Ar AND Cl-BEARING HYDROUS FLUIDS IN NAKHLITES. J. A. Cartwright, R. Burgess, J. D. Gilmour, and G. Turner, School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Williamson Building, Oxford Road, Manchester, M13 9PL, UK. julia.cartwright@postgrad.manchester.ac.uk.

Introduction: The nakhlite meteorites have similar petrography and mineralogy, consistent with cooling within the same cumulate pile [1-2]. Cosmic ray exposure ages indicate a single ejection age at 10-12 Ma, and they have experienced shock pressures of 20 ± 5 GPa [3]. Their strong petrogenetic association suggests a restricted range of crystallisation ages, and that they should have experienced similar degrees of weathering and alteration from fluids acting in or on the Martian surface.

However, attaining reliable crystallization ages of nakhlite meteorites using the Ar-Ar dating technique has proved difficult. Nakhlites give Ar-Ar ages that are slightly high compared to other isotope chronometers [4-5], the latter yielding similar ages in the range 1250-1350 Ma (e.g. [6-9]). This suggests the presence of ^{40}Ar that was not produced by *in situ* decay of ^{40}K since the sample formed – one or more trapped components must be present. The origin and site(s) of this trapped Ar is not well-constrained, with a recent suggestion that terrestrial ^{40}Ar contamination may be present, or that Martian ^{40}Ar has been incorporated into weathered grains [5]. Both melt and fluid inclusions have been reported in pyroxene and olivine from Nakhla, providing further potential sites for hosting excess ^{40}Ar [10-11].

In an attempt to identify trapped Ar components, we have analysed mineral separates from two nakhlites (NWA 998 and Nakhla) by applying methods outlined by Turner [12] which exploit Cl-K-^{40}Ar correlations. Using this approach it is possible to identify different sources of Ar and provides a means of directly linking noble gases to halogens dissolved in inclusion fluids.

Experimental Procedure: Bulk and mineral separates were hand-picked under a binocular microscope in a clean laboratory. Using this procedure samples of bulk, olivine, pyroxene, and mesostasis were obtained for Nakhla, and olivine, pyroxene and feldspar for NWA 998. Following neutron irradiation, Ar isotopes were analysed by mass spectrometry. Argon was released by in vacuo crushing (Nakhla only) and stepped heating using a laser or resistance furnace.

Results and Discussion: In vacuo crushing of mineral separates from Nakhla yielded anomously old apparent ages (~1850–2100 Ma). This shows that a trapped Ar component is present within low retention sites such as fluid inclusions or weathering products. Further insight into this component is evident in Fig. 1, where both crushing and step heating data are presented. Data have been corrected for radiogenic ^{40}Ar (assuming an age of 1350 Ma) and cosmogenic Ar (based on the release of ^{37}Ar produced in the irradiation from calcium). Data are shown for pyroxene and olinive from Nakhla, and for olivine from NWA 998.

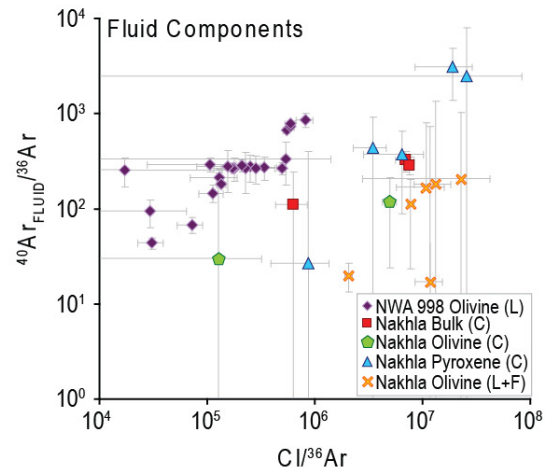

Figure 1: $^{40}Ar/^{36}Ar$ vs. $Cl/^{36}Ar$ for crushing and step heating data for Nakhla amd NWA 998. $^{40}Ar/^{36}Ar$ has been corrected for in situ decay of ^{40}K and a cosmogenic contribution. Data exhibiting high $^{40}Ar/^{36}Ar$ have high $Cl/^{36}Ar$ ratios. (C) = Crush, (F) = Furnace, (L) = Laser.

