NWA 7034 CONTAINS MARTIAN ATMOSPHERIC NOBLE GASES. J. A. Cartwright[1,2], U. Ott[2,3], S. Hermann[2], and C. B. Agee[4,5]. [1]Division of Geological and Planetary Sciences, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125, USA. [2]Max Planck Institut für Chemie, Hahn-Meitner-Weg 1, 55128, Mainz, Germany. [3]University of West Hungary, 9700 Szombathely, Hungary. [4]Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, USA. [5]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA. Email: jac@caltech.edu

Introduction: Northwest Africa (NWA) 7034 – a ~320 g stone, purchased in Morrocco, 2011 – is a porphyritic monomict breccia containing phenocrysts of andesine and pyroxenes set in a fine-grained matrix of non-silicates and metal oxides [1-3]. Preliminary analyses of NWA 7034 found that: 1) Mn/Fe ratios (a good diagnostic for planetary basalt classification [4]) are similar to Martian basalts rather than to terrestrial, eucritic or lunar basalts [1]; and 2) elevated oxygen isotope ratios compared to other Martian meteorites, requiring either significant alteration through impacts/ weathering on Mars, or a different planetary body origin [1]. Further work found: that REE data were similar to Martian meteorites; the sample contained at least ~3000 ppm of extra-terrestrial H_2O; and the sample gave Rb-Sr and Sm-Nd ages of ~2.1 and ~2.2 Ga respectively [2-3]. These features suggested that with a possible origin from Mars, NWA 7034 would represent the first Martian meteorite from the early Amazonian epoch (3.3/2.9 Ga - present) [2-3,5]. Also, unlike other Martian meteorites, there is a remarkable similarity in bulk composition with Martian rocks and soils measured at Gusev Crater (e.g. [6]), rather than Martian meteorites [3], leading the authors to conclude that NWA 7034 is Martian in origin, but may represent an entirely new Martian meteorite group [3].

One key technique to discern a Martian origin for a meteorite sample is through noble gas analysis, as Mars displays noble gas ratios that are distinct from other planetary bodies. Here, we report our first noble gas data for NWA 7034 to determine the types of components present, assess the cosmic ray exposure (CRE) age, and calculate nominal crystallisation ages by K-Ar and U-Th-He techniques.

Methodology: A 69.70 mg bulk fragment of NWA 7034 was analysed for all noble gases (He, Ne, Ar, Kr and Xe) using an MAP 215-50 noble gas mass spectrometer at MPIC, Mainz. Gases were released using step-heating in 600, 1000, and 1800 °C steps.

Table 1: Total noble gas (NG) concentrations and ratios for NWA 7034, Shergotty, Nakhla and Chassigny [9]. t=trapped, c=cosmogenic.

NG	NWA 7034	Shergotty	Nakhla	Chassigny
^{4}He	24.2(5)	1.88(4)	8.43(14)	4.60(1)
^{22}Ne	2.26(3)	0.70(2)	2.78(7)	4.11(7)
^{20}Ne/^{22}Ne	0.769(3)	0.980(17)	0.852(8)	0.833(10)
^{21}Ne/^{22}Ne	0.788(9)	0.782(3)	0.867(3)	0.865(3)
$^{36}Ar_t$	1.54(17)	0.13(2)	0.09(6)	0.08(1)
^{40}Ar	27.1(3.3)	3.1(1)	7.3(4)	2.7(1)
^{40}Ar/^{36}Ar	1348(78)	967(25)	578(35)	1250(32)
^{132}Xe	0.29(1)	0.11(1)	0.11(1)	0.43(1)
^{129}Xe/^{132}Xe	1.55(1)	1.20(2)	1.38(2)	1.03(1)

^{4}He, ^{40}Ar in 10^{-6}, ^{22}Ne, $^{36}Ar_c$ in 10^{-8}, ^{132}Xe in 10^{-10} cm^3STP/g.

Results & Discussion: A selection of our preliminary results are shown in Table 1 and Figs. 1-3, with comparison to some Martian meteorite literature data.

