REVISITING THE ROLE OF GALACTIC COSMIC RAY COSMOGENIC ISOTOPES IN MARTIAN NOBLE GAS SYSTEMATICS.

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Introduction: As the most atmophile of elements, noble gases provide a unique tool for investigating planetary evolution, particularly since they also include the daughter isotopes of a number of lithophile elements. On the dense atmosphere terrestrial planets (Earth and Venus), noble gas systematics are dominated by a combination of hydrodynamically fractionated primordial noble gases of solar/meteoritic origin mixed with isotopes derived from a variety of radiogenic processes. Only the atmospheric helium system is spallation dominated, due to the rapid atmospheric loss of helium isotopes to space. The situation on Mars is very different. The atmospheric density is low at ~15g/cm^2, allowing an essentially unmodified galactic cosmic ray flux to reach the surface. As a result, unlike Earth and Venus, where the major spallation targets are carbon oxygen and nitrogen, the full range of lithophile elements are possible targets. The low total inventory of atmospheric noble gases also increases the potential impact of spallation derived isotopes. A final difference is that on Mars surface turnover is very slow, with major topographic features having lives of billions of years. This means that time integrated muon production must be considered for near surface martian sample material which is deep enough to be shielded from primary cosmic rays and secondary cosmic ray neutrons.

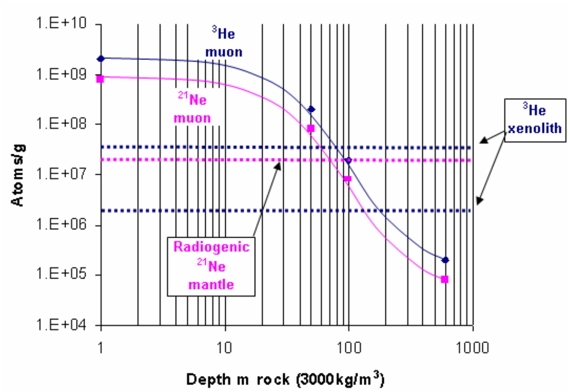
This work will therefore reassess the impact of time integrated spallation noble gases on the atmosphere, in the light of more recent spacecraft observations of the martian regolith and examine the depth at which muon produced noble gases cease to be an important component.

Method: Spallation driven production of a substantial fraction of martian atmospheric neon was first suggested by Yanagita and Imamura [1]. This role of spallation neon has been discussed by Lal [2], and the production of cosmogenic Ne, Ar, ^{80}Kr, and ^{128}Xe has been examined in detail by Rao et al [3] using both direct spallation and neutron capture on appropriate parent isotopes. Rao et al assumed a Shergottite regolith composition, modified for high chlorine and bromine concentrations in the light of the Pathfinder and Viking soil and rock analyses. Since the time of their work, orbiting gamma ray and infrared spectroscopy has indicated a more evolved mixed basaltic and andesitic composition with the implication that regolith spallation target elements, barium and the early lanthanides, are five to ten times more abundant than in the shergottite model. In addition Rao et al used a low, 0.5ppm, iodine concentration. However in an arid, oxidizing, photolytic environment volatile iodine compounds in the atmosphere can become fixed in desert soils as complex iodates. In the hyperarid Atacama desert, levels of 10^2-10^4 ppm are seen [4]. On earth, the volatile organic compound is primarily biogenic methyl iodide, but on Mars the volatile parent would be volcanically derived hydrogen iodide. Thick lava piles exist on mars, and their degassing on eruption would have provided large volumes of hydrogen iodide, as well as better known volcanic gases such as sulphurdioxide and the lighter hydrogen halides.

The model used is simple, based on a 300g/cm^2 spallation cumulative depth and a 450g/cm^2 neutron capture cumulative depth, both time integrated over 1Ga. This timestep was selected as a time period over which atmospheric density was too low to provide significant shielding for primary cosmic rays. The spallation and neutron capture figures of Hohenberg et al [5] were used. For simplicity, complete degassing of the regolith is assumed and the resulting GCR derived isotope is compared with modern atmospheric abundances. A 50% basalt, 50% andesite regolith composition with 100ppm iodine was used, and similar levels of chlorine and bromine enrichment to those utilised by Rao et al.

