TRAPPED ARGON AND XENON IN EET79001 AND ALH84001: CLUES TO LOW TEMPERATURE AQUEOUS ACTIVITY ON MARS.

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Introduction: Among the Martian meteorites, EET79001 and ALH 84001 contain largest amounts of Martian atmospheric noble gases. In this study we examine the conditions under which they were incorporated into ALH84001. The elemental and isotopic composition of noble gases in these meteorites are determined in several laboratories[1-8]. In EET79001, the radiogenic Ar contribution is small because of its ~180Ma Rb-Sr age and one can consider the Ar in this meteorite to be a mixture of Martian atmosphere, cosmogenic and terrestrial/Chassigny-type components. Similarly Xe (for 124-130 isotopes) in this meteorite can be treated as a mixture of these three components. However, in the case of ALH84001, the situation is different for Ar because of its ~4.5 Gyr age eventhough Xe can be treated as in EET79001. In ALH84001, the radiogenic Ar contribution dominates in several temperature steps during stepwise heating analysis. Earlier workers [6-8] tried to estimate trapped ^{36}Ar by applying cosmogenic ^{36}Ar correction and by correcting for radiogenic Ar using K content in a given sample assuming the age. But [10] and [9] addressed the trapped Ar problem in ALH84001 differently using correlation plots of trapped $^{36}Ar/^{40}Ar$ versus $^{39}Ar/^{40}Ar$ based on data obtained for reactor-irradiated samples and reached different conclussions regarding the proportion of Martian and terrestrial Ar in this meteorite. Here we propose to address this problem from another point of view.

In Fig.1 we plot $^{40}Ar/^{36}Ar$ versus $^{38}Ar/^{36}Ar$ data for EET79001 LithC & LithA and Shergotty and Zagami glasses from [2],[3],[5] and [11]. The data are consistent with three component mixing model having Martian atmosphere ($^{40}Ar/^{36}Ar=~2000$), terrestrial or Chassigny-type Ar ($^{40}Ar/^{36}Ar=~300$) and cosmogenic Ar ($^{38}Ar/^{36}Ar =1.6$) as three end-members. In Fig.1, also the Ar data of unirradiated ALH84001 samples are plotted for comparison. If a ALH84001 sample releases large amounts of radiogenic Ar from K-bearing phases, it results in very high $^{40}Ar/^{36}Ar$ ratios. Samples analyzed by [7] and [8] belong to this category because they yield $^{40}Ar/^{36}Ar$ ratios as high as ~5000 or more which cannot be plotted in Fig.1. On the otherhand if a sample contains very small amounts of maskelynite, the measured Ar will essentially be a mixture of the three components mentioned above. The stepwise heating data of [5] and [6] for unirradiated ALH84001 samples ,113 and ,28 belong to the second group because they plot close to the line join-

ing the Martian atmosphere and cosmogenic Ar in Fig.1. Also the unirradiated ALH84001 sample analyzed by [12] using O_2 combustion method yielded $^{40}Ar/^{36}Ar$ ratios (except for highest temperature steps) which plot near the line joining Martian atmosphere and cosmogenic Ar. Note that Fig.1, though not sensitive to small amounts of radiogenic Ar contribution, it can graphically show whether it is terrestrial or Martian Ar that moves the data points up or down.

We apply standard analytical techniques to resolve these three components in the data from [5] and [6]. We estimate that ~44% of ^{36}Ar and ~64% of ^{130}Xe is Martian atmosphere in the $1400°C$ fraction of ,28 sample of [6] and ~55% of ^{36}Ar and ~70% of ^{130}Xe in the $1500 °C$ fraction of ,113 sample of [5] in ALH84001. Note that the Martian ^{36}Ar calculated using our method for the $1400 °C$ fraction of ,28 is ~2000 x 10^{-12} cc/g whereas the Martian ^{36}Ar deduced by Swindle et al.[6] is ~1200 x10^{-12} cc/g by assuming ~4.5 Gyr age and correcting for radiogenic Ar basd on measured K in the sample. Martian ^{130}Xe in ALH84 sample from [6] deduced here is 2.6 x 10^{-12}cc/g.

