Fractionated noble gases in the nakhlite Martian meteorites

Conference or Workshop Item

FRACTIONATED NOBLE GASES IN THE NAKHLITE MARTIAN METEORITES. S. P. Schwenzer[1,2,3], Ott[2], U., Hicks[4], L. J., Bridges[4], J. C., Barnes[5,6], G., Treiman[3], A. H., and Swindle[6], T. D., [1]The Open University, Department of Environment, Earth and Ecosystems, Walton Hall, Milton Keynes MK7 5AA, UK; susanne.schwenzer@open.ac.uk. [2]Max-Planck Institute for Chemistry, Germany. [3]Lunar and Planetary Institute, USA. [4]University of Leicester, UK. [5]University of Idaho, USA. [6]University of Arizona, USA.

Introduction: Noble gases measured in Martian meteorites are frequently a mixture of different components, ranging from Martian interior and unfractionated and fractionated atmosphere, to cosmic ray produced isotopes and terrestrial contamination. Here we focus on the Martian components, especially the fractionated Martian atmosphere in the nakhlite meteorites, in comparison to the other Martian components.

The interior component, typified by extracts from the Chassigny Martian meteorite [1,2], has solar-like noble gas isotope ratios, but is elementally fractionated from solar. The Martian atmosphere component, recognized in shock melts in the EET 79001 meteorite (e.g., [3,4]), is essentially identical to the Martian atmosphere analyzed by the Viking landers [5] and the Curiosity rover [6]. It is notable for its high $^{129}Xe/^{132}Xe$ and $^{136}Xe/^{132}Xe$ ratios. In the nakhlites, the high $^{129}Xe/^{132}Xe$ is observed as well, but the Kr/Xe elemental ratio is different from the shergottites and Viking measurements. Thus, the nakhlites contain elementally fractionated Martian atmosphere.

Petrology and alteration mineralogy: The Martian meteorites can be grouped into three main groups - the shergottites (basaltic in composition), the nakhlites (clinopyroxenites) and the chassignites (dunitic/peridotitic in composition). Two other types have been found, the orthopyroxenite and oldest Martian meteorite ALH 84001 [7], and the breccia 7034 and paired stones [8].

The nakhlite meteorites are a group of currently eight known clinopyroxenites [9,10]. The nakhlites are thought to have formed in a thick basic-ultrabasic lava flow or shallow, <100 m, intrusion [11-13]. The nakhlites are unique amongst the Martian meteorites because of their combination of hydrothermal veining [14,15] and known formation depths [12,13]. Secondary minerals are present in veins within the olivines and feldspathic mesostasis [16]. Most of the olivine grain hosted vein deposits in Lafayette contain partially corroded Ca-rich siderite and crystalline ferric saponite; most nakhlite samples contain veins dominated by poorly crystalline silicate gel of ferric saponite composition [15] with minor traces of Fe oxide along veins. Governador Valadares and Nakhla also contain siderite, and Nakhla has anhydrite and halite grains [17]

The nakhlite hydrothermal assemblage may have resulted from an impact adjacent to the nakhlite parent rocks, as suggested by [15]. Further mineralogical investigation and thermochemical modeling established that after the impact a CO_2-rich, ~150 °C hot fluid precipitated Ca-rich siderite. As the fluid cooled to 50 °C, ferric phyllosilicate precipitated, followed in turn by the rapid formation of an amorphous gel and traces of Fe oxide [16,18]. Note that the characteristic reddish-brown colouration of the nakhlite olivines is a result of this veining. The alteration was/is sometimes referred to as 'iddingsite' in the literature, which we use here when referring to literature published prior to 2010.

The nakhlites have a common crystallization age of 1.3 Ga, shown by Rb-Sr, Sm-Nd, U-Pb, and $^{40}Ar/^{39}Ar$ data [19]. Cosmogenic nuclides ^{3}He, ^{21}Ne, and ^{38}Ar in the nakhlites suggest that they were all ejected from Mars in the same event 10-12 Ma [20]. Several methods have been used to measure the age of the hydrothermal assemblage, including Rb-Sr and Sm-Nd isotopic analyses [21,22], and K-Ar [23]. The likely date of hydrothermal alteration is taken as ≤670 Ma [24].