Cosmic ray muon penetration depths are very high with effects observable at shielding depth of 10^5g/cm^2. Cosmic ray muon production in the terrestrial setting has been reviewed by Niederman [6], and his depth production curves are used to derive muon produced noble gas synthesis at varying depths for Mars. These are then compared with typical ^{3}He abundances in modern terrestrial xenoliths. Integration times of 4Ga were assumed as atmospheric shielding would not be an issue unless the atmospheric density was more than 100 times present.

Results and discussion: The simple model confirms that modern martian atmospheric Ne may have a large spallation fraction in keeping with the findings of Lal and Rao et al. The high production of ^{80}Kr and potential high atmospheric cosmogenic fraction found by Rao was reproduced. In addition this work examined spallation produced ^{124}Xe and ^{126}Xe, and these were found to have potentially high spallation components in the modern atmosphere. If an Atacama-like iodine con-



The solid purple curves in the graph below shows the time integrated muon production of ^{21}Ne, the blue of ^{3}He. The horizontal dashed blue lines show typical terrestrial mantle xenolith high and low ^{3}He ranges (based on experimental values in [7]) .The dashed horizontal purple line shows 4Ga of time integrated mantle radiogenic ^{21}Ne taken from [8] .

centration mechanism operated on Mars then a substantial fraction of the modern ^{128}Xe inventory could be cosmogenic. In all cases assuming 100% regolith degassing, the high levels of spallation isotopes were sufficient to form 5 percent or more of the present day martian atmospheric inventory (^{21}Ne 50-250%, ^{22}Ne 25% ^{80}Kr 30-300%, ^{124}Xe 6%, ^{126}Xe 10%, ^{128}Xe 80-260% - where a range of values is given the discrepancy is probably due to differences in neutronics assumptions between sources). In reality these figures should be regarded as maximum values, as regolith degassing is unlikely to approach 100% efficiency, especially for deeper layers.

Muon produced cosmogenic isotopes would be significant to a depth of 100 to 300m from the point of view of mantle xenolith noble gases (see figure).

The potential high spallation contribution to the martian atmosphere from regolith derived noble gases offers a unique tool to assess both atmospheric loss and regolith alteration/degassing on a billion year or more timescale. However, before this can be done, precise measurements of modern martian neon, argon, krypton and xenon isotopes are needed, together with regolith iodine. This is because the Viking data lacked sufficient precision to accurately resolve certain isotopic ratios of interest, while martian meteorites have been heavily overprinted by spallation isotopes acquired in transit, especially in the case of the lighter gases. Another significant implication is that the high possible spallation component in certain martian atmospheric noble gas isotopes indicates that caution is needed, both in making corrections for transit spallation gases, and for assessing the gradient of mass dependent hydrodynamic fractionation in Mars atmospheric evolution models that use a solar/meteoritic starting composition.

Determination of martian mantle ^{3}He/^{4}He would give an interesting insight into martian primordial volatile retention, and the timing of such retention during the accretion of a terrestrial planet. Targeting of intrusive rocks at depths of a few metres or more should prevent problems due to primary spallation and secondary neutron noble gas production. Unfortunately the present work indicates that muon derived cosmogenic noble gases will be present in significant quantities relative to ^{3}He (and ^{21}Ne) to depths of 100m or more. This makes sample retrieval of pristine xenoliths extremely difficult by conventional drilling. To obtain such samples recent landslide scarps or crater walls should be targeted. Vertical mini-tunnel boring-like machines in unlined self supporting holes could be considered, as could explosive formation of a sufficiently deep crater. Sampling of crushed and uncrushed specimen gases may also help in separating post-crystallisation spallation noble gases from fluid inclusion hosted pre-crystallisation gases. Also, if a young intrusive could be identified, it would alleviate many of the muon related problems.

References: [1] Yanagita S. and Imamura M. (1978) Nature 274, 234-235. [2] Lal D. (1992) GCA, 57, 4627-4637. [3] Rao M. N. et al (2002) Icarus 156, 352–372. [4]Greenwood N.N. and Earnshaw A. (1997) Chemistry of the elements 2nd Ed. [5] Hohenberg C. M. et al (1978) Proc. Lunar. Planet. Sci. Conf. 9th. [6] Niederman (2002) Rev. Mineral.Geochem. 47. [7] Stuart et al (2003) Nature, 424, 57-59. [8] Ballentine C.J. and Burnard P.G. (2002) Rev. Mineral.Geochem. 47.