Xenon and krypton in Nakhla mineral separates.

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Introduction

Among the most interesting problems being investigated on Mars are those relating to volatiles. As well as questions like when and where liquid water existed, there are uncertainties about how and when noble gasses were incorporated into solids. The noble gasses in martian meteorites, particularly in phases like the liquid-water-derived weathering product known as iddingsite, can be studied to give some insight into the history of volatiles on Mars.

Background

Previously Swindle *et al.* (1) studied the iddingsite in the Martian meteorite Lafayette. They concluded that the iddingsite was indeed preterrestrial (formed on Mars) and formation may have occurred about 650 Ma ago, based on K-Ar ages. They also analyzed krypton and xenon, partly in response to a paper by Ott and Begemann (2). When ^{129}Xe/^{132}Xe is plotted against ^{84}Kr/^{132}Xe many of the shergottite meteorites plot along a line between Chassigny and the Martian atmosphere (solid line in Figure 1). This would make sense, as it can be understood that some atmospheric gas has been incorporated into the meteorites. However, many of the nakhlites plot along the dashed line, where the high ^{129}Xe/^{132}Xe component has a lower ^{84}Kr/^{132}Xe ratio. Ott and Begemann (2) leached a sample of Nakhla in 6N HCl, and found that the anomalous component disappeared. They noted that about 15% of the meteorite was removed during the process and that the primary mineral removed was olivine. Later, Drake *et al.* (3) noted that iddingsite would also be removed by the leaching process. Furthermore, since Xe is preferentially dissolved in water relative to Kr, they suggested that iddingsite, which formed in water, could contain the nakhlite gas with the atmospheric ^{129}Xe/^{132}Xe ratio, but low Kr/Xe ratio. Bogard and Garrison (4) suggested a similar scenario. Swindle et al. (1) analyzed Kr and Xe in a single sample of Lafayette iddingsite, and found the predicted high ^{129}Xe/^{132}Xe ratio. Meanwhile, Gilmour *et al.* (5) suggested that perhaps the carrier was the mesostasis. However, they did not test iddingsite, and they performed only Xe (no Kr) studies. Our experiment was intended to address these two issues.

Swindle *et al.* (1) noted some problems with the idea that the iddingsite carries the bulk of the fractionated atmospheric noble gas in nakhlites. First, while their data is consistent with that hypothesis, their abundance uncertainties were large enough that the iddingsite could actually be a minor carrier. Also, ALH84001 plots with the nakhlites having fractionated atmosphere, but it has no iddingsite. Finally, the majority of the fractionated atmosphere is released at temperature steps above 800°C. The iddingsite would likely release gas at lower temperatures, whereas the mesostasis would be more likely to release gas at these higher temperatures.

Method

A small piece of Nakhla was ground into almost a powder and then the grains were physically separated into pyroxene (green), olivine (orange), and mesostasis (white). It had been hoped that the iddingsite would have been available in small chunks that could have been separated out for K-Ar dating as they had been in the Lafayette meteorite (1). However, the only iddingsite visible in the ground meteorite was coated on the olivine grains. This made K-Ar impossible. Instead the olivine grains were sorted into pure orange grains with no brown coating and orange grains that were rich in the brown coating (iddingsite). Krypton and xenon were then analyzed to test which mineral is the primary carrier of the noble gasses in this Martian meteorite. Gases were released in two temperature steps, at 500^{0}C and 1500^{0}C, except for one larger pyroxene separate, where four steps were made. Only the high-temperature data are reported, since the low-temperature data were isotopically indistinguishable from terrestrial atmosphere.

Results and Discussion

Our results are given in Table 1 and displayed in Figures 1 and 2. "^{129}Xe$_{XS}$ " is the "excess" atmospheric ^{129}Xe, as defined by Gilmour et al.,

$$^{129}\mathrm{Xe}_{XS} = [^{132}\mathrm{Xe}] * \{(^{129}\mathrm{Xe}/^{132}\mathrm{Xe}) - 1\}$$

^{132}Xe and ^{129}Xe$_{xs}$ are in units of 10^{-12} cm^3 STP g^{-1}.

