ANTARCTIC DRY VALLEY STREAMS AND LAKES: ANALOGS FOR NOACHIAN MARS?. James W. Head[1] and David R. Marchant[2], [1]Dept. of Geological Sciences, Brown University, Box 1846, Providence, RI 02912 USA, james_head@brown.edu, [2]Dept. of Earth & Environment, Boston University, Boston, MA 02215 USA.

Introduction: Recent climate models [1,2] suggest that Noachian Mars may have been characterized by a "cold and icy", rather than a "warm and wet" climate [3]. Noachian valley networks and open basin lakes have been cited as key evidence for a "warm and wet" early Mars. Here we investigate fluvial and lacustrine processes in the Mars-like Antarctic McMurdo Dry Valleys (MDV) [4] to assess whether such processes, which take place in the absence of pluvial activity and with mean annual temperatues (MAT) well below zero, can serve as informative proxies for Noachian Mars [3].

Fluvial Processes: Fluvial processes in temperate climates dominate the evolution of the landscape due to the abundance of pluvial activity and the consequence of its drainage, chemical and physical erosion and transport, and its influence on a host of other processes. In the hyperarid, hypothermal MDV, however, there is no pluvial activity. Delivery of water to the surface environment is by direct snowfall in very small amounts (3-50 mm a^{-1} water equivalent in the MDV [5]) and from snow transported laterally off the polar plateau by katabatic winds. Snowfall can drift and be sequestered in topographic traps and wind shadows. Long-term snow and ice accumulation results in the formation of glaciers, and their seasonal melting represents the major source of liquid water for fluvial activity. Melting occurs only seasonally and all streams are ephemeral on seasonal and sometimes daily time scales. Due to localized sources and the immature topography of the MDV, stream order is very low, and streams tend to form ice-covered, closed-basin lakes.

The range of microenvironments in the MDV results in significant variation in the state and activity of water *within* the MDV [4]. In the *stable upland zone* (SUZ), temperatures are sufficiently cold both annually and seasonally that fluvial activity does not occur. In the *inland mixed zone* (IMZ), streams are minimal in number, drainage basins are by definition small, and streams are virtually all of first order. The shallow substrate is characterized by permafrost with an ice table at 15-40 cm depth beneath a regionally dry active layer. Recharge zones are limited to perennial and annual snow patches, some of which are trapped in alcoves and gully channels that undergo top-down melting. Initially, meltwater percolates vertically downward, wetting the dry active layer below, and then also migrates laterally to create a wetted zone along the margins of channels (the *hyporheic zone*).

Significant voumes of meltwater that infiltrate down from the surface may flow downslope along the top of the ice table (15-40 cm depth), wicking up and feeding the advancing hyporheic zone. Flow in the hyporheic zone along ephermal streams occurs at three scales: 1) locally in the stream bed, flux may be insufficient to overcome the infiltration capacity of the channel sediment, and meltwater percolates into the substrate only to re-emerge a few meters down-channel in springs at a topographic step caused by the presence of rocks ; 2) at the bases of slopes and near valley bottoms, wet-topped polygons form in topographic lows, creating a "swampy" spongy area where patches of water can be seen to emerge to the surface; 3) water may continue to travel along the ice table in the valley floor until it can intersect the surface, forming a local pond [6].

In the *coastal thaw zone* (CTZ), seasonal temperatures exceed the melting point of snow and ice in soils. Alpine and piedmont cold-based glaciers extend down into the CTZ and can undergo significant surface melting, creating the meltwater that feeds the vast majority of ephemeral streams and associated hyporheic zones, and ultimately drains into lakes. Meltwater generation is significantly influenced by the geometry of the glacier relative to solar insolation [7,8]. There is also evidence that significant melting can take place below the solid surface in the upper meter of glacial ice by absorption of solar radiation along crystal boundaries [7]. Glacial meltwater cascades off the edge of the ice, often in waterfalls, and drains downslope in streams. Streamflow is quite variable [9], depending on melting in the source region [7], and streams are of low order. Most streams flow into closed-basin lakes [10]. Since there is no pluvial activity, streamflow is restricted to the meltwater fluvial channel and associated hyporheic zone [6]. Chemical weathering is highly concentrated, especially in stream channels [11], and the large areas of terrain between channels are largely unaffected and unmodified by fluvial activity.

In some cases, epiglacial lakes [10] can serve as the source of streams and, because of short-term storage of liquid water next to the source, these can form longer streams and even rivers that flow for most of the summer season. Meltwater from Wright Lower Glacier is impounded behind a moraine complex, forming Lake Brownsworth. Drainage from Lake Brownsworth forms the ~35 km long Onyx River that flows into Lake Vanda, a closed-basin lake toward the western end of Wright Valley. The immature nature of the Onyx River retains a memory of recent antecedent climatic events and can thus be used to compare fluvial histories between valleys [12].