Concentations and Ratios: The Ar data for NWA 7034 is striking, showing ^{40}Ar/^{36}Ar ratios approaching ~3000 (1000 °C step) (Fig. 1). This value is similar to Martian atmosphere (MA) - as measured by Viking (^{40}Ar/^{36}Ar 3000 ± 500) [8], and observed previously in EET 79001 Lith. C [7]. However, the ratio represents a mixture of three possible components: trapped (MA), cosmogenic and radiogenic. Correcting our data for spallation increases the ^{40}Ar/^{36}Ar ratios to ~4150 (1000 °C), clearly higher than MA, indicating a true mixture of radiogenic and trapped MA (Fig. 1). This is also observed for Nakhla and ALH 84001 (Fig. 1). The presence of a trapped component similar to MA is also highlighted in Fig. 2, where elevated ^{129}Xe/^{132}Xe ratios (~1.7, 1800 °C) approach MA (~2.4, [15,18]), (^{36}Ar/^{132}Xe)$_t$ ratios are similar to MA, and suggest possible mixing between MA, Martian interior (MI) and Earth's

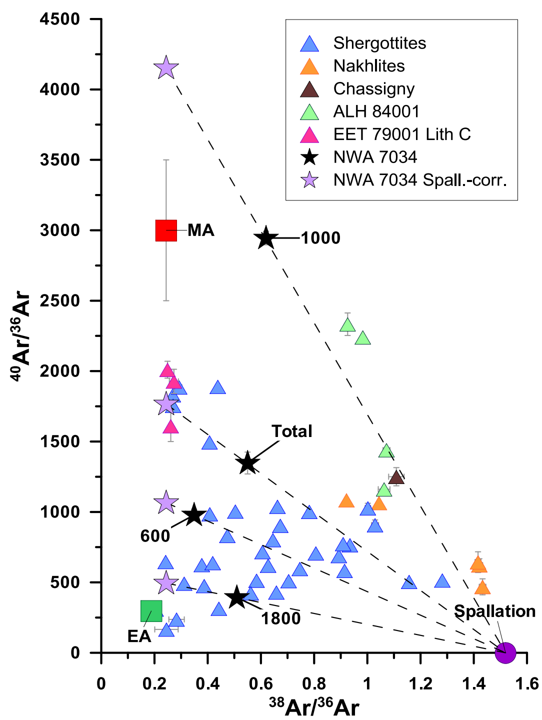

Figure 1: Three-isotope plot of ^{40}Ar/^{36}Ar vs. ^{38}Ar/^{36}Ar for NWA 7034, with Martian meteorite literature data [9-15]. Also plotted are components MA [8,15], EA [16] and the effect of spallation. Dashed lines show spallation correction on NWA 7034.

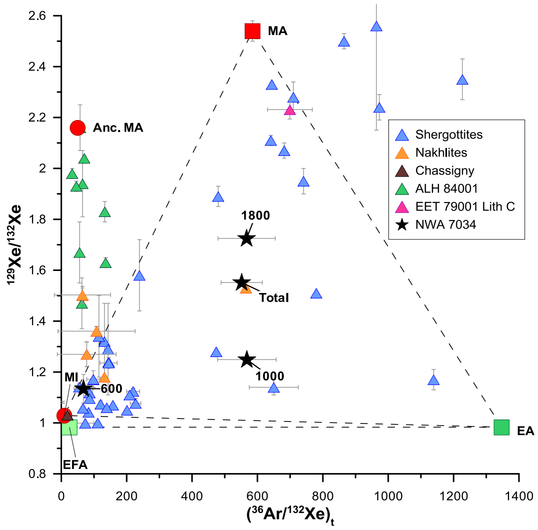

Figure 2: Three-isotope plot of $^{129}Xe/^{132}Xe$ vs. $(^{36}Ar/^{132}Xe)_t$ for NWA 7034, with Martian meteorite literature data [9-10,13-14,21]. Also plotted are components MA [15,18], EA [19-20], fractionated air (EFA) [14], an ancient MA component (Anc. MA) [21] and MI [9].

