NOBLE GASES IN NAKHLA AND THREE NAKHLITES MILLER RANGE 090030, 090032, AND 090136.

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Introduction: Nakhlites are cumulates consisting of mostly magnesian augite. The nakhlites differ from shergottites in 1) having generally higher volatile contents; 2) being LREE-enriched [1, 2]; 3) having essentially no features indicating strong shock; and 4) showing clear evidence – e.g., the presence of iddingsite - for low-temperature aqueous alteration on Mars [3, 4]. Ref. [5] showed that the $^{129}Xe/^{132}Xe$ of iddingsite from the nakhlite Lafayette can be as high as 2.04 ± 0.28 and $^{84}Kr/^{132}Xe$ as low as 6 ± 3. These ratios differ from terrestrial and planetary values and are thought to indicate the presence of elementally fractionated Martian atmosphere trapped during aqueous alteration [5]. Young $^{40}Ar/^{39}Ar$ ages, 0.6–0.7 Ma for a component in the paired nakhlites MIL 090030, MIL 090032, MIL 090136 (henceforth M30, M32, and M136) have been attributed to iddingsite [6].We measured noble gas compositions of bulk samples from Nakhla and from M30, M32, and M136, with special attention to possible contributions from alteration products. Noble gas data for MIL 03346 (M346) measured by [7] are also considered.

Experimental method: Elemental and isotopic compositions of noble gases were analyzed using a noble gas mass spectrometer (modified-VG5400) at the University of Tokyo, which was moved to KOPRI in 2015. Stepwise heating methods, 8 steps from 400 to 1800ºC and 9 steps from 300 to 1800ºC, were applied to Nakhla (126.4 mg) and to M30 (43.7 mg), M32 (44.3 mg), and M136 (49.0 mg), respectively, to extract noble gases from the samples.

Results and discussion: Most of the He and the radiogenic ^{40}Ar were released at low temperatures (600–900ºC), while release peaks of Kr and Xe were different among the samples at rather higher temperature range (600-1800ºC). Neon released at temperatures lower than 1600ºC was mostly cosmogenic. Cosmogenic ^{3}He concentrations are $(211–227)\times10^{-9}$ cm^3STP/g for 3 MIL 09s and Nakhla; M346 has a slightly lower concentration of $(171–193)\times10^{-9}$ cm^3STP/g. Cosmogenic ^{21}Ne concentrations for 3 MIL 09s are $(21.6–22.9)\times10^{-9}$ cm^3STP/g, in good agreement with the values reported for Yamato nakhlites [8]. The data indicate a common ejection event for many nakhlites, for which cosmic ray exposure ages were so far reported. Somewhat higher concentrations of cosmogenic ^{21}Ne, $(25.9–30.3)\times10^{-9}$ cm^3STP/g, in Nakhla and M346 may reflect a higher ^{21}Ne production rate.

A high $^{129}Xe/^{132}Xe$ ratio (>2.6) suggests a Martian atmospheric origin [9]. All the MIL nakhlites released Xe with $^{129}Xe/^{132}Xe$ ratios ranging 2.22–2.37 at temperatures from 1000 to 1400ºC. Slightly lower ratios of 1.95–2.13 were observed at the lowest temperatures, 300ºC (M30 and M32) and 400ºC (M346). High $^{129}Xe/^{132}Xe$ ratios for low-T extractions could be from the products of aqueous alteration; high $^{129}Xe/^{132}Xe$ ratios for high-T extractions may be from the Martian interior as suggested for Ar by [10]. At low T and in contrast to the 3 MIL09 nakhlites, M136 and Nakhla showed distinctly lower $^{129}Xe/^{132}Xe$ ratios of 1.37 and 1.01, respectively. M136 and Nakhla may have lost some Xe-bearing material either during laboratory processing or as a result of weathering [7]. In plots of $^{129}Xe/^{132}Xe$ *vs.* $^{84}Kr/^{132}Xe$, MILs show high $^{129}Xe/^{132}Xe$ and low $^{84}Kr/^{132}Xe$ (≤1) at both low (300–400ºC, exclude M136) and high (800–1600ºC, different among the samples) temperatures. Nakhla is clearly different in the sense that the ratios ($^{129}Xe/^{132}Xe \approx 2$ and $^{84}Kr/^{132}Xe \approx 6$) for $800 < T < 1400$ºC are close to those of iddingsite [5]. M346 shows remarkably high $^{40}Ar/^{36}Ar_{trap}$ ratios (>5000) in the temperature range of 500–900ºC, reflecting low concentration of trapped ^{36}Ar in this sample. Taken together, these data indicate heterogeneous noble gas compositions among the nakhlites even though they were ejected from Mars by a single impact event.

References: [1] McSween Jr. H. Y. 1994. *Meteoritics & Planetary Science* 29:757–779. [2] Nakamura N. et al. 1982. *Geochimica et Cosmochimica Acta* 46: 1555–1573. [3] Gooding J. L. et al. 1991. *Meteoritics* 26:135–143. [4] Treiman A. H. and Gooding J. L. 1991. *Meteoritics* 26:402 (Abstract). [5] Drake M. J. et al. 1994. *Meteoritics & Planetary Science* 29:854–859. [6] Park J. et al. 2016. Abstract #1821. 47th Lunar & Planetary Science Conference. [7] Nagao K. and Park J. 2008. Abstract #1614. 39th Lunar & Planetary Science Conference. [8] Okazaki R. et al. 2003. Antarctic Meteorite Research 16:58–79. [9] Garrison D. H. and Bogard D. D. 1998. *Meteoritics & Planetary Science* 33:721–736. [10] Park J. et al. 2013. *Geochimica et Cosmochimica Acta* 121:546–570.