

NOBLE GASES AS TRACERS OF THE ORIGIN AND EVOLUTION OF THE MARTIAN ATMOSPHERE AND THE DEGASSING HISTORY OF THE PLANET; T. D. Swindle, Lunar and Planetary Laboratory and Department of Planetary Sciences, University of Arizona, Tucson, AZ 85710.

Noble gas analysis of Martian samples can provide answers to a number of crucial questions. Some of the most obvious benefits will be in Martian chronology, using techniques that have been applied with success to lunar samples (^{40}Ar - ^{39}Ar ages and galactic cosmic ray exposure ages). However, these are by no means the only relevant noble gas studies possible. Since Mars has a substantial atmosphere, we can use noble gases to study the origin and evolution of that atmosphere, including the degassing history of the planet. This type of study can provide constraints on 1) the total noble gas inventory of the planet, 2) the number of noble gas reservoirs existing (related to the structure of Mars' interior), and 3) the exchange of gases between these reservoirs (related to the dynamics of the interior).

Comparison of terrestrial and SNC data

On Earth, there are at least two isotopically distinct noble gas reservoirs, the atmosphere (and most crustal rocks) and the source region of Mid-Ocean Ridge Basalts (MORB). The major distinction is that MORB noble gases are more radiogenic, i.e., are enriched in the decay products of the radioactive species ^{129}I (^{129}Xe) and ^{40}K (^{40}Ar). This suggests that the MORB source region (presumably the upper mantle) has been extensively degassed while a significant amount of ^{129}I (with a 16 m.y. half-life) was still present, which would require an intense early outgassing [1]. There are also suggestions that some hot spots (e.g., Loihi Seamount) contain noble gases from a third component, isotopically similar to the atmosphere (except for He and small differences in Ar), and postulated to represent the undegassed lower mantle [1].

Data from SNC meteorites suggest that the relationship of the various noble gas reservoirs on their parent body is different from that on the Earth. The gases in the Martian atmosphere (and the glass in EETA 79001) are far more radiogenic than the terrestrial atmosphere. However, Chassigny contains Xe that is less radiogenic than either the terrestrial atmosphere or the gas in EETA 79001 glass [2]. And stepwise heating experiments on EETA 79001 glass usually yield at least one extraction with Ar that is less radiogenic than the Martian atmosphere or any terrestrial samples [3]. Thus, if the SNC meteorites are from Mars, Mars must also contain at least two noble gas components, with the atmosphere as the more radiogenic reservoir. It is difficult, but not impossible, to explain the occurrence of an atmosphere less radiogenic than the interior. One possibility is a volatile-rich veneer [4], another is preferential extraction of radiogenic noble gases or their precursors, perhaps as a result of differentiation [5]. In addition, the nakhlites contain gas that isotopically resembles a mixture of Chassigny and Martian atmosphere, at least at Xe [6]. This is difficult to explain as an actual mixture, both because of the relative elemental abundances [2] and because Mars, with its thinner atmosphere and lack of liquid water or plate tectonics, would not seem as likely as the Earth to have atmospheric noble gases available to mix with interior gases at any great depth. Clearly, we need a better understanding of the number, composition and location of Martian noble gas reservoirs.

Samples that would be useful

The first sample that would be necessary for this sort of work would be a sample of the Martian atmosphere, both for modeling and also to verify that the gas in EETA 79001 glass is really Martian atmosphere. Although it is possible that such analyses could be made with suitable precision in previous (non-sample return) missions, the amount of atmosphere required is not large. One cubic centimeter of Martian atmosphere at ambient (Martian surface) pressure contains an amount of noble gas comparable to that in a typical calibration run. Thus one liter would contain enough gas for duplicate analyses of the noble gases and other atmospheric species of interest.

To sample the interior of Mars, the ideal sample would be a fresh, quickly chilled lava (like the glassy margins on terrestrial MORB samples) or a xenolith in a mantle-derived lava (like the Hawaiian volcanoes). We may not be likely to find a truly pristine Martian sample, but we should look for the freshest basalt we can find, presumably from some of the youngest areas on Mars. Since Chassigny (age 1.3 Ga) contains a substantial amount of non-atmospheric noble gases, we have a reasonable chance of finding an appropriate sample. Conveniently, Olympus Mons and the other shield volcanoes in the Tharsis region have some of the youngest terrain on Mars and a deep (mantle?) source region (7). Thus, the best samples for this study would probably be rocks (not soil) from the flanks of Olympus Mons and/or other volcanoes in the Tharsis region.

It is also possible that, unlike the terrestrial situation, crustal noble gases may be isotopically distinct from those of the atmosphere. This might be determined from a soil sample from almost any site.

Finally, we might be able to set a limit on the degassing rate of Mars (and/or the rate of loss of atmospheric gas) by finding paleoatmospheric samples. On Mars, samples that might have been in equilibrium with the atmosphere at some time in the past include the proposed buried carbonates or water-deposited sedimentary rocks. It might be difficult to find either of these, although some sediments in Valles Marineris and in the ancient cratered terrain may be the result of water deposition (8). Also, the presence of gas similar to the Martian atmosphere in the shock glass in EETA 79001 suggests that shock could implant the ambient atmosphere into a sample. Thus, we might also get a sample of paleoatmosphere from shock glass from a returned sample associated with a crater of known, preferably old, age. Note that the time of the shock event that produced the glass in EETA 79001 is a matter of debate, but is probably within the last 200 Ma.

Rock and soil samples would probably need to be 0.1 to 1.0 grams for high-precision analysis with present-day equipment. The best samples would be ones that had never been exposed to galactic cosmic rays, which would require a burial depth of at least one meter. Samples with detectable galactic cosmic ray spallation products might still be useful, but the present limit on the amount of information we can extract from SNC meteorites is largely determined by their cosmic ray exposure history.

References: 1) Staudacher T. et al. (1986) Chem. Geol. 56, 193. 2) Ott U. and Begemann F. (1985) Nature 317, 509. 3) Swindle T. D. et al. (1986) Geochim. Cosmochim. Acta, 50, 1001. 4) Anders E. and Owen T. (1977) Science 198, 453. 5) Dreibus G. and Wanke H. (1987) Lunar Planet. Sci. XVIII, 248. 6) Swindle T. D. et al. (1987) Lunar Planet. Sci. XVIII, 982. 7) Carr M. H. (1981) The Surface of Mars; 8) Squyres, S. W. (1987) This conference.