

VOLATILE INVENTORY OF MARS. R. O. Pepin, School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455.

Elemental and isotopic abundances of atmophilic elements and molecules trapped in the glassy lithology of the EETA 79001 shergottite are in good agreement with Viking measurements of martian atmospheric composition(1,2). The data base for the 79001 glass is quite extensive: results from several noble gas studies(3-8), and from nitrogen(6,7) and carbon(9) analyses, are now available. The geochemical case for EETA 79001 in particular, and the SNC meteorites in general, as Mars derivatives is further strengthened by the fact that absolute number densities (particles per unit volume) of gases trapped in the 79001 glass and gases in the contemporary ground-level martian atmosphere *are essentially identical*(10). This remarkable observation, first made by Ott and Begemann(11), certainly sets stringent boundary conditions on details of the trapping mechanism, but these conditions are much more credible than the incredible coincidence that must be invoked in any scenario of non-martian origin.

This direct evidence for origin of the SNC meteorites on Mars, and for trapping of an unfractionated sample of martian atmospheric gases in the 79001 glass, provides a reasonable basis for comparing the martian and terrestrial atmospheres with more precision than that afforded by the Viking data set.

*Isotopes.* The  $^{20}\text{Ne}/^{22}\text{Ne}$  ratio, not measured by Viking, appears to be about 10; the average of two estimates(7,8) from the 79001 glass is  $10.1 \pm 0.7$ , close to the terrestrial ratio of 9.8. Kr and Xe compositions are non-chondritic; they are generally earth-like except for a small mass fractionation effect favoring the light isotopes, a much higher relative abundance of  $^{129}\text{Xe}$ , and evidence that the component structures of martian and terrestrial xenon are significantly different. There is no evidence for measurable amounts of fissionogenic Xe from either uranium or plutonium decay in martian atmospheric Xe. Ar composition is anomalous, although within the range of the recently revised value from Viking(2): the trapped  $^{36}\text{Ar}/^{38}\text{Ar}$  ratio of  $4.1 \pm 0.2$ (7) in the 79001 glass is strikingly lower than the values near 5.3 that characterize both the earth and major meteoritic gas carriers. A primordial martian ratio of 5.3 could in principle have been altered by some planet-specific process operating over geologic time, but we have not yet found one that works. A conceptually attractive possibility, cosmic-ray spallation of surface materials, would require irradiation of a planet-wide calcite deposit for much of the age of the solar system with the present galactic cosmic-ray flux in order to fit the data(7).

*Elemental Abundances.* There is a remarkable empirical relationship between martian and terrestrial abundances ( $[A]$ ) of  $\text{N}_2$ ,  $\text{CO}_2$ ,  $^{20}\text{Ne}$ ,  $^{36}\text{Ar}$ ,  $^{84}\text{Kr}$  and  $^{132}\text{Xe}$  in *observable* volatile reservoirs (atmosphere at maximum pressure for Mars, and atmosphere, hydrosphere, biosphere, and sedimentary rocks for Earth), which can be expressed as  $[A]_{\sigma} = 1.27 \times 10^{-4} [A]_{\text{earth}}^{0.865}$ . The average deviation from this correlation for the six volatile species is  $\sim 25\%$ . If the relationship also holds for  $\text{H}_2\text{O}$ , then the known martian water reservoir, the north polar cap, would contain an average of  $\sim 150$  meters of  $\text{H}_2\text{O}$  ice over its area, equivalent to a planet-wide 75 centimeter water column. The radiogenic gases  $^{40}\text{Ar}$  and  $^{129}\text{Xe}$  fall well off this correlation, in the direction of higher abundances for Mars.

Relative elemental abundance ratios of noble gases in the martian and terrestrial atmospheres, expressed as  $[M/^{130}\text{Xe}]_{\sigma} / [M/^{130}\text{Xe}]_{\text{earth}}$  for  $M = ^{84}\text{Kr}$ ,  $^{36}\text{Ar}$  and  $^{20}\text{Ne}$ , decrease with decreasing mass in a functional relationship of

depletion *vs.* mass that points to the operation of some type of mass-fractionating process. This suggests that Mars, or its protoplanetary feedstock, may have suffered mass-dependent noble gas losses from a reservoir that initially was compositionally similar to the Earth's. With this assumption concerning the initial reservoir, an episode of atmospheric escape early in the history of Mars could have generated the observed noble gas depletions; loss of a few hundred meters of water from Mars by hydrodynamic escape of photochemically-produced hydrogen would be required to yield these depletions(12). In the limit of negligible Xe loss during this episode of hydrodynamic escape, the noble gas inventory for Mars, prior to the onset of fractionating losses of the lighter gases, would have been  $\sim 1/70$  of the present terrestrial atmospheric inventory, or  $> 1/70$  if Xe was lost as well. There is no way in this model to further limit this number, or to address quantitatively the question of the "missing" martian volatiles compared to the terrestrial inventory. It may be that these volatiles as well were lost in hydrodynamic escape, during an earlier episode in which the hydrogen escape fluxes were so large that mass fractionation of the noble gases carried away with the hydrogen was negligible(12). Alternatively, they may never have been present, or they remain even now in the interior, sequestered in an extensive undepleted mantle untapped by outgassing processes over the lifetime of the planet.

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