^{40}AR/^{39}AR SYSTEMATICS AND NOBLE GAS COMPONENTS IN THE EARLY AMAZONIAN MARTIAN METEORITE NORTHWEST AFRICA 8159.

W. S. Cassata[1]
[1]Lawrence Livermore National Laboratory, 7000 East Avenue (L-231), Livermore, CA 94550 (cassata2@llnl.gov).

Introduction: Northwest Africa 7635 [1] and Northwest Africa 8159 [2] are the only Martian meteorites identified to date with crystallization ages in the early Amazonian (~2.3 Ga; [3,4]). Little is known about the isotopic composition of the Martian atmosphere at this time. As such, paleoatmospheric gases trapped in NWA 7635 and NWA 8159 have the potential to improve our understanding of planetary degassing and atmospheric escape during the early Amazonian, and therefore the extent to which these processes have altered Mars' climate through time.

He, Ne, Ar, Kr, and Xe isotopic measurements, (U-Th)/He chronometry, and ^{40}Ar/^{39}Ar chronometry were conducted on whole-rock and shock melt glass fragments of NWA 8159. The ^{40}Ar/^{39}Ar data are used to better constrain the shock and thermal history of NWA 8159, the time at which its trapped gas components were acquired, and the nature of its trapped components (e.g., shock implanted, atmospheric, mantle, terrestrial, etc.). Cosmic ray exposure ages based on ^{3}He, ^{21}Ne, and ^{38}Ar measurements are also reported.

^{40}Ar/^{39}Ar and (U-Th)/He chronometry: Figure 1 depicts an isochron diagram obtained from the incremental heating of ~1 mg of glass extracted from a mm-sized shock melt vein within NWA 8159. The ^{40}Ar/^{36}Ar ratio of the trapped component is consistent with terrestrial contamination and was likely acquired during desert weathering. The data define an isochron with an age of 2.15 ± 0.10 Ga. Statistically indistinguishable Sm-Nd ages of 2.33 ± 0.13 Ga [3] and 2.3 ± 0.5 Ga [4] were obtained from NWA 7635 and NWA 8159, respectively. The similarity of the ^{40}Ar/^{39}Ar age obtained from shock melt glass with the Sm-Nd mineral isochron ages suggests that either (1) the shock melt glass formed shortly after the rock crystalized (within 0.18 ± 0.23 Ga assuming NWA 8159 and NWA 7635 are of equivalent age), or (2) the shock melt glass formed without significant loss of Ar (e.g., [5]). While both interpretations indicate that ancient Martian gas is retained within the shock melt glass, the latter implies a second, shock-implanted component may have been acquired much later in time.

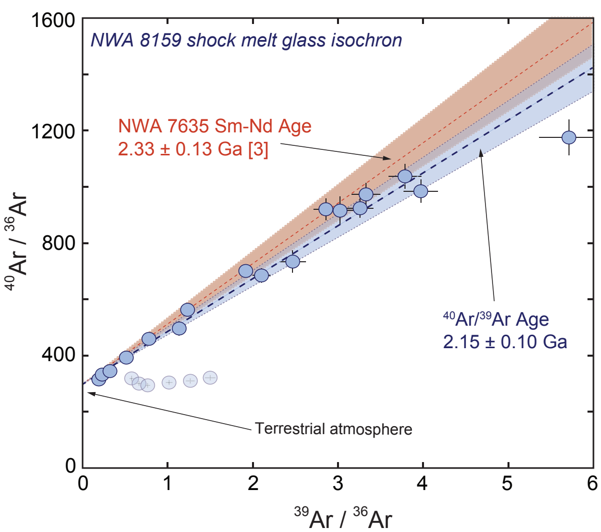

Figure 1: ^{40}Ar/^{39}Ar isochron diagram obtained from NWA 8159 shock melt glass. The Sm-Nd age of NWA 7635 [3] is shown for reference.

