^{40}AR/^{39}AR AGES OF CARBONACEOUS XENOLITHS IN HED METEORITES NORTHWEST AFRICA 6475 AND NORTHWEST AFRICA 6695.

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Introduction: The generally young K/Ar and ^{40}Ar/^{39}Ar ages [1-3; *cf.* 4] of CM chondrites made us wonder whether carbonaceous xenoliths (CMX) entombed in HED meteorites might retain more radiogenic ^{40}Ar than do 'free-range' CM-chondrites. To find out, we selected two HED breccias with carbonaceous inclusions in order to compare the ^{40}Ar/^{39}Ar release patterns and ages of the inclusions with those of nearby HED material.

Experimental methods: Northwest Africa 6475 is a polymict achondrite breccia dominated by mafic/eucritic lithic clasts and mineral fragments with no recognized diogenitic component and has been classified as a polymict eucrite [5]. Northwest Africa 6695, also a polymict breccia, has a significant diogenite component, and therefore is classified as a howardite. Clasts in both samples consist of matrix-supported assemblages of chondrules with fine-grained rims and lithic clasts. Matrix consists mainly of phyllosilicates, tochilinite and Fe-Ni sulfides. We conclude that these clasts are mainly CM2 material. One CM2 clast contains a fine-grained lithic clast that is C1 rather than CM1 as it apparently lacks chondrules. NWA 6474 and 6695 are part of the spectrum of HED polymict achondrites; their populations of achondritic materials (clasts and minerals) and carbonaceous clasts overlap with respect to textures and mineral chemistry [5].

The samples were irradiated for 78 hours at the USGS TRIGA nuclear reactor (no Cd shielding). The irradiated samples were heated stepwise with a CO$_2$ laser and the Ar isotopes released analyzed with a MAP215-50 mass spectrometer [6]. Typical blanks (10^{-18} mol) were: ^{40}Ar, 4680; ^{39}Ar, 7; ^{38}Ar, 4; ^{37}Ar, 48; ^{36}Ar, 18.

Results: *Mafic clast in Northwest Africa 6475; matrix in Northwest Africa 6695* – The integrated, plateau, and isochron ages of these two silicate samples agree within the uncertainties at ~3.7 Ga comparable to a peak comprising eight HED meteorites with ages between 3.7 Ga and 3.8 Ga noted by [7].

The measured ^{36,38,40}Ar concentrations are typical of howardites and eucrites [8]. The concentrations of cosmogenic ^{38}Ar were calculated from the relation $^{38}\mathrm{Ar}_c = (5.35\times{}^{38}\mathrm{Ar}-{}^{36}\mathrm{Ar})/(5.35-0.65)$, where 5.35 and 0.65 are the trapped and cosmogenic ^{36}Ar/^{38}Ar ratios, respectively. ^{38}Ar$_c$ is produced primarily from Ca, for which the measured quantity ^{37}Ar$_{Ca}$ (reactor-produced, calcium-derived ^{37}Ar) serves as a proxy. The measured ratios of ^{38}Ar$_c$/^{37}Ar$_{Ca}$, are roughly proportional to exposure age. Ignoring shielding and using the production rates of [9], we obtain cosmic-ray exposure ages of 17 Ma for NWA 6475 mafic clast and 18 Ma for NWA 6695 matrix.

Carbonaceous xenoliths (CMX) in Northwest Africa 6475 and Northwest Africa 6695 – The integrated ages (Ma±1σ) of 2821±28 and 2894±17 are noticeably lower than those of their silicate counterparts, 3709±27 and 3730±23. No step age for either CMX exceeds those of the silicates.

Only ~35% of the ^{39}Ar was released from CMX NWA 6475 at the lowest temperatures. This limited, low-temperature release and a generally rising release pattern (~2.7 Ga to 3.6 Ga), are unusual for CM material [2,10,11]. The apparent ages of CMX in NWA 6695 also mostly increase with increasing temperature, from 2.1 to 3.3 Ga with minor exceptions for steps E and F.

