NOBLE GAS ANALYSIS AND INAA OF AQUEOUS ALTERATION PRODUCTS FROM THE LAFAYETTE METEORITE: LIQUID WATER ON MARS <350 Ma AGO

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Noble gas and INAA analyses of aqueous alteration products from the Lafayette meteorite confirm that the aqueous alteration was pre-terrestrial [1], and are consistent with the aqueous alteration products being the host of elementally-fractionated martian atmospheric noble gas [2]. Furthermore, K-Ar ages of 100-300 Ma suggest that aqueous alteration, presumably on the surface of Mars, occurred in that time range.

The three nakhlite meteorites (Nakhla, Lafayette and Governador Valadares) all contain a mineral assemblage, "iddingsite", consisting of clays, iron oxides and iron hydroxides, that must have formed through aqueous alteration [1,3]. Since these meteorites probably come from Mars (they represent the "N" of the SNC meteorites), the iddingsite can potentially tell us something about the history of Mars, including the timing of aqueous alteration and surface-atmosphere interactions. We have performed INAA and noble gas analyses on separated samples of iddingsite from Lafayette.

Experimental procedure: Samples weighing about 2-35μg were extracted from six different pockets of iddingsite in Lafayette. Most were extracted as single chunks, although in some cases, two or more fragments were grouped. At this stage, one sample was set aside for Kr and Xe analysis. Since we were concerned about possible recoil of ^{39}Ar from the fine-grained clays, the samples were sealed in evacuated, high purity quartz vials and irradiated with about 1.4 x 10^{20} neutrons at the University of Missouri Research Reactor. After γ-ray counting of the irradiated samples, all the samples were transferred to Tucson for noble gas analysis. The vials were loaded into the extraction line of the mass spectrometer, heated to typically 120°C overnight to expel adsorbed atmosphere, then mechanically cracked and the gas inside analyzed. The samples were left in the now-broken vials and loaded into a laser extraction system, where gas was extracted with an Ar-ion laser. The unirradiated sample was analyzed separately, again using the laser for gas extraction.

INAA: Since the quartz vials contained approximately 10^4 times as much mass as the samples, even the trace impurities present in the quartz compromised the analysis for many elements. Those elements for which reasonable numbers could be obtained are listed in Table 1. Perhaps the most interesting observation is the enrichment of Cs, leading to a Rb/Cs ratio of about 1.7, an order of magnitude higher than in bulk Lafayette.

Kr-Xe: The Kr and Xe in the shergottite meteorites and Chassigny ("S" and "C" of "SNC") are broadly consistent with a two-component mixture of martian atmosphere and another component (martian mantle?), and tend to plot along the line in Fig. 1 [4]. However, the nakhlites all plot above the line, suggesting either a different component altogether or a process that fractionates elements (Kr/Xe), but not isotopes (^{129}Xe/^{132}Xe). Drake et al. [2] suggested that the latter is the case, and that the process is the incorporation of noble gases into iddingsite. Fig. 1 shows that the sample does indeed have ^{129}Xe/^{132}Xe and Kr/Xe ratios consistent with that hypothesis. The amount of ^{132}Xe is about 10 times that in the bulk sample (though uncertain by about a factor of two), but still amounts to only about 20,000 atoms in the sample (about 3 counts/second). Mass balance arguments would predict about 40 times the bulk abundance in the iddingsite, so although the agreement is reasonable, it is not conclusive.

K-Ar: From 30 to 90% of the ^{39}Ar we analyzed for each sample came from the vial cracking (Table 1). This suggests either that recoil was a very serious problem, or that our pre-heating outgassed some of the Ar. The gas from the vials was dominated by atmospheric Ar, with the amount being roughly that expected to remain after the vials had been pumped out to forepump pressure. There is no evidence for any radiogenic ^{40}Ar (regardless of the ^{39}Ar/^{36}Ar ratios, the ^{40}Ar/^{36}Ar ratios vary by less than 1% from the value we typically measure for our terrestrial atmospheric standard), but the actual upper limit we can set could allow a ^{40}Ar/^{39}Ar ratio comparable to that observed in the best laser shots.

For the two best samples, LA10.4 and LA10.5, more than half the ^{39}Ar was released in the laser heating. Although there was one to two orders of magnitude less terrestrial contamination than in the vials, it still dominated the signal at ^{40}Ar. For LA10.4, the blank-corrected ^{40}Ar/^{36}Ar ratio is 359 ± 22, 3σ larger than the terrestrial value. For LA10.5, the ^{40}Ar/^{36}Ar is about 1σ greater than terrestrial. Using these two points, and assuming that the terrestrial contamination is not fractionated by more than 2%, we get a $^{40}Ar/^{39}Ar$ ratio of 0.48±0.13. Coupled with the $^{40}Ar/^{39}Ar$ ratio of grains of the MMhb-1 standard which were included in the irradiation, we get an age of 278±71 Ma (1σ). If all the ^{39}Ar in the vials was from recoil, and no ^{40}Ar outgassed in the pre-heating, the ^{39}Ar from the vials should be added in, giving an age of 178±46 Ma. Similarly, if some martian atmospheric Ar ($^{40}Ar/^{36}Ar$=2500) was incorporated in the samples, these ages would be upper limits, but from the Kr/Xe data, we would not expect a noticeable signal from martian atmospheric Ar.

