MCMURDO DRY VALLEYS: EXPLORING ANTARCTICA AS A MARS ANALOGUE. Hunter Quintal[1], James Head[1], Ashley Palumbo[1], James Dickson[2], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912 USA (Hunter_Quintal@Brown.edu), [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125 USA.

Introduction: The current martian climate is hyperarid and hypothermal, similar in many ways to the climate of the Antarctic McMurdo Dry Valleys (MDV) [1]. This climate has persisted throughout the Amazonian (past ~3 Gyr) on Mars. Geologic evidence, including the widespread fluvial valley networks (VNs) [2] and lakes [3], suggest that the earlier Late Noachian and Early Hesperian (~3.7 Ga) climate may have been much different than today, with abundant stable liquid water at the surface and persistent rainfall to form these fluvial and lacustrine features [4]. In contrast with this geologic evidence, recent climate models have suggested that the early climate may have been "cold and icy", characterized by mean annual temperatures far below the melting point of water (~225 K), an adiabatic cooling effect [5], and ice distributed across the southern highlands [6]. In this climate scenario, transient or punctuated heating events would be responsible for ice melting, liquid water runoff, ponding at the surface, and formation of the VNs and lakes [7]. One possible transient heating mechanism that can produce significant meltwater is seasonal temperature variations and summertime melting [8]. Thus, it is possible that early Mars was also similar to the MDV: mean annual temperatures are far below freezing but the warmest part of the summer season is characterized by temperatures >273 K, permitting ice melting and runoff [6].

In this work, we consider the MDV as an analogue for early Mars to better understand the role of ice melting and liquid water runoff in a "cold and icy" environment. We explore the characteristics of the Onyx River [9–11], the longest river in the Dry Valleys that flows for approximately ~30 km, and compare to the characteristics of the martian VNs to determine whether these features could have formed through the proposed "cold and icy" climate. If the VNs appear inconsistent with the Onyx River, we consider that a "warm and wet" climate, characterized by abundant rainfall and runoff instead of snowmelt and runoff, may have been necessary for the formation of the VNs.

Onyx River Sources and Sinks: The Onyx River is a glacial meltwater-fed stream, and is an example of an endorheic dendritic drainage that forms annually from summertime ablation (sublimation and top-down melting) of multiple glacial toes that bound the valley. Meltwater from Lower Wright Glacier collects in the glacial Lake Brownworth (~300 m above sea level). When Lake Brownworth overflows, water flows into the headwaters of the Onyx River, continuing downslope in a meandering channel until it ponds in Lake Vanda (~160 m above sea level) (Fig. 1) [11].

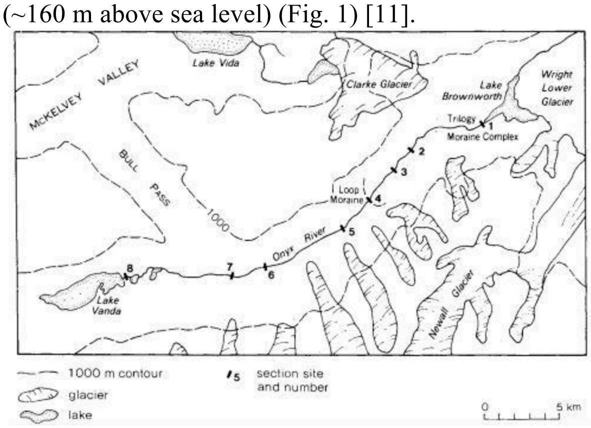

Fig. 1. Schematic map view of Southfork Valley Antarctica, highlighting the path of the Onyx River. From [11].

McMurdo Dry Valleys Climate: We utilized Long-Term Ecological Research (LTER) data [12] to determine which climatic factors appear best correlated with discharge rate at the Onyx River. Specifically, we focus on solar radiation, relative humidity, and temperature at the Lake Brownworth and Lake Vanda LTER stations. Data were collected from 1980-2015 [12].

Solar radiation and temperatures >273 K have a stronger correlation with discharge rate than relative humidity. This is consistent with previous observations of the Onyx River: the river is fed by glacial meltwater, not precipitation. Temperature and incident solar radiation are major controls on ice stability and top-down melting.

The river only flows during the summer season and begins and ends liquid water activity around the same time every year. We observe that discharge rates vary annually, directly reflecting peak summertime conditions; the Onyx River is characterized by the highest discharge rates during the years with the warmest summertime temperatures. This observation is consistent with observations at other locations in the Antarctic Dry Valleys which experienced peak stream flows during the anomalously warm year of 2002 [13]. Thus, the Onyx River, like much of the other MDV environment, can have dramatic responses to small climatic changes, leading to more intense flooding of the river in the warmest years. Following an unsually warm year, discharge rates can be relatively high for up to ten subsequent years, implying that the climate takes time to equilibrate back to its original state [13].