Fractionated noble gases: Elementally fractionated Martian atmosphere has long been recognized [1,25, 26] in the nakhlites. However, there is an open debate whether it represents pure Martian atmosphere with a noble gas signature different from today's [26-29]. Or if the elementally fractionated noble gas could have entered the rocks via the magma, either as an internal (crustal?) component or via magmatic assimilation from aqueously altered crustal rock [30-33]. Alternatively, the elementally fractionated noble gases could be specific to their aqueous alteration minerals. In this case, elemental fractionation arose either as the atmosphere dissolved in the altering water, or as alteration minerals formed in the rock, or during both of these steps [1,24,35-39].

Evaluating the case from maesurements of 'iddingsite' [24]). Elementally fractionated Martian atmosphere is best investigated on plots of $^{129}Xe/^{132}Xe$ vs. $^{84}Kr/^{132}Xe$ (Fig. 1), in which noble gas extractions from nakhlite meteorites are not consistent with the mixture of Mars interior and atmosphere components as observed in the shergottites. The composition of Earth's atmosphere is also indicated for comparison. This plot is similar to the plot first shown by [1] and contains data on various SNC meteorites, particularly nakhlites. The martian atmosphere is plotted using the data from EETA 79001 [40]. The shergottites generally plot as a mixture between Martian interior and the current Martian atmosphere. Previous whole rock studies of the

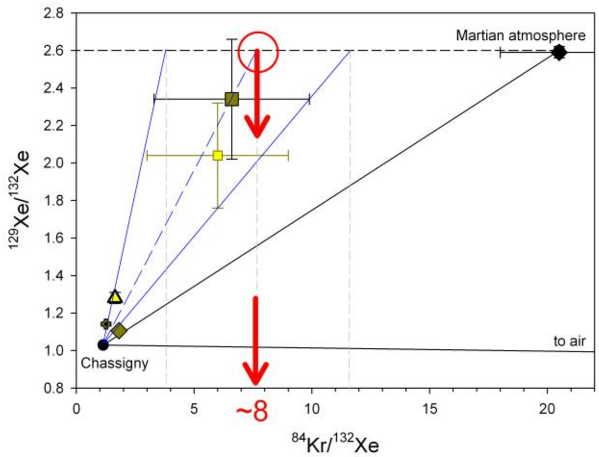

Figure 1. $^{129}Xe/^{132}Xe$ vs. $^{84}Kr/^{132}Xe$ in gas extracts from the nakhlite meteorite Lafayette, corrected for Earth atmosphere contamination ('air'), as described in [36]. Within uncertainties, the data suggest that Lafayette's noble gases are a mixture of Martian interior and elementally fractionated Martian atmosphere with $^{129}Xe/^{132}Xe$ of the Mars atmosphere, and $^{84}Kr/^{132}Xe$ of ~8. Data points from [1,24,40] [iddingsite as yellow square; corrected as brown square],[36,41-43].

nakhlites, however, show that they do not lie along this mixing line, but are all enriched in ^{129}Xe compared to shergottites with the same $^{84}Kr/^{132}Xe$ ratio.

The nakhlite fractionated atmospheric component is best investigated in single phase experiments, because they allow to assign the measured signature to a specific phase more precisely than stepwise heating protocols.. To date, only one measurement of the alteration phase in the nakhlite meteorites has been reported: Lafayette 'iddingsite' [24], which corresponds to the saponite-siderite bearing reddish-brown vein fillings described in [16]. [36] used those data, and in ddition olivine with Martian alteration, bulk rock, and cleaned mineral separates to show that the data fall (within uncertainty) on a mixing line between the Martian interior component (Chassigny; [1]) and a component with high $^{129}Xe/^{132}Xe$ and moderate $^{84}Kr/^{132}Xe$. Assuming that the pure component has the atmospheric $^{129}Xe/^{132}Xe$ = 2.6, then its $^{84}Kr/^{132}Xe$ ratio is ~8 (Fig. 1; [36]), far lower than the Martian atmosphere value of 20.5 [2]. This component, then, appears to be elementally fractionated Martian atmosphere observed in previous nakhlite investigations (1,25-28,30-33,35,41,43,44].

Evaluating the case with new and literature data. We are currently assemblinng a data base, which includes the available literature data on mineral separates and step heating experiments of the nakhlite Martian meteorites. To this we add unpublished data from Mainz [41] and University of Tucson (Barnes, unpublished data) to further investigate the nature of this component.

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