MARS VOLATILE AND CLIMATE EVOLUTION: WATER THE REAL CONSTRAINTS? B. M. Jakosky[1] and R. J. Phillips[2]. [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309-0392 (bruce.jakosky@lasp.colorado.edu). [2]McDonnell Center for the Space Sciences and Dept. Earth & Planetary Sci., Washington University, St. Louis, MO 63130 (phillips@wustite.wustl.edu).

A large number of observations of the surface, atmosphere, geophysical properties, and solar-wind interactions of Mars, along with analysis of martian meteorites, are relevant to understanding the history of martian volatiles and climate. Our goal here is two-fold: First, to examine the different observations and to determine which ones provide the key constraints to understanding the nature of the martian climate system. Second, to examine all of the observational constraints together and to see if there is a scenario of volatile history with which they would be consistent; although this scenario may not be unique, our goal is to see if at least one exists. To this end, we have sorted the observations into (*i*) those relevant to the nature of the earliest atmosphere and climate, and the connections between the early climate and the geology and geophysics of the planet, (*ii*) understanding the processes by which the atmosphere can (and has) evolved and the timing of the changes, (*iii*) the geological evidence for crustal liquid water, (*iv*) and the nature of the present-day climate. Each of these topics is discussed below, and includes a list of the relevant observations and their implications; at the end, we summarize with a scenario that is consistent with all of the observations and with suggestions for new observations that would provide key additional constraints.

Nature of the early climate, and connections to geology and geophysics.

- Valley networks and high erosion rates on ancient surfaces suggest a warmer and wetter early climate.
- Valley networks tend to follow slopes that result from formation of Tharsis (or have the same age as those that do), indicating that Tharsis must have been nearly complete when valleys formed and that this had occurred by the late Noachian.
- Tharsis volcanism was likely to have been a source of outgassed CO_2 and H_2O, and therefore likely contributed to the early climate.
- Stripping of Margaritifer Sinus and northwestern Arabia Terra would have provided sediment to northern plains; erosion by water is the best mechanism, and debris would have filled the northern plains to a depth of ~120 m or more, obviating the sedimentological need for a northern ocean.
- Linear gravity anomalies may indicate buried ancient channels, which would have provided pathways to move water and sediment from the southern highlands to the northern oceans.
- Later outflow channels terminate at ~ 45°N, in region of polygonal terrain, and may indicate the greatest equatorward extent of any standing surface water.
- Tharsis trough is focus of fluvial activity throughout much of martian history, indicating the importance of the relationship between Tharsis and the climate.
- Predominantly ancient sedimentary rocks identified via their layering, although one cannot uniquely distinguish between aqueous and fluvial versus aeolian mechanism for their formation.
- Location of valley networks coincides with location of magnetic anomalies, with some exceptions.

Processes and timing in evolution of the atmosphere.

- Observed impact craters constrain impact erosion of atmosphere, likely indicating loss of 50-90 % of an early atmosphere since the time of onset of the geological record.
- Stable isotope ratios in modern atmosphere constrain time-integrated stripping of atmosphere by solar wind, indicating loss of up to 90 % of volatiles to space.
- Gas trapped in ALH84001 may represent atmosphere 3.9 b.y.a., and contains essentially unfractionated N, Ar; this constraints the timing of the bulk of atmospheric stripping to postdate 3.9 b.y.a. - Remnant magnetic anomalies indicate past intrinsic field, although the timing of the shut-off of the field is very uncertain; the intrinsic field would protect the atmosphere from the solar wind until shut-off, and the localized anomalies also protect the atmosphere locally until subsequently "erased".
- Substantial quantities of carbonate or sulfate minerals have not been identified on the surface, although they could be buried or distributed throughout the crust.

Geological evidence for crustal liquid water

- Weathering products are present in ALH84001 in percent amounts, and in other martian meteorites in trace amounts, indicating that liquid water has circulated through the crust.
- Weathering products in Lafayette indicate that liquid water was present within the crust ~600 m.y.a. or more recently.

- Outflow channels occur sporadically through martian history, requiring large crustal reservoirs of liquid water throughout history.

- Geologically young gullies and seeps are best explained as carved by liquid water

Nature of the present-day climate

- Liquid water is not stable at surface today, although this does not change the significance of any of the previous discussion.

- Vigorous seasonal cycles of CO_2, H_2O, and dust occur annually.

- Magnitude of obliquity oscillations, and presence of layering in polar deposits, suggest that climate change has occurred relatively recently and that it can occur (to some extent) even without liquid water.

What's the bottom line?

Water self-consistent (but not yet unique) scenarios that can be constructed for evolution of martian volatiles and climate? During some period of the Noachian the climate was sufficiently clement to allow significant fluvial erosion, possibly accompanied by precipitation. This warm period terminated abruptly at the end of the Noachian. This scenario involves outgassing by volcanism associated with ancient highlands and Tharsis, turn-on of solar-wind stripping of atmosphere associated with turn-off of the intrinsic magnetic field and "erasure" of some local magnetic anomalies, and loss of volatiles to space by solar-wind stripping and by impact erosion. There is no evidence for formation of substantial crustal deposits of volatile-bearing minerals.

This is a testable scenario, with new information likely to come from continued analysis of high-resolution images, determination of present-day isotope ratios in the atmosphere, continued spectroscopic/in situ search for carbonates, and sample evidence for history of weathering and of weathering products formed at different epochs.