the composition of any potential alteration fluid. In order to progress with a better understanding of this unusual meteorite, and what its light element chemistry can reveal about Mars, we plan to make undertake pyrolysis GC-MS of matrix and clasts, to determine speciation and isotopic composition of organics and the siting of the different Ne-components – are they terrestrial, or is there a martian surface component, and what is the irradiation history of Mars?

References: [1] Met. Bull. (2014) http://www.lpi.usra.edu/meteor/metbull.php. [2] Agee C. B. et al. (2013) *Science, 339*, 780-785. [3] Humayun M. et al. (2013) *Nature, 503*, 513-516. [4] Cartwright J. A. et al. (2013) *LPS XLIV*, Abstract #2314. [5] Eugster O. (2003) *Chem. Erde, 63*, 3–30 [6] Schwenzer, S. P. et al. (2007) *Meteoritics & Planetary Science, 42*, 387–412.

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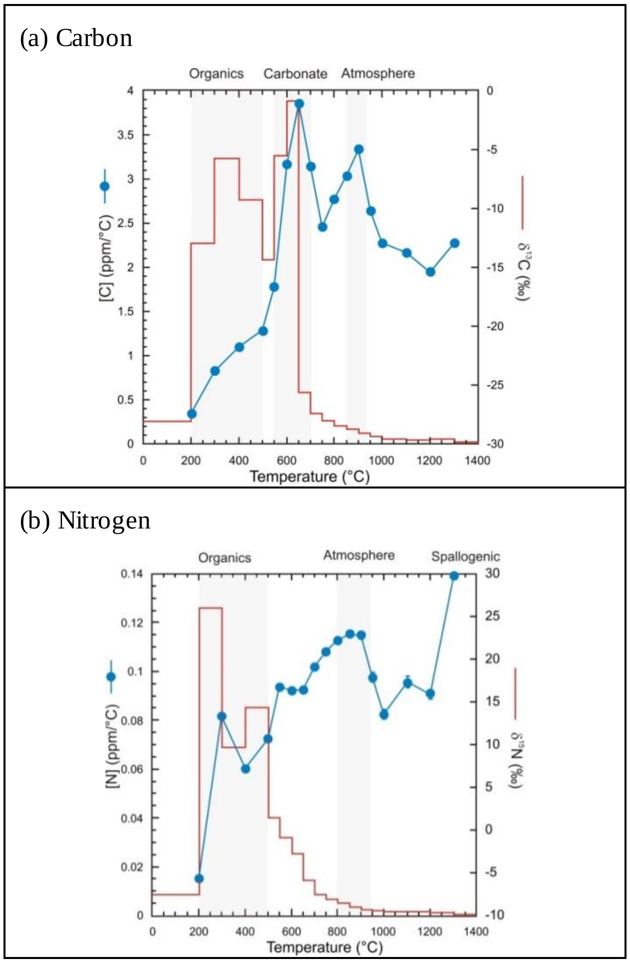

Figure 1: Data from stepped combustion of NWA 7034. (a) Carbon and (b) Nitrogen. The histogram is the amount of carbon released (scaled on the LH axis) and the dotted line is isotopic composition (scaled on the RH axis). Errors in isotopic composition are less than the size of the symbol, unless shown otherwise.

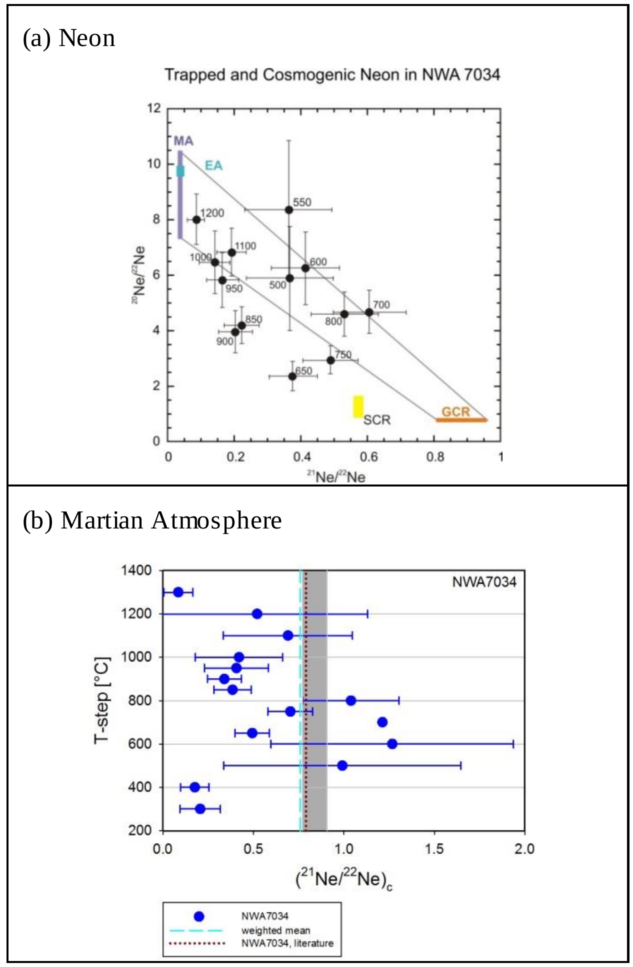

Figure 2. Noble gas data from stepped combustion of NWA 7034. (a) Neon 3-isotope plot showing partitioning between indigenous, trapped and spallogenic components ; (b) Cosmogenic $^{21}Ne/^{22}Ne$ ratio for each T-step. Literature values from [4, 6].

[C] (ppm)	$\delta^{13}C$ (‰)	[N] (ppm)	$\delta^{15}N$ (‰)	^{4}He cm^3g^{-1} x 10^{-8}	^{20}Ne cm^3g^{-1} x 10^{-6}	^{36}Ar cm^3g^{-1} x 10^{-8}	^{40}Ar cm^3g^{-1} x 10^{-6}
1411	-16.0	36.5	+11.5	2.99	0.34	0.039	0.03