Figure 2 depicts an age spectrum obtained from the incremental heating of a ~4 mg whole-rock fragment of NWA 8159. Data were corrected for cosmogenic contributions using an exposure of 1.5 Ma (Table 1) following the procedure of [6] and for trapped ^{40}Ar using the terrestrial atmospheric ^{40}Ar/^{36}Ar ratio (as constrained by the isochron shown in Figure 1). By inspection it is apparent that the whole-rock groundmass experienced significant loss of Ar. Maximum ages do not exceed ~1.2 Ga, excluding low temperature steps that appear to be affected by ^{39}Ar recoil. The results post-date both the crystallization age and the ^{40}Ar/^{39}Ar age of the shock melt glass by >1 Ga. This observation suggests that shock melt glass within NWA 8159 was more retentive of ^{40}Ar than the whole-rock groundmass during the thermal event responsible for partial resetting of K-Ar system. Diffusion kinetics inferred from the laboratory release of ^{39}Ar are also consistent with shock melt glass being more retentive of Ar than the fine-grained groundmass.

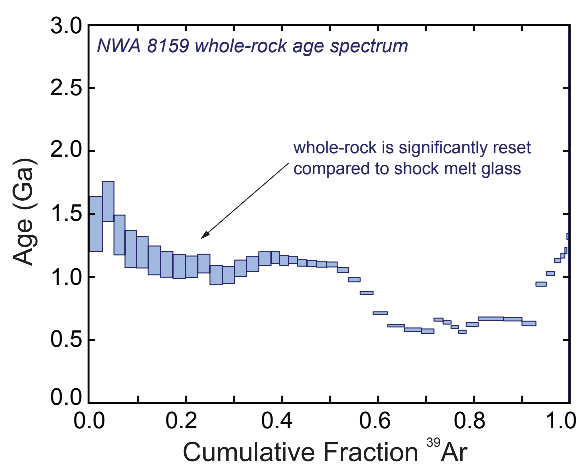

Figure 2: ^{40}Ar/^{39}Ar age spectrum obtained from a whole-rock fragment of NWA 8159.

(U-Th)/He measurements of a whole-rock fragment yielded an age of 72 ± 7 Ma, consistent with >95% loss of He during the ejection event that occurred at ~1.5 Ma. Given such extensive resetting of the (U-Th)/He system, this thermal event may also be responsible for the diffusive loss of radiogenic ^{40}Ar apparent in the whole-rock ^{40}Ar/^{39}Ar age spectrum (Fig. 2). In light of these observations, the ^{40}Ar/^{39}Ar isochron age obtained from the shock melt glass (Fig. 1) may be systematically biased toward a younger age than the Sm-Nd system due to diffusive loss of radiogenic ^{40}Ar, and likely represents a minimum age. From available data it is not possible to discern whether the shock melt glass is ancient or formed during the ejection event with little loss of radiogenic Ar. The lack of a modern Martian atmospheric Ar component suggests shock-implantation of Martian atmosphere during ejection was not significant, although it is possible that such a signature has been obscured by the appreciable abundance of terrestrial Ar contamination.

Cosmic ray exposure ages: Cosmic ray exposure ages were determined from ^{3}He, ^{21}Ne, and ^{38}Ar measurements of whole-rock fragments and shock melt glass (Table1). Exposure ages were calculated using the bulk rock chemistry of [7], potassium concentration determined by ICP-MS, and production rate estimates of [8]. Shock melt glass exposure ages are concordant at 1.4-1.5 Ma. Whole rock ^{3}He and ^{21}Ne ages are slightly younger at 1.0-1.2 Ma. Measurements of ^{26}Al and ^{10}Be in NWA 7635 yielded an exposure age of 1.0 ± 0.1 Ma [9].

