ISOTOPIC EVIDENCE FOR A MARTIAN REGOLITH COMPONENT IN MARTIAN METEORITES.
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Introduction: Noble gas measurements in gas-rich impact-melt (GRIM) glasses in EET79001 shergottite showed that their elemental and isotopic composition is similar to that of the Martian atmosphere [1-3]. The GRIM glasses contain large amounts of Martian atmospheric gases. Those measurements further suggested that the Kr isotopic composition of Martian atmosphere is approximately similar to that of solar Kr. This suggestion was validated by [4] after detailed comparison of the lunar and Martian meteorite noble gas data. Subsequently, Garrison and Bogard [5] carried out improved noble gas measurements on GRIM glasses (,8 and ,104) which showed that the lighter isotopes of Kr in GRIM glasses are slightly enriched relative to the lighter Kr isotopes in solar wind implanted into lunar soils, suggesting a mass-fractionation trend of 0.5-1.0% per amu (Fig. 1). The data-average from [2] and [3] for GRIM glass ,27 shows a slightly lower mass fractionation trend compared to the data-average from [5] for ,8A and ,8B glasses. Considering the uncertainities in the measurements of ,27 and ,8 glasses, we adopt a value of 1.03 for $(^{80}Kr/^{84}Kr)_{Mars\ atmos}$ / $(^{80}Kr/^{84}Kr)_{solar}$. As a result, we obtain a value of 0.042 for the $^{80}Kr/^{84}Kr$ ratio in Martian atmosphere. Furthermore, the data plotted in Fig.1 show a large enrichment of ^{80}Kr in GRIM glasses relative to solar Kr. This plot shows that ^{80}Kr excesses are heterogeneously distributed in GRIM glasses suggesting a possible contribution from a source other than the Martian atmosphere. This additional ^{80}Kr source is usually attributed to neutron capture reactions by ^{79}Br on Mars [1,2,3]

In 2002, Rao et al. [6] investigated possible neutron capture effects in the Martian regolith. They attempted to estimate the neutron fluence that irradiated the constituent materials in GRIM glasses ,27; ,8; ,104; Shergotty and Nakhla salt assemblages using ^{80}Kr and ^{149}Sm isotopes. ^{149}Sm captures neutrons to produce ^{150}Sm. The isotopic deficit in ^{149}Sm was more precisely determined than the ^{150}Sm isotopic excess because of a possible isobaric interference in the ^{150}Sm measurements. The isotopic deficits in ^{149}Sm which were accurately determined in ,27 GRIM glasses (multiple measurements) yielded an average neutron fluence $[\Phi_n]$ of (10±4) x 10^{14} neutrons / cm^2 [6]. The Sm isotopic deficit ($\epsilon^{149} = - 0.57 \pm 0.17$) could not have originated from the Martian atmosphere, as it has no Sm. It could be produced only by *in- situ* neutron irradiation of Martian regolith materials that contains Sm.

Earlier, Rao et al. [6] determined $^{80}Kr_n$ (neutron capture) excesses in GRIM glasses by subtracting the Martian atmospheric Kr and the spallation produced Kr from the measured Kr isotopic composition [5]. They assumed that the Martian atmospheric Kr composition is similar to solar Kr [4]. As a result, the $^{80}Kr_n$ excesses determined in the GRIM glasses showed a positive correlation with Martian atmospheric implantated ^{129}Xe. This result suggested that the $^{80}Kr_n$ excesses were mainly introduced into the GRIM glasses from the Martian atmosphere by shock processes similar to those for ^{129}Xe. Further, these observations led to the inference that the $^{80}Kr_n$ – $^{80}Kr_M$ mixing ratio in the Martian atmosphere is ~ 9%. ($^{80}Kr_M$ is atmospheric ^{80}Kr exclusive of the neutron capture and spallation components). The neutron fluences calculated from $^{80}Kr_n$ excesses apparently disagreed with those based on ^{149}Sm isotopic deficits in the same GRIM glassses.

