DO SNC NOBLE GAS AND DEUTERIUM DATA PROVIDE EVIDENCE FOR A LARGE COMETARY IMPACT BETWEEN 1300 – 300 MA ON MARS?

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Introduction: The Martian volatile inventory and climate have changed markedly throughout the planet's history. It is generally accepted that the volatiles of the Martian and terrestrial atmospheres were initially derived from the same major reservoir, such as the solar nebula, or gases modified during planetary formation. This reservoir is now represented in primitive meteorites and comets. From the beginning, the Martian atmosphere was subject by mass fractionation and to addition of specific components (e.g., radioactive gases, or material introduced by asteroids and comets [1-3]). Today there are many models and assumptions, but none of them can explain exactly the processes that have modified the volatiles of the Martian atmosphere. There is evidence of appreciable mass fractionation of hydrogen, argon, and xenon, compared to the solar wind components, the composition of which are assumed to be similar to the initial composition of proto-Mars. Krypton appears not to have been mass fractionated, whereas Xe is strongly fractionated [e.g., 4].

There is substantial evidence that the Martian volatiles, especially Ar/Kr/Xe ratios and D/H ratios, have changed markedly between ~1300 Myr (crystallization age of the nakhlites) and ~300 Myr (crystallization age of the shergottites), whereas the atmosphere seems to be stable between 3.9 Gyr (crystallization age of ALH 84001) and the 1.3 Gyr old nakhlites.

General Results: The 12 SNC meteorites used for this study are divided into four sub-groups based on their mineralogy: seven shergottites (Shergotty, Zagami, EETA 79001, ALH 77005, LEW 88516, Y 793605, QUE 94201) with a crystallization age of 327-165 Myr, three nakhlites (Nakhla, Lafayette, Governador Valadares) with a crystallization age of 1.27-1.33 Gyr, one chassignite (Chassigny) with a crystallization age of 1.34 Gyr, and ALH 84001 with a crystallization age of 3.92 Gyr. ^{129}Xe/^{132}Xe ratio *versus* ^{84}Kr/^{132}Xe ratio, ^{129}Xe/^{132}Xe ratio *versus* ^{36}Ar/^{132}Xe ratio, and ^{40}Ar/^{36}Ar ratio *versus* ^{36}Ar/^{132}Xe ratio from these SNC meteorites are plotted against the crystallization age (Fig. 1). Data are from different possible Martian atmospheric bearing components, like glasses, mesostasis, orthopyroxene and carbonates as well as for bulk samples. That could contain traces of the Martian atmosphere, which have been predominated during the time of crystallization of the specific meteorites (for sources of data see references in [5]). All data, are corrected for adsorbed terrestrial gas released at low temperatures during step-heating analyses and for cosmogenic components. For comparison, also shown are the noble gas ratios for Earth atmosphere [6-8], Mars-Viking data for surface atmosphere [9-11], Mars atmosphere data derived from EETA 79001 Martian meteorite [12,13], and Mars mantle data derived from Chassigny [14,15].

Black lines in the diagrams in Fig. 1 show an average Martian mantle-Martian atmospheric mixing line. Lines are derived from linear regression of meteroites data points, which go through the Chassigny data point. For the present study, it is not as important to find the exact mantle-atmospheric mixing line, as the trend of the mantle-atmospheric mixing lines of the different meteoritic groups *versus* their crystallization age. It is obvious from Fig. 1 that the ^{129}Xe/^{132}Xe ratio *versus* ^{84}Kr/^{132}Xe ratio, ^{129}Xe/^{132}Xe ratio *versus* ^{36}Ar/^{132}Xe ratio, and ^{40}Ar/^{36}Ar ratio *versus* ^{36}Ar/^{132}Xe ratio of ALH 84001 and nakhlites match fairly well, but are quite different to shergottites data. It seems that there is no significant difference in atmospherical composition between ~4 Gyr (age of ALH 84001) and ~1.3 Gyr (age of the nakhlites). The Martian atmosphere was stable during this 2.7 Gyr. However, between 1300 and 300 Myr abundances of the lighter isotopes ^{84}Kr and ^{36}Ar were increased compared to ^{132}Xe, and ^{36}Ar relative to ^{40}Ar. The ^{129}Xe/^{132}Xe ratios seem to be nearly constant or show a slight increase of the lighter ^{129}Xe isotope between 1300 and 300 Myr. This depends on the exact trend of the Martian mantle-Martian atmosphere mixing line, which is not yet known. Also obvious from the plots of ^{129}Xe/^{132}Xe ratio *versus* ^{84}Kr/^{132}Xe ratio, ^{129}Xe/^{132}Xe ratio *versus* ^{36}Ar/^{132}Xe ratio, and ^{40}Ar/^{36}Ar ratio *versus* ^{36}Ar/^{132}Xe ratio from shergottites (represent the younger Martian meteorites from 327-165 Myr) is that the mantle-atmospheric mixing lines do not cross the "Martian-derived" point derived from EETA 79001 data, which represents the present Martian atmosphere and were also predominating during their crystallization time. In the ^{129}Xe/^{132}Xe ratio *versus* ^{84}Kr/^{132}Xe ratio and ^{129}Xe/^{132}Xe ratio *versus* ^{36}Ar/^{132}Xe ratio plots of this meteorites group, an influence of terrestrial atmosphere is obvious, and causes a shift from the real mantle-atmospheric mixing line, which normally should go through the "Martian-derived" point. The $^{40}Ar/^{36}Ar$ ratio *versus* $^{36}Ar/^{132}Xe$ ratio plot shows an average mantle-atmospheric mixing line near the value derived from EETA 79001 glass inclusions. But there is a broad distribution of data points that is caused by possible radiogenic ^{36}Ar components that shift the mixing line towards the side.

