THE “FLASHY” HYDROLOGY OF THE McMURDO DRY VALLEYS OF ANTARCTICA AND IMPLICATIONS FOR PAST AND PRESENT MARTIAN CRYOSPHERIC PROCESSES. M. R. Salvatore1, J. S. Levy2, J. W. Head3, and J. L. Dickson4, 1Dept. of Astronomy and Planetary Science, Northern Arizona University, mark.salvatore@nau.edu, 2Dept. of Geology, Colgate University, 3Dept. of Earth, Environmental, and Planetary Sciences, Brown University, 4Division of Geological and Planetary Sciences, Caltech.

Introduction: Geological evidence for extensive and long-lived aqueous processes at or near the martian surface have long been in conflict with paleoclimate models that have difficulty producing mean annual temperatures above 0° C [1-2]. These inconsistencies have led to several competing models of early martian climatic conditions, including the “warm and wet” and “cold and icy” models. We characterize the “flashy” hydrology of the McMurdo Dry Valleys (MDV) of Antarctica and present evidence of how locally optimized microclimatic conditions can support significant amounts of punctuated liquid water at or near the surface [3-5]. These environments are also able to support long-lived and stable ecosystems that are adapted to the unique flashy environmental conditions found in the MDV, suggesting that seemingly inhospitable mean annual climatic conditions may be poor indicators of the astrobiological potential of the martian surface.

The Great Martian Climate Debate: A warm and wet early Mars is challenged by the location of Mars in the solar system, a faint early Sun, and uncertainties about the density and composition of the early martian atmosphere [2]. Nevertheless, such a climate scenario has long been hypothesized based on the geologic evidence for fluvial channels, paleolakes, sedimentary deposits, and aqueous alteration minerals [6-7]. More recent studies have shown that the distribution of Noachian-aged fluvial channels is most consistent with the distribution of snow deposits in a cold and icy climate model than with rainfall in a warm and wet model [8-9]. Is it possible for cold and icy conditions to sustain sufficient melting to generate the observed mature fluvial and lacustrine features? How “cold” is “too cold?” These and other questions remain unanswered and are critical to understand early martian environmental conditions and habitability over geologic timescales.

Modern Mars is currently dominated by anhydrous environmental conditions. Although buried ice in the shallow subsurface is present at both mid- and high-latitudes where the relatively thin regolith cover prevents sublimation by solar heating, there is no direct evidence that this ice is actively melting or sourcing liquid water [10-12]. Debate continues as to whether modern features including gullies and recurring slope lineae (RSL) form through the episodic flow of liquid water or through dry processes [13-16]. How different must the climate of ancient Mars have been to generate the observed fluvial and lacustrine features at the surface? The MDV of Antarctica might help to provide important clues that can help us to understand the distribution, frequency, and activity of liquid water on the surface of Mars, including implications for habitability.

The McMurdo Dry Valleys of Antarctica: The MDV have long been used as an environmental analog to “modern” Mars because of their cold, dry, and stable environmental conditions that lack significant rainfall or the geographically widespread melting of snow or ice [17]. Similar morphologies identified in the MDV and modern Mars also hint at the potential for similar processes to be occurring (Fig. 1). Both Mars and the MDV have been shown to be dominated by shallow buried ice, overprinting of glacial processes, and limited surface alteration that, on a whole, is dominated by anhydrous oxidative weathering [18]. Mean annual temperatures in the MDV are less than -20° C and can drop below -60° C during the austral winter [19]. These conditions, along with <50 mm water equivalent mean annual precipitation, prevent any vascular plants or soil humus from forming anywhere in this region [20-21].

“Flashy” Hydrology of the MDV: Despite the
extreme “Mars-like” environmental conditions, liquid water is present throughout the MDV, resulting from locally optimized environmental conditions that promote snow and ice melt, overland and subsurface flow, and accumulation and preservation in permanently frozen lakes. High solar fluxes during the austral summer can cause the soils in the MDV to reach temperatures well above freezing. At the surface, soil temperatures have been found to reach temperatures of 25.7°C (nearly 80°F), while temperatures at 10 cm depth can also reach temperatures greater than 10°C [19]. These high temperatures can promote subsurface ice melting, which can wick to the surface to form water tracks in the soil and can also promote increased chemical weathering [22]. Direct solar heating of glaciers can also promote significant amounts of melting to form melt streams that run off of glaciers and onto the surrounding geologic landscape. These ephemeral glacial meltwater streams have been shown to discharge more than 80,000 m³ of water in an austral summer [23].

Implications for Habitability: The “flashy” nature of the MDV hydrological system fuels metabolically complex ecosystems that are dominated by microbial communities, mosses, algae, and microinvertebrates. Chemical alteration of rock and soil provides the necessary nutrients for these communities. When environmental conditions cannot support metabolic activity, these communities can enter a cryptobiotic state (Fig. 2). Photosynthetic communities have been shown to survive in cryptobiosis for more than a decade and are able to reactivate within minutes of rehydration.

These communities are an interesting analog for potential past (or present?) martian life, which must have been adapted to similarly extreme environmental conditions. Both environments experience high UV radiation fluxes, long durations of anhydrous conditions, large swings in daily and seasonal temperatures, and other limiting factors that, in their totality, are not found anywhere else on Earth [24].

Conclusions: The “flashy” nature of hydrological activity in the MDV of Antarctica provides a unique terrestrial analog for both modern and ancient hydrological activity on Mars [25]. While martian climate models continue to struggle producing mean annual temperatures greater than 0°C during early martian geologic epochs (long thought to have been a requirement to sustain sufficient fluvial and lacustrine activity), the MDV show that “flashy” and episodic environmental excursions can sustain a complex and high-volume hydrological system in the absence of seemingly evident mean annual conditions. In addition, the hydrology of the MDV is almost exclusively driven by glacial and cryospheric processes, not direct rainfall precipitation or regional snowmelt runoff. As such, this analog environment suggests that the surface of Mars may have seen significant amounts of surface or near-surface water long after the atmosphere was capable of sustaining widespread precipitation in any form.