Revised interpretation of $^{80}Kr_n$ excesses: To find out the reasons for these differences in the calculated neutron fluences, we revisit the issue of neutron capture Kr isotopes in these glasses. We adopt the updated Martian atmospheric Kr composition based on recent measurements of the Kr isotopic composition in GRIM glasses ,8; ,104; and Shergotty of [5], where Kr light isotope enrichment (^{80}Kr and ^{82}Kr) relative to solar wind Kr [4] is clearly shown (Fig. 1). The $^{80}Kr_n$ excesses calculated here for GRIM glasses and Nakhla using the updated Martian atmospheric Kr composition [5] are given in Table 1. The calculation methodology is similar to that discussed in [6]. The $^{80}Kr_n$ excesses obtained for GRIM glasses and Nakhla are plotted against ^{129}Xe in Fig. 2, which shows that there is no correlation between $^{80}Kr_n$ and ^{129}Xe in these GRIM glasses. Moreover, if the $^{80}Kr_n$ is introduced by implantation of Martian atmosphere into these samples, the $^{80}Kr_n$ / $^{80}Kr_M$ mixing ratio is expected to be the same in both nakhlites and shergottites. The experimental results show otherwise. The $^{80}Kr_n$ / $^{80}Kr_M$ ratio in shergottite GRIM glasses ranges from 2-6, whereas the same ratio in Nakhla ranges from 40-45. These observations indicate that the observed $^{80}Kr_n$ excess in GRIM glasses can not be completely attributed to only implanted Martian atmosphere.

The other possibility for the production of $^{80}Kr_n$ excesses in these glasses is by neutron capture by ^{79}Br

as in the case of neutron capture by ^{149}Sm. The ^{149}Sm isotopic deficit in GRIM glasses results from exposure of glass-precursor regolith materials containing Sm to a neutron fluence [Φ_n] of (10±4) x 10^{14} n/cm^2 [6] as discussed above.

We examine below whether a similar neutron fluence could produce the observed ^{80}Kr$_n$ excess in GRIM glasses. For this pupose, we need to know the target Br abundance in the regolith material that was shock-melted to produce the GRIM glasses. The Br abundances in these glasses were determined by INAA [7] and by XANES (this study). The Br content of GRIM glasses ,27 and ,8 are 0.38 ppm and 0.36 ppm, whereas the Br content of ,104 and Shergotty glasses are 0.83 and 0.72 ppm, resp. Further, the Br content in Nakhla is 4.1 ppm. The neutron fluences in individual glasses are determined from the observed ^{80}Kr$_n$ excesses, Br abundances, and the σ_{eff} values (effective neutron-absorption cross sections) calculated according to Lingenfelter et al. [8] method. The results are given in Table 1.

The neutron fluence, [Φ_n] , in these GRIM glasses range from (2– 6) x 10^{14} n/cm^2 and compares favorably with that determined using ^{149}Sm isotopic deficits within a factor of ~2. In particular, [Φ_n] values calculated for EET79001,27 of (2.4±1.3) and (3.9±1.8) x 10^{14} n/cm^2 , resp., using ^{80}Kr$_n$ are in adequate agreement with (10±4) x 10^{14} n/cm^2 determined from the ^{149}Sm measurements on ,27 glass. These results suggest that both the ^{149}Sm isotopic deficits and ^{80}Kr$_n$ excesses in GRIM glasses from EET79001 and Shergotty have a common source in the Martian regolith, and were likely produced by similar neutron capture reactions in glass-precursor regolith materials on Mars. In contrast, the host rock constituent materials in Lith A and B yield considerably lower neutron-fluence [6]. The order of magnitude lower fluence in Nakhla than in the GRIM glasses also is consistent with failure to find a detectable ^{149}Sm deficit in nakhlites ([Φ_n] < 0.6 x 10^{14} n/cm^2).

Conclusions: The ^{80}Kr$_n$ – ^{80}Kr$_M$ mixing ratio in the Martian atmosphere obtained here is ~3%. These neutron-capture reactions presumably occurred in the glass-precursor regolith materials containing Sm- and Br- bearing mineral phases near the EET79001/ Shergotty sites on Mars. The irradiated materials were mobilized into host rock voids either during shock-melting or possibly by earlier aeolian / fluivial activity.