Conclusions: The extreme mass fractionation of noble gases between 1300-300 Myr cannot be explained by hydrodynamic loss processes generated by intense extreme-ultraviolet radiation from the sun, like in the earlier times of the solar system. Also, an intrinsic magnetic field, which would prevent the solar wind to reach the planet and, thus, limiting its ability to strip the atmosphere, could not be the reason for the stable time between 4 and 1.3 Gyr, because magnetic anomalies were found in ALH 84001, but not in the nakhlites [16].

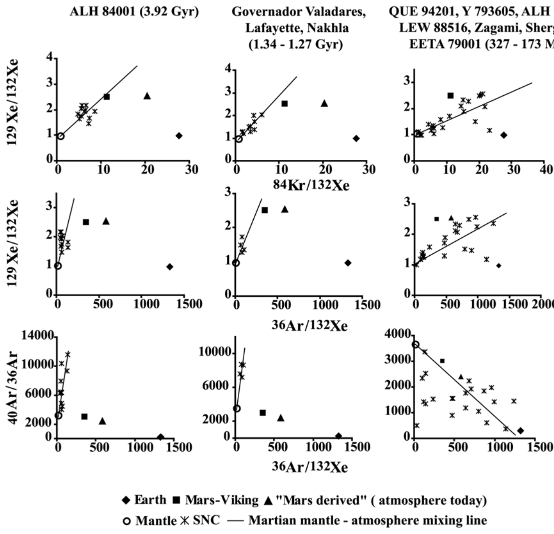

Figure 1. $^{129}Xe/^{132}Xe$ ratio *versus* $^{84}Kr/^{132}Xe$ ratio, $^{129}Xe/^{132}Xe$ ratio *versus* $^{36}Ar/^{132}Xe$ ratio, and $^{40}Ar/^{36}Ar$ ratio *versus* $^{36}Ar/^{132}Xe$ ratio from SNC meteorites are plotted against the crystallization age. For comparison also shown are the noble gas ratios for Earth atmosphere, Mars-Viking data for surface atmosphere, Mars atmospheric data derived from EETA 79001 Martian meteorites and Mars mantle data derived from Chassigny. The black lines show an average Martian mantle - atmospheric mixing line.

A possible explanation would be a large impact event between 1300 and 300 Myr, which generated hydrodynamic loss due to very high thermal energy (several thousands °C) and blew-off a large part of the Martian atmosphere [17,18]. Heavier gas components were enriched, because for lighter gas components a lower kinetic energy is necessary to carry them into space. Taking into account D/H ratios [19] of the four Martian meteorite sub-groups compared to each other and to the D/H ratios of comets (Fig. 2), a cometary impactor is likely. Also, the comet may have introduced a solar mixture of noble gases enriched in lighter noble gases, which are present in the Martian atmosphere today.

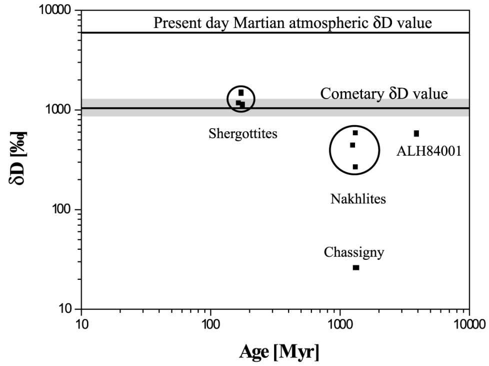

Figure 2. D/H ratios of several Martian meteorites plotted against the crystallization age, of the present Martian atmosphere and from comets. Line shows an average D/H value derived from data of three comets, Halley [20], Hale-Bopp [21], and Hyakutake [22], respectively, and shaded area shows errors.

Acknowledgments: We thank Christian Koeberl and Hugh Rice (both University of Vienna) for helpful suggestions.

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