REVISITING THE ^{40}AR/^{39}AR CHRONOLOGY OF LUNAR METEORITE NWA 773 PROVIDES NEW CONSTRAINTS ON ITS DIACHRONOUS GEOLOGIC HISTORY.

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Introduction: ^{40}Ar/^{39}Ar chronometry has been applied extensively over the last fifty years to study the geologic history of lunar materials. Specifically, ^{40}Ar/^{39}Ar data have been used to assess the timing of impact events that disturb this thermally-sensitive geochronological system, thereby providing absolute time constraints on relative crater counting chronologies [1]. Despite their widespread use, many lunar ^{40}Ar/^{39}Ar step-heating datasets exhibit complex behavior that precludes quantitative, statistically robust interpretations. This behavior may be associated with: (1) the presence and sometimes inaccurate accounting of multiple argon components, (2) partial resetting of the ^{40}Ar/^{39}Ar system during one or more impact events, (3) different thermal sensitivities and thermal histories recorded in multiphase, heterogeneous samples, or (4) some combination therein. Here, we demonstrate how problem (1) can be accounted for with new ^{40}Ar/^{39}Ar data from lunar meteorite NWA 773.

Previous chronometric constraints on the geologic history of NWA 773: NWA 773 comprises two lithologies: olivine-gabbro and regolith breccia. The regolith breccia component contains clasts of gabbro as well as of silica glass, pyroxene, and volcanic rocks. A weighted mean ^{207}Pb-^{206}Pb baddeleyite age of 3115.6 ± 6.8 Ma (2σ, n = 47) was measured from the NWA 773 clan of meteorites; baddeleyite ages from gabbro and breccia components were indistinguishable [2]. A significantly younger Sm-Nd age of 2865 ± 31 Ma (2σ) was obtained for the gabbro portion of NWA 773 [3]. Fernandes et al. [4] conducted ^{40}Ar/^{39}Ar step heating experiments on both the gabbro and breccia components. In both cases they observed complex ^{40}Ar/^{39}Ar age spectra, with individual step ages ranging between 2000 and 5000 Ma and no statistically significant age plateau obtained.

Methods: We revisited the ^{40}Ar/^{39}Ar chronometry of NWA 773. Aliquots of pyroxene crystals and groundmass fragments from the breccia were neutron irradiated for 40 hours in the Cd-lined TRIGA reactor, Oregon State University. Argon isotopes were measured by step heating at SUERC on a MAP-215 sector-field mass spectrometer. We used an approach recently detailed by Cassata and Borg [5] to deconvolve the different components of argon (trapped, cosmogenic, radiogenic) in these neutron-irradiated experiments with independent knowledge of the cosmic ray exposure (CRE) age. Briefly, with independent constraints on the CRE age we can subtract the fraction of ^{36}Ar that is cosmogenic from the total ^{36}Ar in each individual heating step. Then, by plotting cosmogenic-corrected ^{36}Ar/^{40}Ar as a function of ^{39}Ar/^{40}Ar for each heating step (i.e., an inverse isochron, Fig. 1), we can determine the ^{36}Ar/^{40}Ar of the trapped argon component (y-intercept) and both (1) determine the isochron age from the x-intercept, and (2) correct the individual step ages for trapped ^{40}Ar to obtain accurate plateau ages (Fig. 2).

Eugster and Lorenzetti [6] measured a CRE age of 160 Ma in an unirradiated fragment of NWA 773. This agrees with the CRE age calculated by Fernandes et al. [4] for the breccia component (~154 Ma), although we note that the latter CRE age was determined from ^{38}Ar measurements on an irradiated aliquot [4], and it is not clear whether reactor-produced ^{38}Ar was accounted for. Based on these two CRE age determinations, we conservatively assume a CRE age of 160 ± 16 Ma. We will confirm these CRE ages with new measurements of argon isotopes on an unirradiated aliquot of NWA 773 breccia.

Results: Using a CRE age of 160 ± 16 Ma, we corrected for the amount of cosmogenic ^{36}Ar in each heating step of the neutron-irradiated pyroxene to obtain the inverse isochron shown in Fig. 1.

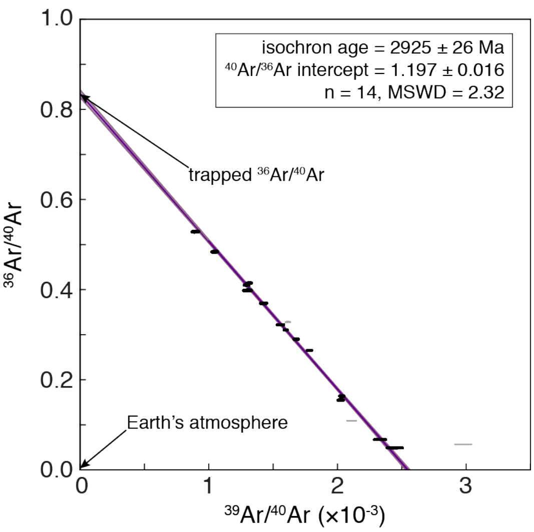

Figure 1. Inverse isochron used to define the trapped ^{36}Ar/^{40}Ar component and isochron age for pyroxene from NWA 773 breccia. Data in grey are not included in the linear regression.