In summary, in contrast to temperate climates, fluvial processes in the MDV (and thus a host of weathering, erosion and transport processes there) are severely limited by the lack of rainfall. Fluvial activity is absent in the stable upland zone, seasonal and intermittent in the inland mixed zone, and often seasonally continuous, but ephemeral in the coastal thaw zone [4]. The limited sources of meltwater provide very local streams and hyporheic zones, serving to concentrate chemical weathering processes and biological ecosystems. The horizontally stratified hydrologic system means that localized meltwater is constrained to flow in a very shallow and narrow aquifer perched on top of the ice table aquiclude (Fig. 1).

Lacustrine Processes: More than 20 permanent lakes and ponds occur in the MDV [10] and, in contrast to temperate lakes, almost all are characterized by perennial ice cover up to 6 m thick, overlying liquid lake water. Ice cover serves to: 1) limit exchange of gases between the lake and the atmosphere, 2) restrict sediment deposition in the lake, 3) reduce light penetration, and 4) minimize wind-generated currents [13]. Lake levels have been rising in the recent past at about 15 cm a^{-1} [10], a trend interpreted to be due to a corresponding increase in summertime surface air temperature [14].

Chinn [10] subdivided lakes in the Dry Valleys into several hydrological types: 1) *Wet-based* lakes do not freeze to the ground during austral winter and have either permanent, seasonal or no ice cover; summer inflow of meltwater beneath the ice cover causes lake levels to rise seasonally and they lower from sublimation of the ice cover and evaporation of the summer meltwater moat. 2) *Dry-based lakes* include ice-block lakes that are permanently frozen through to the lake bed; ice thicknesses may far exceed those in wet-based lakes and such lakes rise by addition of meltwater by flooding on top of the ice surface, and fall by ablation of the surface. Some dry-based lakes may have a thin film of highly saline water at their base. 3) *Ice-free lakes*, such as Don Juan Pond, are very highly saline, and usually do not freeze even in winter. Chinn [10] further subdivided MDV lakes on the basis of their openness and associations: 1) *Enclosed lakes* have no surface outflow (*closed-basin* lakes); summer inflow is balanced by annual sublimation and evaporation and such lakes are usually warm, saline, and meromictic. 2) *Lakes with throughflow* overflow into outlet streams (*open-basin* lakes), have relatively stable levels, and are commonly not saline. 3) *Epiglacial lakes* are on or against glaciers.

How do these lakes differ from temperate lakes? First, MDV lakes lie on top of a 200-300 m thick permafrost layer; intuitively, one might imagine that these lakes should freeze solid due to mean annual surface air temperature of ~<-20°C. However, very finely-tuned conditions lead to the present characteristics in MDV wet-based lakes. Stratfication results from saline density gradients and the ice cover prevents wind mixing of lake water.

Where does the lakewater come from and under what conditions is excess meltwater produced to cause modifications in their levels? The dominant means of supply (meltwater) and loss (ablation) are clearly seasonally and climatically controlled. Throughout their recent history it is clear that small perturbations to the climate can result in large changes in the lake systems, often in non-intuitive ways [10]. Clearly, the main source of meltwater supply in the MDV is from surface melting of glaciers and snowbanks, but this is not a simple function of increasing MDV surface air temperature [10]. The observed positive correlation between increased lake levels and streamflow is thought to represent a complex relationship with the climate-related behavior of glaciers, specifically depending on the distribution of glacier area with elevation in the watershed [10,15]. As the H_2O melting temperature rises seasonally in altitude, glaciers are encountered and melting of their fronts will begin in a complex non-linear manner [7,16], feeding streamflow. The rate of stream flow will increase as seasonal warming brings the melting temperature up to the specific elevation that represents the maximum glacier area per elevation contour in the ablation zone [7,10,15,16].

Summary: Lakes and ponds in temperate areas are largely of pluvial origin and characterized by abundant vegetation, large drainage basins and higher order streams delivering rainwater. In contrast, the hyperarid, hypothermal conditions in the MDV mean that there is no rainfall, water sources are limited primarily to meltwater from the surface of cold-based glaciers, and drainage into lakes is seasonal and highly variable, being related to changing and sluggish response to surface ice hypsometry, itself a function of changing climate. Lake surface level fluctuations are caused by imbalances between meltwater input and sublimation from the lake surface ice and this sensitive balance tends to magnify even minor climate signals. This framework of seasonal melting and fluvial/lacustrine processes in an otherwise hyperarid, hypothermal Mars-like Antarctic cold-based non-pluvial environment [4,7,8,10] provides a baseline of environmental conditions to test the hypothesis that a "cold and icy" Noachian Mars [1,2] might produce the observed fluvial and lacustrine features [e.g., 17,18] during transient warming periods [3].

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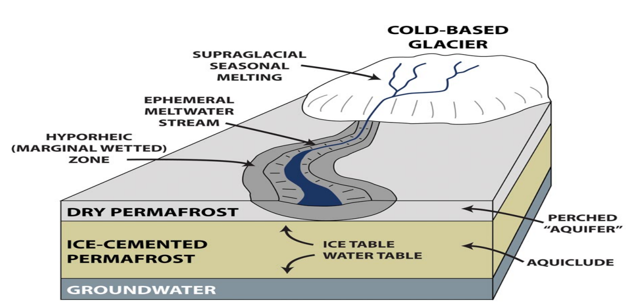

Figure 1. Antartcic MDV Hydrological System [4].