FORMATION OF CHLORIDE SALTS ON ANCIENT MARS: A FRAMEWORK FOR DEPOSITION ON AN ICY PLANET FROM ANTARCTIC ANALOGS. Ariel N. Deutsch[1] and James W. Head[1], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA (ariel_deutsch@brown.edu).

Introduction: Spectral data acquired by the Thermal Emission Imaging System, the Thermal Emission Spectrometer, and the Compact Reconnaissance Imaging Spectrometer for Mars have been interpreted to represent the widespread presence of chloride salt deposits on Mars, on the basis of a higher emissivity from 1260–900 cm^{-1} and a featureless spectral slope toward lower wave numbers [1]. Overall, the chloride deposits are globally consistent with the elevation trend of the southern highlands, and are locally found in topographic lows [1]. The deposits are primarily located within the ancient Noachian and Hesperian terrains [1], eras in which the climatic conditions are still in dispute: either warm and wet [e.g., 2] or predominantly cold and icy with punctuated warming [e.g., 3, 4].

While the chloride deposits are local in nature, their widespread distribution indicates that they represent a potentially global-scale process of ancient Mars. Many formation hypotheses have been proposed to explain the deposition of the observed salts, including precipitation in ponds, hydrothermal brines, efflorescence, and sulfides [1]. Previously these formation hypotheses have been framed in the context of an ancient warm and wet climate on Mars [2]. Here we present an interpretive framework to test the consistencies between deposition of chloride salts under the cold and icy Late Noachian Icy Highlands (LNIH) model [4, 5]. Because the chloride deposits are typically not found in proximity to phyllosilicates [1], they may be consistent with a cold and icy framework that is characterized by low temperatures and low water-to-rock ratios [6]. We use the Antarctic Dry Valleys (ADV) as an analog environment for disussing conditions in which salts can form in a cold and icy environment with minor melting. Understanding the formation environments and mechanisms of the chloride salts is critical in characterizing the history and evolution of the early martian climate and hydrology.

Chloride Formation Mechanisms: In this interpretive framework [5] we call on an ADV-like top-down melting process. On early Mars, transient warming can be attained through peak seasonal temperatures [e.g., 5], volcanism [e.g., 7], or impact events [e.g., 8], and can produce rainfall, snowmelt, and runoff. The resulting snow melt incises valleys and channels. 3-D global climate models demonstrate that precipitation patterns and snow accumulation in a cold and icy climate are positively correlated with the distribution of valley networks [4].

The formation conditions for chlorides under a cold and icy climate with transient warming are shown in ***Fig. 1.*** In ***Fig. 1A***, transient melting from peak annual temperatures produces runoff meltwater channels. Over time, a channel system develops and the hyporheic zone is defined as the regions beneath and lateral to the stream beds, where mixing of shallow groundwater and surface water occur (***Fig. 1B***). The hyporheic zone can mobilize salts, producing saline solutions and brines, and can locally redeposit salts in soil horizons and on the surface [9]. In ***Fig. 1C***, a more substantial episode of warming is induced by volcanism [7] or an impact [8], creating flood conditions in the region. Meltwater is trapped in topographic lows in the post-flood state, where aqueous alteration of the crustal material and/or evaporative concentration results in the concentration of salts (***Fig. 1D***). Such candidate overbank-type deposits are observed for some chloride occurrences on Mars (e.g., ***Fig. 2***).

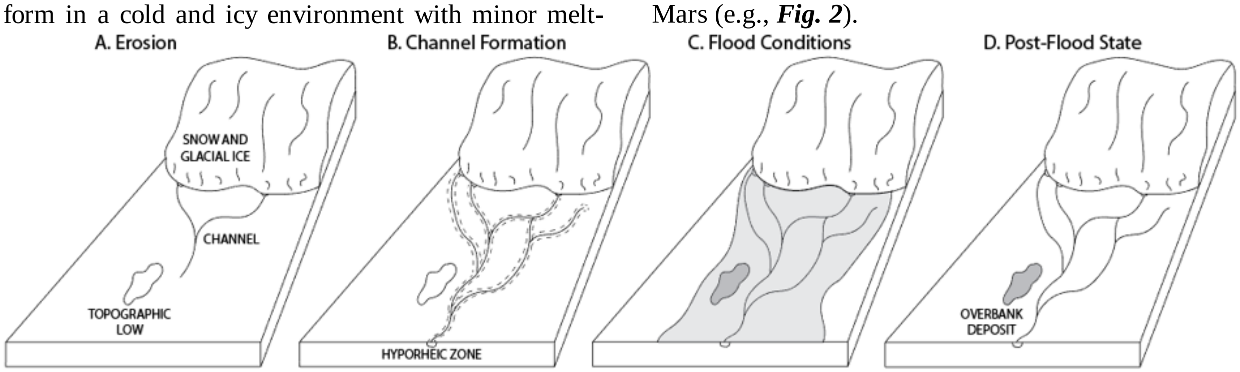

Fig. 1. Conceptual diagram for formation of salts in a cold and icy framework. **A)** Channel heads form off the ice sheet from runoff that is induced by temperatures >273 K. **B)** Channel network develops. The hyporheic zone experiences mixing of surface water and shallow groundwater. **C)** The channel system is flooded due to an episodic warming event. **D)** Water ponds in topographic lows, resulting in the precipitation and concentration of salts.