Below we discuss the ($^{130}Xe/^{36}Ar$) ratios obtained in these samples. For EET79001,LithC samples analyzed by [2] to [5], we deduce ($^{130}Xe/^{36}Ar)_M$ values (M refers to Martian atmosphere) ranging from 1.75 to 3.9 x 10^{-4}. In the case of ALH84001 samples analyzed by [5] to [8], we deduce ($^{130}Xe/^{36}Ar)_M$ values ranging from 0.94 to 2.64 x 10^{-3}. Using procedures similar to [6], the Martian ^{36}Ar content deduced by [8] for their sample is 1420 and by [7], for their two samples, are 1252 and 1631, in units of 10^{-12} cc/g. The variation of Martian ^{130}Xe in all these samples is much less i.e.2 to 2.6 x 10^{-12} cc/g. Using these ($^{130}Xe/^{36}Ar)_M$ values we calculate the fractionation factor in ALH84001 with reference to Martian atmosphere obtained from EET79001 i.e. Fm = ($^{130}Xe/^{36}Ar)_M$ in ALH84001 / ($^{130}Xe/^{36}Ar)_M$ in EET79001. The Fm values thus calculated for ALH84001 are 9 for Swindle et al. [6] sample, 8 for Murthy and Mahopatra [8] sample, 6 and 5 for Miura et al. [7] samples and 3.5 for Garrison and Bogard [5] sample. Recently [5] estimated a Xe/Ar enrichment factor of ~11 for the mass-fractionated noble gas component in ALH84001 by analyzing all available data.

Under terrestrial conditions such type of Fm values showing shallow mass-fractionation pattern between Ar and Xe are charecteristic of noble gases dissolved in aqueous solutions [13,5]. The Fm value for

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^{130}Xe/^{36}Ar ratio in pure water at 0 °C is ~4.5 [13,5]. At lower temperatures this value goes up to ~8 in CO_2 bearing solutions. On the Mars surface when aqueous solutions equilibrated with atmosphere in the past, both CO_2 and noble gases dissolved in these solutions. Subsequently they found their way deep underground through fractures and faults. The shallow noble gas fractionation pattern observed for ALH 84001 samples indicates that the abundant fractures and pores in this meteorite were once exposed to CO_2-rich solutions for some time near Martian surface. These solutions seem to have percolated through granular bands in ALH84001 consisting of very fine-grained material which provided large surface area for selective adsorption of mass-fractionated Martian noble gases. To account for the trapped noble gases in ALH84001, recently [14] proposed a machanism for Ar and Xe entrapment by direct adsorption of Martian atmosphere on fractures in ALH84001 at the topmost surface on Mars. But direct adsorption is a non-selective process though it has the advantage of producing high concentrations at low temperatures. In general direct adsorption results in very steep fractionation factors of ~100 or more and it predicts large variations in ^{130}Xe/^{36}Ar ratios from one sample to another. Several ALH84001 samples studied in five labs, instead, yield tightly clustered values of ~4-8 for this ratio. Hence we propose an alternate scenario here. The Xe/Ar ratios deduced above suggest that the shallow mass-fractionated noble gas pattern was established during equilibration of noble gases with CO_2 bearing solutions at low temperatures (<~40 oC) on Mars surface sometime ~4 Gyr ago. These solutions were exposed to fractures and pore space in ALH84001 on Mars. The very fine-grained minerals mixed with sub-

micron carbon particulate matter[15] in granular bands and carbonate globules generated enoromous surface area and provided innumarable adsorption sites for multiple trapping of mass-fractionated noble gases at low temperatures in ALH84001. This mechanism can account for both shallow mass-fractionation and high concentration of Martian noble gases in ALH84001. At higher temperatures this model predicts the Fm factors for Xe/Ar to be ~1. At a later time, the adsorbed noble gases were shock-implanted into the mineral grains by another impact on Mars.

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Figure 1. 40Ar/36Ar versus in EET79001 LithC and LithA [2,3,5], Zagami [11] and Shergotty [5] glasses. Note only two data points[5,6] belong to ALH84001 among all these points.

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