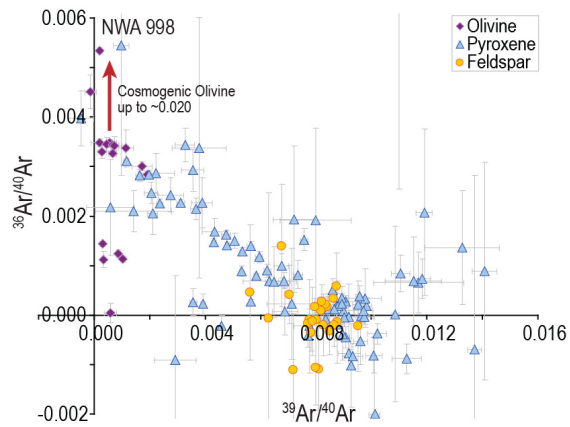

Figure 2: $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ for NWA 998 minerals. Olivine data indicate identifiable contributions from a high Cl (Fig. 1) fluid phase with argon derived from the Martian atmosphere ($^{36}Ar/^{40}Ar$ ~0 .0012) and melt inclusions that may represent a Martian interior composition ($^{36}Ar/^{40}Ar$ ~ 0.0035). Production of cosmogenic ^{36}Ar from Fe may account for releases from olivine with elevated $^{36}Ar/^{40}Ar$ ratios.

It is evident that those releases with the highest $^{40}Ar_{FLUID}/^{36}Ar$ ratios – which would lead to anomalously high Ar-Ar ages – have high Cl/^{36}Ar ratios. This suggests the presence of a phase with $^{40}Ar/^{36}Ar \geq 1000$ and ^{40}Ar/Cl ratios of $\approx 9 \times 10^{-4}$ and $\approx 3 \times 10^{-5}$ in NWA 998 and Nakhla respectively. We identify this Cl-related component, which is released by crushing and at low to intermediate temperature during stepped heating, as Ar dissolved in hydrous fluid inclusions. The relatively high $^{40}Ar/^{36}Ar$ value is consistent with dissolved Martian atmosphere ($^{40}Ar/^{36}Ar$ not well defined, but 3000 ± 500, as measured by Viking [13], or 1750-1900 as measured from analysis of trapped gases in shergottites [14]).

A second Ar component is released from NWA 998, predominantly in high temperature steps. This component contributes to a well defined $^{36}Ar/^{40}Ar$ intercept for pyroxene and olivine on the ^{40}Ar-^{39}Ar isochron diagram shown in Fig. 2. It has a $^{40}Ar/^{36}Ar$ of ~280 (also evident in the horizontal segment of NWA 998 olivine data in Fig. 1). The low $^{40}Ar/^{36}Ar$ ratio and the high temperature release of this trapped Ar component suggests it is not related to terrestrial air (298.6 [15]). The high temperature of release and contribution to the isochron derived from olivine and pyroxene data indicates that the component is most likely to be released from melt inclusions and may represent the $^{40}Ar/^{36}Ar$ ratio of the Martian interior.

Previously suggested $^{40}Ar/^{36}Ar$ ratios for the Martian interior include 298 [16], 500 [14] and 430-680 [17]. More recent work has suggested elevated ratios of up to 2000, with such a range caused by an inhomogenous Martian mantle [18]. Ar inherited from the Martian mantle appears to be much more prevalent in NWA 998 compared to Nakhla, though the $^{40}Ar/^{36}Ar$ ratio is identical within error (Fig. 1).

The final Ar component is Cl-poor and has $^{40}Ar/^{36}Ar < 100$ (Fig. 1). In the absence of any known Martian components with this Ar composition we suggests that this is dominated by release of cosmogenic ^{36}Ar formed from Fe in the olivine.

It is possible to correct $^{40}Ar/^{36}Ar$ data from Nakhla for the fluid-related Ar by using the measured Cl contents, and the observed ^{40}Ar/Cl ratios from the crushing experiments. Following this correction the total K-Ar age for Nakhla is 1345 ± 10 Ma. This compares well with recent work by [5], who report an age of 1357 ± 11 Ma. The age of NWA 998 can be obtained from the $^{39}Ar/^{40}Ar$ intercept in Fig.2 which is best defined by feldspar at 1411 ± 2 Ma. Again, comparing with work by [5] who reported an age of 1334 ± 11 Ma, our age is older. This difference may be related differences in the cosmogenic correction applied to each data-set. Interestingly the feldspar does not contain any trapped Ar components observed in olivine and pyroxene.

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