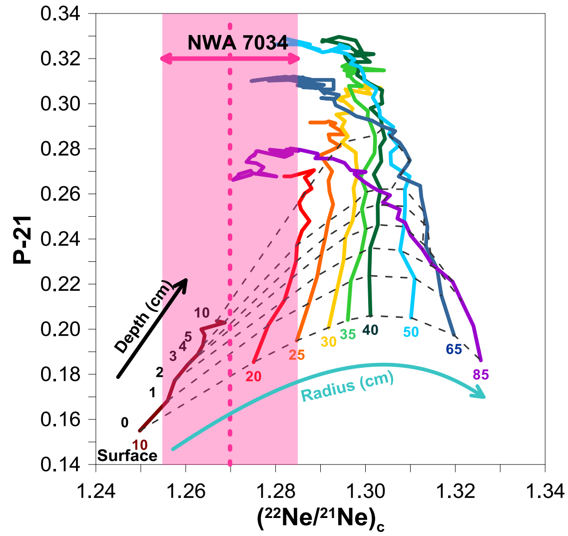

Figure 3: Plot of P-21 vs. $(^{22}Ne/^{21}Ne)_c$ the Monte-Carlo model [22] and NWA 7034 element abundances [3]. Coloured full lines = potential pre-atmospheric radii. Dashed black lines = depth within a sample of such radius. Pink band = total measured $(^{22}Ne/^{21}Ne)_c$ for NWA 7034.

atmosphere (EA). For Ne, NWA 7034 displays typical ratios, showing dominance of galactic cosmic rays (GCR) (Table 1). In addition, the $(^{22}Ne/^{21}Ne)_c$ ratio of ~1.27, combined with modeled ^{21}Ne production rates (P-21) [22] from the chemistry of the sample [3] suggests that NWA 7034 was likely a small meteoroid, with a pre-atmospheric radius of <25 cm (Fig. 3).

Crystallisation ages: Using a K concentration of 0.28 wt% [3] and our measured ^{40}Ar concentration (assuming all ^{40}Ar is radiogenic), we obtain an upper limit K-Ar age of ~1560 Ma, younger than the Rb-Sr and Sm-Nd ages for the sample [3].

Using U and Th concentrations of 0.51 and 2.64 ppm respectively [3], combined with our measured ^{4}He concentration (Table 1), and assuming a range of cosmogenic $(^{4}He/^{3}He)_c$ of 4-6 [23-24], we obtain a U-Th-He age of ~170 Ma. This is curiously young given the reported 2.1 Ga Rb-Sr age of the sample, and if it represents simple resetting, it would require near-complete He-loss at this point. He-loss is a common feature in Martian meteorites (e.g. [23]), resulting from thermal / shock metamorphism that resets U-Th-He ages, and causes low He concentrations in effected meteorites. That the ^{4}He concentration for NWA 7034 is elevated compared to other meteorites (e.g. Table 1) is likely a symptom of the old age of the sample. The U-Th-He age is also similar to reported crystallisation ages for most shergottites (e.g. [25]). Though this could be coincidental, a similar age for shergottite formation and thermal metamorphism of NWA 7034 could suggest a single event is responsible for both.

CRE ages: Using the empirical model (eucrite/shergottite, [11,26]) we have calculated CRE ages assuming: that all ^{3}He is cosmogenic; $^{21}Ne_c$ to have typical GCR ($^{20}Ne/^{22}Ne$ ~0.8 [26]) and trapped MA; $^{38}Ar_c$ to have $(^{38}Ar/^{36}Ar)_c$ of ~1.543 and trapped MA. We obtain T_3, T_{21} and T_{38} ages of 5.1 Ma, 11.4 Ma and 5.4 Ma respectively. The older T_{21} age may result from heterogeneity of target elements like Ca and Mg within the breccia. T_3 has little dependency on chemical composition, and with elevated ^{4}He concenrations, perhaps ^{3}He loss was minimal, and thus the lower age is real. A CRE age >5 Ma is older than observed previously for shergottite CRE ages, though the 11.4 Ma age is similar to Nakhlite/Chassigny CRE ages.

Conclusions: Our preliminary noble gas analyses show strong influence of a trapped component with MA composition, confirming a Martian origin for NWA 7034.

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