Table 1: Cosmic ray exposure age calculations

	shock melt glass	whole-rock
Method	Age ± 1σ (Ma)	Age ± 1σ (Ma)
^{38}Ar	1.5 ± 0.1	--- ± ---
^{21}Ne	1.4 ± 0.1	1.0 ± 0.1
^{3}He	1.4 ± 0.1	1.2 ± 0.1

^{38}Ar ages calculated assuming $(^{38}Ar/^{36}Ar)_{trap}$ is 0.188
Production rates based on the bulk rock chemistry of [7] and this study

Xenon isotopes: Xenon isotopes were measured in a 3.4 mg whole-rock fragment. A three-isotope plot of ^{129}Xe/^{132}Xe vs. ^{131}Xe/^{132}Xe obtained from the incremental degassing of this sample is shown in Figure 3. The data are consistent with mixing between terrestrial atmospheric Xe, a Martian atmospheric component with elevated ^{129}Xe/^{132}Xe, and ^{238}U-derived spontaneous fission Xe. Cosmogenic contributions are not significant. Spontaneous fission Xe is minor compared to the atmospheric components. The observation of an elevated ^{129}Xe/^{132}Xe ratio indicates that a Martian atmospheric component is present in NWA 8159, although it is not clear at this time whether it was acquired in the early Amazonian or during a more recent shock event (e.g., ejection from Mars).

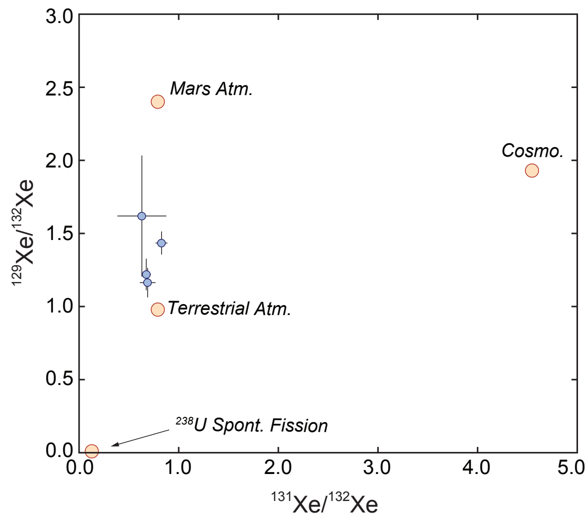

Figure 3: Three-isotope plot of ^{129}Xe/^{132}Xe vs. ^{131}Xe/^{132}Xe obtained from the incremental degassing of a whole-rock fragment of NWA 8159.

Conclusions: ^{40}Ar/^{39}Ar data confirm an early Amazonian age for NWA 8159. The rock experienced one or more thermal events in its history that resulted in significant loss of radiogenic Ar and He from the fine-grained groundmass. The shock melt glass that was analyzed appears to have retained >95% of its radiogenic Ar during these thermal events. Although Xe measurements provide evidence for trapped Martian atmospheric gases is this rock, it is difficult to constrain the isotopic composition of this component due to significant terrestrial contamination.

References: [1] Irving A.J. et al. (2013) 76th Meteoritical Society Meeting, Abstract #5274. [2] Agee C.B. et al. (2014) AGU Fall Meeting, Abstract #P54B-02. [3] Righter M. et al. (2014) LPSC XXXXV, Abstract #2550. [4] Simon J.I. et al. (2014) 77th Meteoritical Society Meeting, Abstract #5363. [5] Shaw C.S.J. and Walton E. (2013) *Meteoritics & Planetary Science, 48,* 758-770. [6] Cassata W.S. and Borg L.E. (2015) LPSC XXXXVI, Abstract #2742. [7] Herd C.D.K. et al. (2014) LPSC XXXXV, Abstract #2423. [8] Eugster O. and Michel T. (1995) *Geochimica et Cosmochimica Acta, 59,* 177-199. [9] Andreasen R. et al. (2014) LPSC XXXXV, Abstract #2865.

Acknowledgments: This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Financial support was provided by the NASA Mars Fundamental Research Program (grant NNH14AX56I to W.S.C.). Carl Agee is thanked for generously providing NWA 8159.