Relative to HED meteorites, CM chondrites typically contain higher concentrations of trapped ^{36,38}Ar and lower concentrations of ^{40}Ar. The measured ^{38}Ar and ^{40}Ar concentrations of our samples conform to these generalizations.

By assuming the CMXs contain no trapped ^{36,38}Ar, we set an upper limit on the concentration of cosmogenic ^{38}Ar. The results are larger than for adjacent silicates, despite higher concentrations of Ca-derived ^{37}Ar$_{Ca}$ and hence of Ca in those silicates. We infer that much of the measured ^{38}Ar in the CMXs derived from the irradiation of Cl in the nuclear reactor.

Discussion: *Pairing* - NWA 6475 and NWA 6695 may be paired. The ^{40}Ar/^{39}Ar ages, release patterns, and cosmic-ray exposure ages agree. Although their official types and shock classifications differ [5], the two meteorites appear to have sampled effectively identical Vestan lithologies in different proportions. Confirmation of pairing requires further comparisons of the petrographic and isotopic properties of lithic clasts and the determination of the terrestrial ages.

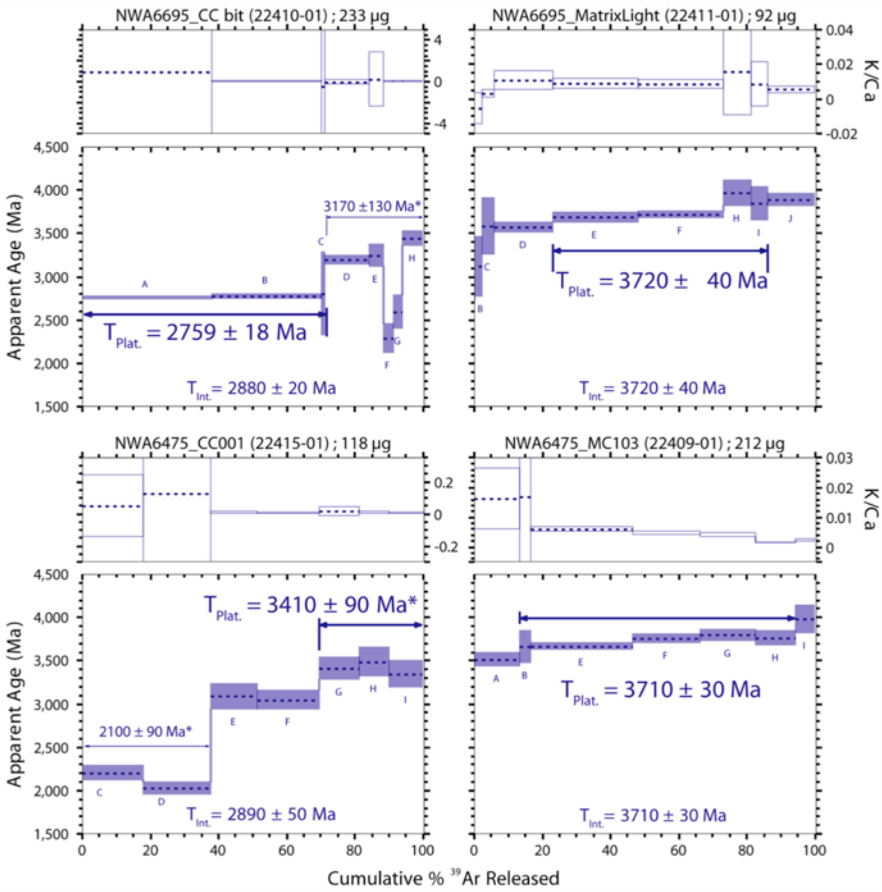
^{40}Ar losses: CMXs vs. silicates - Bogard [7] argued that an intense early bombardment of the Solar System re-set the ^{40}Ar/^{39}Ar ages of many HED meteorites. In this picture, a large impact on Vesta indirectly heated near-surface material enough to de-gas Ar. Such heating likely degassed the Ar in carbonaceous xenoliths as well, if we discount the remote possibility that they