The isochron age we obtain for NWA 773 pyroxene is 2925 ± 26 Ma (2σ). We also corrected individual step ages in both the pyroxene and groundmass step-heating experiments for the trapped component obtained from the inverse isochron (^{40}Ar/^{36}Ar = 1.197 ± 0.016); these results are shown in Fig. 2. In contrast to the complex age spectra obtained by Fernandes et al. [4], with our cosmogenic corrections we observe remarkably simple age spectra with statistically significant plateau ages for both the groundmass (2956 ± 22 Ma, 94.0% ^{39}Ar, MSWD = 0.74, 19 steps) and pyroxene (2936 ± 24 Ma, 92.2% ^{39}Ar, MSWD = 0.56, 16 steps).

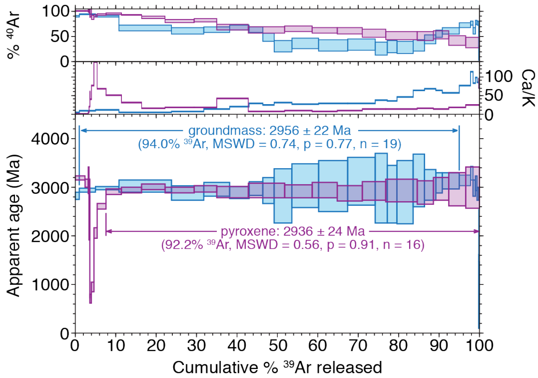

Figure 2. ^{40}Ar/^{39}Ar step age spectra for a pyroxene (purple) and groundmass (blue) from the breccia component of NWA 773, corrected for cosmogenic and trapped argon components using the approach of Cassata and Borg [5]. All uncertainties are reported at 2σ. Both step-heating experiments resulted in statistically significant age plateaus within uncertainty of one another, yielding a weighted mean age of 2947 ± 15 Ma.

Our weighted mean age of 2947 ± 15 Ma broadly agrees with the total gas ^{40}Ar/^{39}Ar age of ~2940 Ma reported by Fernandes et al. [4] for the breccia portion of NWA 773. Before, this integrated age was of unclear significance given the substantial over-dispersion in step ages from the Fernandes et al. [4] data. We note that if the argon isotope data from Fernandes et al. [4] were available, the same cosmogenic corrections utilized here could be applied to those data, allowing for a fully consistent comparison of these datasets.

Discussion and conclusions: The new ^{40}Ar/^{39}Ar ages we report are 169 ± 17 Ma younger than the ^{207}Pb-^{206}Pb baddeleyite ages obtained by Shaulis et al. [2], and interestingly 82 ± 34 Ma older than the Sm-Nd age reported by Borg et al. [3] for the gabbro component. Fernandes et al. [4] also obtain a younger ^{40}Ar/^{39}Ar total gas age for the NWA 773 gabbro of ~2670 Ma (although as stated above the significance of this integrated age is still uncertain).

Taken collectively, these geochronologic constraints imply distinct, diachronous geologic histories for the breccia and gabbro components of NWA 773. Baddeleyite grains in the breccia came from the gabbro during brecciation; coeval ^{207}Pb-^{206}Pb baddeleyite ages from the breccia and gabbro components are therefore expected and represent the crystallization age of the gabbro. The Sm-Nd (2865 ± 31 Ma) and ^{40}Ar/^{39}Ar (~2670 Ma) ages in the gabbro likely reflect conductive, post-emplacement cooling of the gabbro rather than excavation-related cooling due to an impact event, which would cause synchronous ages to be recorded by these two chronometers.

Our observation of a significantly older ^{40}Ar/^{39}Ar age (2947 ± 15 Ma) for the breccia implies that some subcomponent(s) of the breccia cooled prior to and independently of cooling of the gabbro. A single zircon U-Pb age from the breccia component of NWA 773 (3953 ± 18 Ma) also implies an older geologic history for this portion of the meteorite [2]. Pyroxenes in the polymict breccia have a much wider range of compositions than those in gabbroic components of NWA 773 clan meteorites [2], which is also consistent with the presence of geologically distinct material in the breccia. The uniformity of step ages we observed in pyroxene and groundmass from the breccia (Fig. 2) implies rapid cooling, either associated with excavation by an impact event or extrusive crystallization.

Paired with the geochronological constraints from the gabbro, our pyroxene and groundmass ^{40}Ar/^{39}Ar ages constrain the timing of the impact event responsible for brecciation of NWA 773 to younger than 2865 Ma, and possibly younger than 2670 Ma. Revisiting the ^{40}Ar/^{39}Ar chronology of the gabbro portion of NWA 773 with the approach for deconvolving argon components used here [5] will provide better resolution on this upper temporal bound. Since the ^{40}Ar/^{39}Ar age spectra from the breccia exhibit no evidence for partial resetting, this also suggests that there was not substantial enough heating during the impact brecciation event to thermally disturb these systems. Future experiments to determine the kinetics of argon diffusion in these phases will be used to constrain the maximum temperature and heating duration during brecciation.

References: [1] Stöffler D. and Ryder G. (2001) *Space Sci. Rev.* 96, 9-54. [2] Shaulis B. J. et al. (2017) *GCA,* 213, 435-456. [3] Borg L. E. et al. (2004) *Nature,* 432, 209-211. [4] Fernandes V. A. (2003) *MAPS,* 38(4), 555-564. [5] Cassata W. S. and Borg L. E. (2016) *GCA*, 187, 279-293. [6] Eugster O. and Lorenzetti S. (2001), *MAPS* 36, A54.