Implications for Early Mars Climate: River and stream systems in the MDV environment can experience noticeable changes in discharge and flow rate due to small increases in temperature, as was observed in data that was collected in 2002 [13]. If the martian VNs were formed in a temperature environment similar to the MDV, one can assume that they, too, would be largely influenced by small climatic perturbations because the major formation mechanism would be ice melting and runoff, not rainfall. It is possible that the structure of the VN systems reflects a flooding event that occurred during one or a few anomalously warm years, and not "average" flow conditions.

Onyx River Tributaries and Stream Order: The nature of tributaries and branching in a river can be used to identify stream order, which we estimate using the Strahler method [14]. There are approximately 30 tributaries to the river, all of which are sources from cold-based glaciers. Most tributaries of the Onyx River have Strahler stream order 2. The Strahler stream order of the Onyx River varies seasonally and we have measured values up to Strahler stream order 7 in high resolution CAMBOT imagery [15]. However, high resolution imagery allows for the identification of smaller tributaries [16] than can be seen in lower resolution imagery. For this reason, we have down-sampled the CAMBOT data to match that of the global martian VN database [2] to provide the most accurate comparison. In doing so, we find that the Onyx River is typically characterized by Strahler stream order 2.

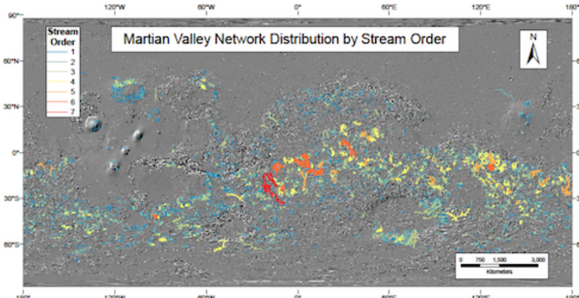

Fig. 2. Map of VN stream order, calculated by [2] using the Strahler method. VN distribution is overlain on MOLA hillshade topography.

Implications for Mars Stream Order: We produced a map of VN Strahler stream order using the VN database from [2] to compare the VNs to our analysis of the Onyx River (Fig. 2). Approximately 87% of the martian VNs have Strahler stream order 1 or 2 (blue and dark green lines in Fig. 2), implying that the majority of the VNs are either equally as developed or less developed than the Onyx River when analyzed at a similar spatial resolution. As previously stated, spatial resolution of image data can influence estimates of stream order because the smallest tributaries might not be visible at low resolution. In future work, some of the VNs should be analyzed at higher resolution to see if these systems, too, appear to have a higher Strahler stream order when observed at higher spatial resolution, or if they really do have mostly stream order 1 and 2. This will help to further determine if the majority of the VNs are consistent in stream order with the Onyx River, or if the observation made here is related to spatial resolution and the VNs are actually much more developed. If the VNs are much more developed, they may have formed in a warmer and wetter climate scenario, with persistent rainfall and runoff instead of intermittent ice melting and runoff [4]. Future work will also extend this analysis to compare stream order of terrestrial rivers in more clement climates with the martian VNs to determine which climate scenario produces rivers more consistent with the VNs.

Conclusions: We have characterized the climatic controls and stream order of the Onyx River to better understand the possible formation conditions of the martian VNs. Our analysis of meteorology at the Onyx River highlights the importance of temperature and solar radiation on discharge rate, largely due to the fact that the river is fed by glacial meltwater. As a result, anomalously warm years lead to significant increases in discharge rate, which would likely not be an important effect for precipitation-fed rivers. Thus, if the VNs formed in a temperature environment similar to the MDV, the structure of the VNs may have been largely controlled by a few unusually warm years that caused increased discharge rates through the VNs.

We have analyzed the Onyx River at a similar spatial resolution to the resolution used to map the VNs and find that ~87% of the VNs have Strahler stream order less than or equal to that of the Onyx River. This implies that the water availability, sources and sinks, and general climatic conditions during VN formation may have been similar to those of the MDV. If this is true, it is possible that the VNs formed through ice melting and runoff in a "cold and icy" climate. This conclusion agrees with previous analyses that suggest the distribution of VNs is consistent with melting and runoff at the edges of the predicted ice sheet in a "cold and icy" climate [6,7]. In future work, we will (1) analyze multiple VNs at higher resolution to confirm that this observation is not related to the spatial resolution used in this analysis, and (2) compare characteristics of terrestrial rivers from clement environments with the martian VNs.

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