were captured later. Judging from their flat release patterns, the silicate samples retained all the Ar that accumulated thereafter. In contrast, the $^{40}Ar^{*}/^{39}Ar_K$ ratios of the CMXs suggest the loss by diffusion of about 40% of the radiogenic ^{40}Ar during the same period. Larger losses for the CMXs are expected qualitatively based on a consideration of relative diffusion parameters, but the full extent of those losses may have been reduced by the lower porosity of the surrounding achondrite matrix.

^{40}Ar losses: CMXs vs. Murchison and other CMs – We assess the magnitudes of ^{40}Ar losses from CMs based on formation ages of ~ 4.57 Ga [12]. So calculated, the $^{40}Ar^{*}$ loss is 58% for a CM chondrite with an age of 3.2 Ga and 82% for an age of 2.0 Ga. These values exceed the 40% losses inferred for the CMXs. Furthermore, the *patterns* of ^{40}Ar release in most Murchison samples and the CMXs differ: The former tend to decrease and the latter to increase with increasing heating temperature. Primary factors influencing the integrated losses in space include the value of, and the time spent at, the peak temperature. The cosmic ray exposure ages of NWA 6475 and NWA 6695 are 10 to 20 times larger than those of Murchison [13] and, typically, of other CMs [14]. We infer that either 1) the orbits of the two HED meteorites studied had larger perihelia than the orbits of CMs; and/or 2) as noted above, the matrix surrounding the CMXs impeded the loss of radiogenic ^{40}Ar. Observations of the $^{40}Ar/^{39}Ar$ systematics of heavily altered CMs extend these trends [11].

Conclusions: Carbonaceous inclusions (CMXs) in two HED meteorites lost a greater fraction of radiogenic ^{40}Ar than did surrounding host material, but a smaller fraction of it than did free-range CM-chondrites such as Murchison or more heavily altered ones. Importantly, however, the siting of the CMXs in HED matrix did not prevent the ^{40}Ar loss of about 40% of the radiogenic ^{40}Ar, even from phases that degas at high laboratory temperatures. We infer that carbonaceous asteroids with perihelia of 1 AU probably experience losses of at least this size. The usefulness of $^{40}Ar/^{39}Ar$ dating for samples returned from C-type asteroids may hinge, therefore, on identifying and analyzing separately small quantities of the most retentive phases of carbonaceous chondrites.

Figure 1. Apparent ages and K/Ca ratios for step-heated carbonaceous and step-heated silicate samples from NWA 6695 and NWA 6475.



References: **[1]** Mazor E. et al. (1970) *GCA, 34*, 781-824. **[2]** Eugster O. et al. (1998) *GCA, 62,* 2573-2582. **[3]** Turrin B. et al. (2014). *LPSC, 45*, 2485.pdf. **[4]** Bogard D.D. et al. (1971) *JGR., 76*, 4076- 4083. **[5]** Ruzicka A. et al. (2014) *Meteoritic Bull.*, *100.* **[6]** **[**Lindsay F.N. et al. (2015) *EPSL, 413*, 208-213. **[7]** Bogard D.D. (2011) *Chem. Erde Geochem., 71*, 207-226. **[8]** Schultz L. and Franke L. (2004) *MPS, 39*, 1889-1890. **[9]** Eugster O. and Michel T. (1995) *GCA, 59,* 177-199. **[10]** Dominik B. and Jessberger E. (1979) *LPS*, *10*, 306-308. **[11]** Nakamura T., et al. (2015) *MPS, 50*, 5147.pdf. **[12]** McKeegan K.D. and Davis A.M. (2004) *Treat. Geochem., 1,* 431-460. **[13]** Herzog G.F. et al. (1997) *MPS*, *32*, 413-422. **[14]** Takenouchi A. et al. (2014) *LPSC*, *45***,** 1827.pdf.