The Ar data suggest two things. First, like the Kr-Xe data, the presence of gas that can not be explained by formation or contamination on Earth provides further evidence that the iddingsite really is pre-terrestrial in origin [1,3]. Second, the fact that the age is considerably less than the crystallization age of 1.3 Ga [5] suggests that the aqueous alteration did not occur during emplacement of the magma that formed the nakhlites. This is consistent with the petrography - none of the minerals expected to form if water had been present when the rocks were at high temperatures (e.g., amphibole, chlorite) are found. This means that liquid water was present near the surface of Mars << 1.3 Ga ago [2,6]. An intriguing possibility permitted, though not required, by this data is that the water responsible for the alteration was liberated by nearby magmatic activity, such as the shergottite-forming event (180 Ma ago? [5]).

References: [1] Treiman A. H. et al. (1993) *Met.* **28**, 86; [2] Drake M. J. et al. (1994) *Met.* **29**, 854; [3] Gooding J. L. et al. (1991) *Met.* **26**, 135; [4] Ott U. (1988) *GCA* **52**, 1937; [5] McSween H. Y. Jr. (1994) *Met.* **29**, 757; [6] Gooding J. L. (1992) *Icarus* **99**, 28.

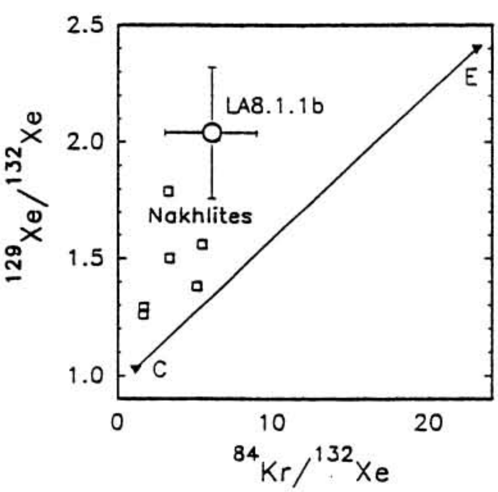

Fig. 1: Lafayette iddingsite sample LA8.1.1b has $^{129}Xe/^{132}Xe$=2.04±0.28, $^{84}Kr/^{132}Xe$=6±3, putting it in the region with bulk nakhlites (squares), not on the mixing line between Chassigny (C) and EET 79001 glass (E), where most other martian meteorites fall.

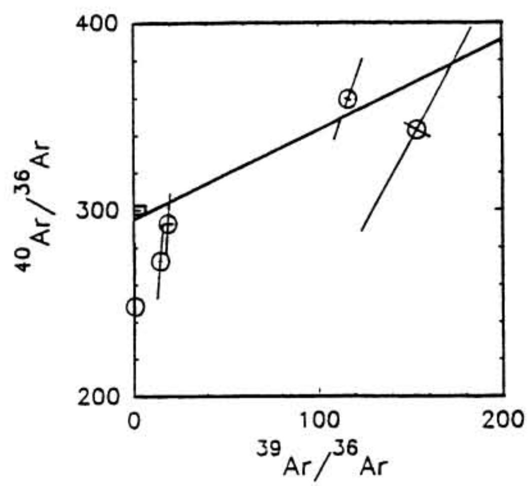

Fig. 2: Ar data for Lafayette iddingsite. Open circles are gas extracted with laser. All analyses of gas in the vials fall in the box to the left near $^{40}Ar/^{36}Ar$=300.

Table 1: INAA and Ar data

Sample	Mass	K_2O	FeO	Sc	Cr	Co	Rb	Cs	Sr	Vial Ar		Laser Ar		
	μg	----wt%----		---ppm---						36	39	36	39	40/36
LA8.1.1A	8.0	0.55	28.0	8.41	247	59.8	22.0	12.2	191	17.9	11.8	0.2	0.1*	248±34
LA10.4	23.0	0.38	37.0	4.12	657	78.8	22.1	14.4	77	9.5	62.3	0.7	83.6	359±22
LA8.1.4	13.2	0.36	26.9	5.59	771	42.8	19.3	11.9	208	11.5	21.3	1.1	20.0	293±16
LA8.1.2	2.3	10.57	31.6	1.55	1222	47.2	22.6	13.9	320	13.9	4.1	0.3	4.0*	273±20
LA10.5	4.7	0.61	26.4	6.61	155	48.9	12.7	8.1	197	10.8	14.1	0.2	31.9	343±55
Blank tube		0.00	0.0	0.00	0	0.0	0.0	0.0	0	31.3	0.1			
Bulk Lafayette		0.09	22.7	48	1720	44.0	3.3	0.4						

* Sample fragmented during handling. All identified fragments were shot with laser, but some may have been lost. All Ar amounts in 10^{-12} cm^3STP.