LOSS OF MARTIAN VOLATILES TO SPACE AND EVOLUTION OF CLIMATE: A CONSISTENCY CHECK. Bruce M. Jakosky (Laboratory for Atmospheric and Space Physics and Department of Geological Sciences, University of Colorado, Boulder, CO 80309, email jakosky@argyre.colorado.edu)

There has been a lot of discussion recently regarding the nature of the early martian climate as inferred from surface geomorphological and from geochemical arguments. I get the sense that a lot of people believe that these results are not consistent and that there is no consensus as to what early Mars was like. I would like to try to summarize what we do know and what we do not know from each approach, and what the real constraints are that are imposed by each technique.

1) Geomorphology:

Valley networks--These appear on the older surfaces (older than around 3.5 b.y.) and on the flanks of some of the younger volcanoes. There is a consensus that these involve liquid water at or near the surface and that they formed by runoff of precipitation or by sapping or by a combination of processes. Because they formed slowly (rather than catastrophically), they are presumed to involve recycling of water. No matter how you slice it, you need a warmer climate than at present. There is no agreement as to how warm or to the process by which the warming occurred.

Crater degradation--The craters on the older surfaces are heavily eroded (no ejecta, raised rim, or central peaks) and essentially all craters smaller than about 15-20 km have been removed. A few craters show intermediate degrees of degradation; these have gulleys on their interior walls, suggesting that runoff of water at the surface played a substantial role in the degradation process. There is a consensus that these require a warmer atmosphere although, again, there is no agreement as to how warm or by what process the warming occurred.

2) Aeronomy:

Present-day escape--Loss of species from the upper atmosphere to space is occurring at the present. Direct measurement of escaping O has been made from, and the inference of H escape from Mariner 9. In addition, our understanding of the distribution of species and of the physical and chemical processes within the upper atmosphere require present-day loss. Escape processes include Jeans' escape (for H), photochemically driven escape (primarily for N and O), and sputtering by solar-wind pick-up ions (for all species at the exobase). However, the rates of escape are uncertain, as are how they depend on the solar cycle.

Past escape--One can extrapolate the loss backwards through time based on the history of the solar euv flux and the solar-wind intensity, as both of these affect the structure of the upper atmosphere and the loss to space. There is considerable uncertainty, however, because of the uncertainties in the behavior of the sun, the time-dependent composition of the upper atmosphere, and whether Mars ever had an intrinsic magnetic field (that would stand off the solar wind and decrease sputtering loss). Model estimates of loss since 3.5-3.8 b.y. ago sug-

gest loss of hundreds of mbars of CO_2 and tens of meters of water, although there is considerable uncertainty.

3) Isotopic constraints:

Isotopic fractionation--Stable isotopes of the same element are lost at different rates because of their different masses; heavier species are less abundant at the exobase and, therefore, less readily removed. This results in preferential loss of the lighter isotope and an enrichment in the heavier isotope in the gas remaining behind in the atmosphere. Stable-isotope measurement from the martian atmosphere and from the SNC meteorites provides constraints on escape: D/H is five times terrestrial, $^{15}N/^{14}N$ is 1.7 times terrestrial, $^{38}Ar/^{36}Ar$ is 1.3 times terrestrial, $^{13}C/^{12}C$ is 1.05-1.07 times terrestrial, and $^{22}Ne/^{20}Ne$ is about 1.3 times terrestrial. In each case, the enrichment in the heavier isotope can only be explained plausibly by escape to space, and in each case at least half and more likely something like 90 % of the species must be lost to space. Because of the dependence on the solar wind and solar euv, a large fraction of the loss occurred between 4.0 and 3.5 b.y. ago.

Isotopic non-fractionation--$^{18}O/^{16}O$ is not enriched to the same degree as the other isotopes. Because oxygen should be lost as well, there must be an additional reservoir of oxygen with which the atmosphere exchanges; the polar caps cannot provide the proper abundances. The most plausible source of oxygen may be O in silicate minerals, with exchange with atmospheric oxygen occurring as a result of the presence of hydrothermal waters.

Conclusions:

The loss of around 90 % of the atmospheric gases through time is required by the isotopic data. This view is fully consistent with the inferences from the geomorphology that early Mars must have been somewhat warmer and wetter than present-day Mars. Neither approach at this time can uniquely determine the nature of the early climate, although new observations will help. Although we do not understand the actual cause of the warmer early climate (greenhouse? what gas? how warm?), it seems clear that the geomorphology requires it and that the escape theories and isotopic constraints provide an explanation of why the transition to a colder climate occurred.