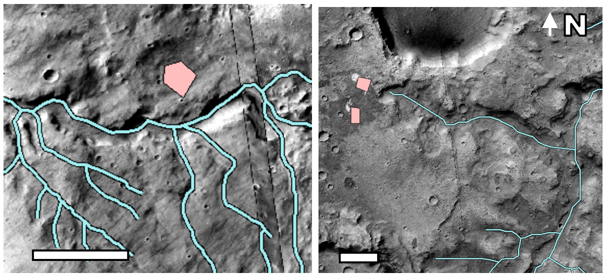

Fig. 2. Context of environments for chloride-bearing materials. Chloride polygons [1] shown in pink. Valley networks [10] shown in cyan. White scale bar is 10 km in each frame.

Antarctic Dry Valleys as a Terrestrial Analog: The ADV are a hyperarid, hypothermal environment that provide an important terrestrial analog of Mars. In the ADV, salts have been deposited via evaporation of early lobes of meltwater and become concentrated due to seasonal sublimation and dehydration [5]. Transported meltwater drains into topographic lows, collecting in lacustrine environments [5]. The local ponds could contain significant amounts of solutes from both the erosion of surface salts and also water flushed from the hyporheic zone [11]. For terrestrial evaporite systems, the composition of the dilute water at the first stages of evaporation affects the resulting brine composition [12].

There is a gradient in soluble ion and dust content in Antarctic glaciers that decreases with elevation and distance from the ocean [13, 14]; however not all salts are derived from marine sources. For example, some ion concentrations originate in valley floors [15]. These salts can either remain in-situ, or wind-blown salts and dust from the valley floor can be differentially added to glaciers and redeposited across the Antarctic landscape [14]. Chloride samples in the ADV have been documented to be from both marine sources and crustal source species, including evaporates [15]. Thus, in our martian cold and icy framework, which lacks the presence of a large salty ocean, we limit our terrestrial analog site to continental sources of salts.

Time-lapse data and meteorological measurements in the ADV show that small amounts of meltwater and deliquescence are capable of producing brines [11]. We have continued to document the surface expression of evaporate salts in the ADV, comparing episodes of deliquescence and efflorescence of salts and with relative humidity (RH) and temperature data (***Fig. 3***). We find that episodes of deliquescence correlate with levels of higher RH and that episodes of efflorescence correlate with levels of lower RH. The measured summer Garwood temperatures (267–281 K) and RH levels (30–100%) are similar to peak annual conditions predicted for early Mars [16].

Observing this pattern at other locations across the ADV illustrates that this process is not a localized occurrence, but instead a widely distributed process that operates across the ADV within different microclimates and for different salt species (here, calcium chloride [17] and mirabilite [18]). Groundwater has not been observed as an input [11], and thus we suggest formation via surface water processes can be responsible for the formation of substantial salt deposits on early Mars, as well. Characterizing the conditions under which salts are deposited and preserved in the ADV allows us to test the consistencies of salt formation on Mars under the LNIH model [4, 5].

Here we have discussed a range of terrestrial mechanisms by which chloride deposits can be produced in a cold and icy climate, namely: 1) transported meltwater draining into topographic lows, 2) mobilization and deposition of salts in the hyporheic zone, and 3) deliquescence and efflorescence.

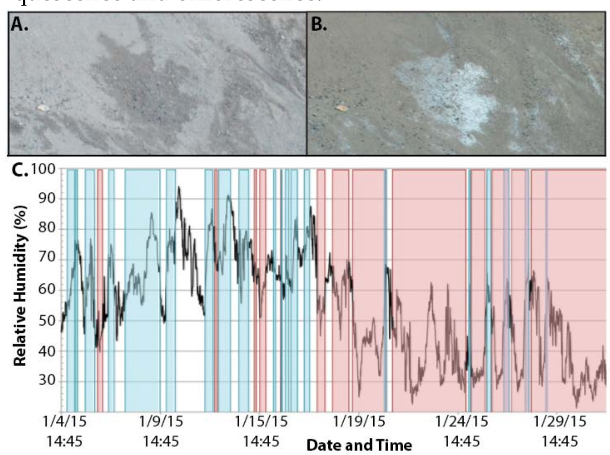

Fig. 3. Evaporite salts on the Garwood Ice Cliff. **A)** Solute salts absorb moisture from the atmosphere and form solution, resulting in a lower albedo. **B)** When the water in which salts are dissolved evaporates, a coating of salt is left behind on the surface. **C)** Deliquescence (blue) and efflorescence (pink) correlate with higher and lower RH, respectively.

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