References: [1] Bogard D.D. and Johnson P. H. (1983) Science, *221*, 651-654. [2] Becker R.H. and Pepin R.O. (1984) *EPSL*, *69*, 225-242. [3] Swindle T.D. et al. (1986) *GCA, 50,* 1001-1015. [4] Pepin R.O. et al. (1995) *GCA, 59*, 4997-5022. [5] Garrison D.H. and Bogard D.D. (1998) *Meteoritics & Planet. Sci. 33*, 721-736, [6] Rao M.N. et al. (2002) *Icarus, 156*, 352-372. [7] Dreibus G. and Waenke H. (1987) *Icarus, 71*, 225-240. [8] Lingenfelter R.E. et al. (1972) *EPSL, 16*, 355-369.

Fig.1. Kr isotopic composition in EET79001 GRIM glasses normalized to mass 84 and solar wind Kr.

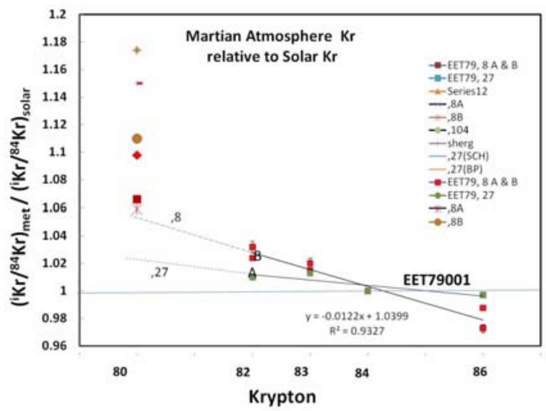

Fig. 2. Neutron-produced ^{80}Kr$_n$ excess versus Martian atmospheric ^{129}Xe in GRIM glasses and Nakhla.

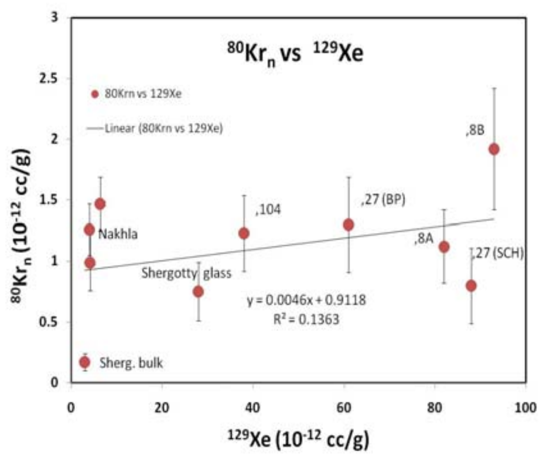

Table. 1. Neutron fluences in shergottite GRIM glasses and Nakhla meteorite.

Sample	^{80}Kr$_n$ (10^{-12} cc/g)	Br (ppm)	Neutron fluence [Φ_n] (10^{14} n/cm^2)	Reference
EET79001,8A	1.12 ± 0.29	0.32 ± 0.17	3.2 ± 1.3	GB, 1998
EET79001,8B	1.92 ± 0.54	0.34 ± 0.17	6.1 ± 2.6	GB, 1998
EET79001,27	0.80 ± 0.31	0.34 ± 0.05	2.4 ± 1.3	SCH, 1986
EET79001,27	1.30 ± 0.39	0.38 ± 0.05	3.9 ± 1.8	BP, 1984
Shergotty B glass	0.75 ± 0.24	0.83 ± 0.28	1.0 ± 0.5	GB, 1998
EET79001, 104	1.23 ± 0.31	0.72 ± 0.26	1.9 ± 0.7	GB, 1998
Nakhla P1	1.26 ± 0.21	4.2 ± 0.62	0.33 ± 0.14	Ott, 1988
Nakhla P 2/3	0.99 ± 0.23	4.0 ± 0.60	0.27 ± 0.14	Ott, 1988
Nakhla H1	1.47 ± 0.22	4.1 ± 0.61	0.39 ± 0.14	Ott,1988