Table 1: Xe and Kr in Nakhla mineral separates

	^{132}Xe	^{129}Xe/^{132}Xe	^{84}Kr/^{132}Xe	^{129}Xe$_{xs}$
Px (large)	0.7	1.14±..14	1.09	0.10
Px (small)	9.1	1.07±.06	7.70	0.6
Meso	28.6	1.38±.07	4.81	10.8
Olivine	32.0	1.32±.10	7.83	10.1
Oliv w/ Idd	25.5	1.17±.05	6.78	4.2

Our data show much more ^{132}Xe than those of (5). On Figure 1, our data appear to be a mixture of nakhlite gas and terrestrial atmosphere. This probably means that we ground terrestrial atmospheric Xe into our samples. The experiment may be better performed in the future by grinding in an environment free of Xe and Kr, such as in a Nitrogen glove box or under acetone. Gilmour *et al.* (5) noted that when they prepared their sample of Nakhla, the sample simply fell apart. Thus they did not have to grind the sample in order to separate the grains of pyroxene and olivine. In Figure 2, our data for mesostasis and pyroxene look very similar to those of (5), except for the terrestrial contamination. Unfortunately for the hypothesis of iddingsite as the carrier of the fractionated atmosphere, our sample of olivine with iddingsite plotted near the olivine samples of (5). No enhanced ^{129}Xe was seen. Ironically, the olivine sample that had no iddingsite plotted close to the mesostasis. This olivine may have included a gas-rich inclusion.

Conclusion

Our data support the hypothesis of (5) that the mesostasis carries the fractionated martian atmosphere in Nakhla. This will require a different fractionation method than fractionation by liquid water into the iddingsite, as (3) and (4) had suggested. Although magmatic incorporation of previously fractionated gas (as suggested by (5)) is possible, we think it is more likely to be shock implantation of gas that had previously been fractionated either by adsorption (6) or by trapping of the atmosphere into clathrates in the polar caps (7).

Figure 1

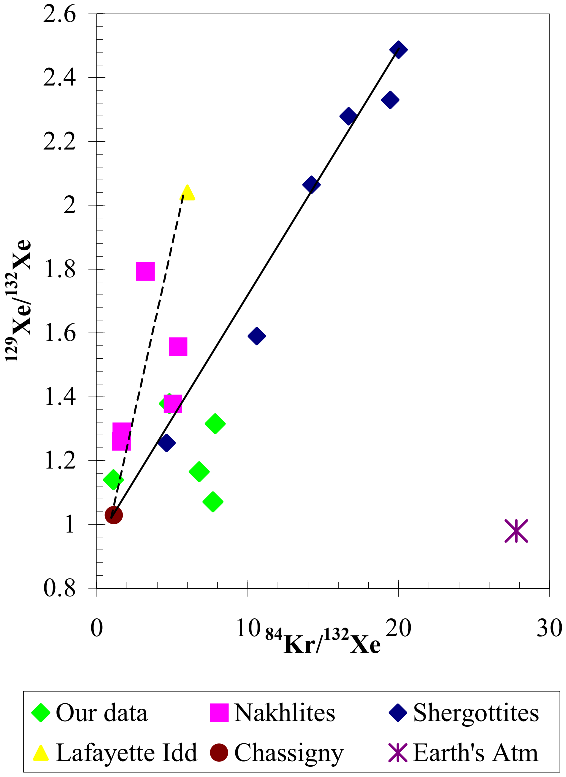

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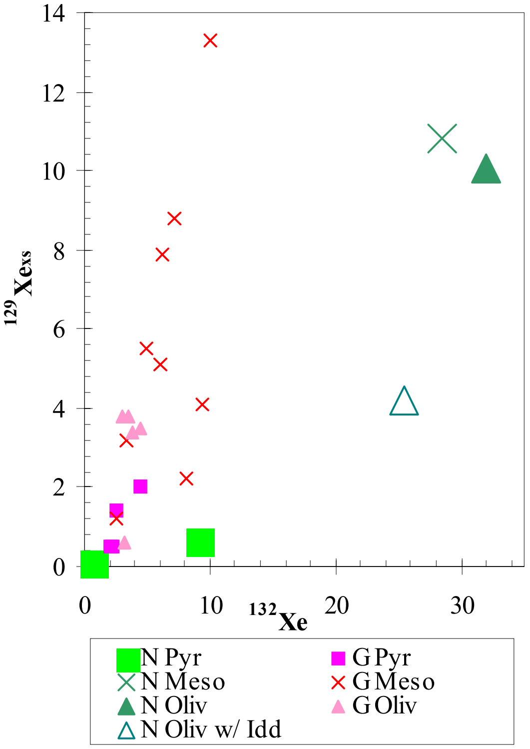
Figure 2



↑ Fig. 2. "N" represents our Nakhla data, "G" represents data from (5).

← Fig. 1. Data for nakhlites, Lafayette Idd, Chassigny, and Earth's Atm from (1) and (3). Data for shergottites from (8).