ARGON DIFFUSION: IMPLICATIONS FOR METEORITES FROM VENUS AND MERCURY AND FOR VENUS OUTGASSING HISTORY; James N. Head and Timothy D. Swindle, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721

Abstract: Computer models of argon diffusion under Venusian and Hermian conditions show that Venusian meteorites, if ever found, should have anomalously young K-Ar ages, comparable to the transit time to Earth. We propose this as a signature of Venus origin. Hermian meteorites should not have anomalously young K-Ar ages unless they come from very near the surface (~cm) near the equator at the hot longitudes. Diffusion of argon produced in the upper crust over the age of the solar system could produce a substantial fraction of Venus' atmospheric argon reservoir, depending on the potassium abundance and permeability of the crust.

Introduction: We have been modeling argon diffusion under model ambient Venusian and Hermian conditions using the MacArgon 3.14 program described in [1]. The potassium-bearing phases that may be modeled are orthoclase, hornblende, phengite, muscovite, biotite, and phlogopite. Orthoclase appears to be the appropriate mineral phase to consider [2]. However, we checked the other phases, which have a range of diffusive properties, and found that only hornblende affects the details of our results. Volume diffusion is modeled. Once argon reaches a grain boundary it is assumed to be lost to the system. A time-temperature-pressure history is imposed on the system followed by a model bulk fusion age analysis made with the MacSpectrometer.

Our initial interest was directed toward determining if ambient Venusian and hermian conditions could alter the argon abundance in surface rocks, with a view towards providing a ready means of identifying these rocks should they ever fall to Earth (cf. the martian meteorite clan). We soon realized, however, that the Venus results had some potentially important implications for the outgassing history of Venus and the conclusions derived therefrom.

Venus meteorites: We model Venus surface conditions as 750K and zero pressure. Pressures up to 3kbars (equivalent depth 10km) were examined and had little effect on system behavior, given a modest (~5K/km) temperature gradient. Within the limits of the program, over a 100Ma model history there was no retained argon in any mineral phase except hornblende and phengite. For phengite we get a bulk fusion age of 0.2Ma and for hornblende a bulk fusion age of 59.7 Ma. Thus, any Venusian meteorite would have an K-Ar bulk fusion age of essentially zero when ejected unless the dominant K-bearing mineral phase was something as retentive as hornblende. Even for hornblende, the maximum (steady-state) K-Ar age is about 100 Ma. This, of course, ignores any argon produced in transit and any entrained atmospheric component. In principle, atmospheric contamination could be detected via isotopic analysis (the Venusian $^{40}Ar/^{36}Ar$ ratio is distinct from either Mars or Earth [3]). Hence the K-Ar age would be a direct measure of transit time. The end result is that Venusian meteorites should have K-Ar ages on the order of a few million years, much less than the surface age derived from crater counts.

Mercury meteorites: Mercury is somewhat more complicated in that its surface temperature varies considerably in time and space and is never as warm as Venus. Calculations by [4] show that at a depth of about 2 meters the temperature is constant and approximately 460K at the equator at the hot longitude (0 and 180 degrees). Assuming that this temperature structure has been constant over ~3Ga yields a null result: the model argon

ARGON IN VENUS METEORITES: Head J. N. and Swindle T. D.

loss is about 0.2%. At a depth of 4cm, the temperature is above 600K about 1/6 of the time. In a simple constant temperature model, more than 95% of the argon is outgassed, e.g., a 100Ma old sample gives a model bulk fusion age of 3.9Ma. This means that we should expect an altered Ar age for any (sufficiently lucky) Hermian meteorite from the hot longitudes. Material nearer the surface (~1cm) does get much hotter, however it is unreasonable to expect this sort of material to survive ablation on entry into Earth's atmosphere. Samples not from the hot longitude, especially those any distance from the equator, should have K-Ar ages that are essentially unaffected.

Venus outgassing: The Venusian results have potentially important implications for the outgassing history of Venus. It is clear that any argon produced *in situ* should volume diffuse quickly (*i.e.* faster than it can be replaced) from the grain to a boundary, thence even more quickly to the atmosphere. The limiting factor will be the depth to which the crust is permeable. For a K abundance of 1% (cf. [5]) and a "permeable crust" 7km thick (corresponding to a pressure of 2kbars [6]) we obtain ~1.4×10^{16}kg of argon over 4.5 Ga. This is equivalent to the current atmospheric reservoir. For smaller K abundances (e.g., [7,8]), it is a less substantial effect, unless the crust is permeable to an even greater depth. In [7], crustal ^{40}Ar is recycled into the mantle to be delivered into the atmosphere via magmatism. This leads to a trade-off between the crustal volume generated in catastrophic resurfacing events and magmatic flux between K and ^{40}Ar reservoirs. We find, however, that there is also a direct trade-off between diffusive crust thickness and crustal potassium abundance. This trade-off should set some upper limits to both parameters (see figure). Pollack and Black [9] discussed ^{40}Ar diffusion through the crust in the context of eliminating the crust as a reservoir for Venus' unreleased argon, but did not go so far as setting limits to K abundances.

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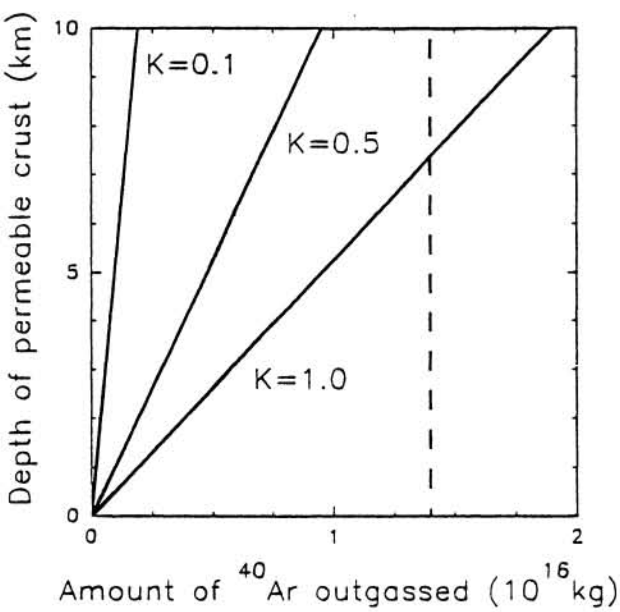

The amount of ^{40}Ar outgassed from the crust of Venus depends on the potassium content (given in weight percent) and the depth from which Ar can escape once it has left its host mineral. Solid lines are for 4.5 Ga of outgassing. Dashed line represents total amount of ^{40}Ar in Venus' atmosphere at present.