CRYOGENIC EVAPORITE FORMATION AT LEWIS CLIFF, ANTARCTICA: A MARS ANALOG STUDY  
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Introduction: The discovery of substantial evaporite deposits at the Opportunity rover landing site in Meridiani Planum on Mars argues for significant interactions between liquid water and local rocks during some stage of the Martian past. However, evaporites can form under a dazzling variety of water/rock ratios, from long-term evaporation of expansive reservoirs to periodic recycling of water on the surface of individual rocks. On the warm and high water/rock ratio end, evaporites can form from evaporating pools of brine as large as oceans; on the cold and low water/rock ratio end, evaporites can form through extremely short-term but periodic recycling of water percolating across grain and rock surfaces. Between these two extremes is a broad continuum of processes that can produce evaporites - however, the cold, low water/rock ratio processes that may be most relevant to current day Mars are among the least understood. Exploring the full range of possible mechanisms is thus crucial for interpreting MER results and those from future exploration of Mars, and terrestrial analog studies offer an important approach.

This abstract describes the initial results of fieldwork now being conducted during December 2005 and January of 2006 in a moraine surrounding the Lewis Cliff Ice Tongue in the Transantarctic Mountains, Antarctica. Exploration of the region by meteorite recovery teams revealed that the moraine contains significant amounts of evaporite minerals in a variety of formats. The morainal regolith consists of a mixture of finely ground "glacial flour" and larger cobbles of locally exposed rock types. These include Permian-Triassic sedimentary sequences (the Beacon Supergroup) and later Jurassic intrusives and volcanics (the Ferrar Group). These sequences contain a wide variety of rocks, from igneous dolerites to cyclothemic coal and volcanioclastic sequences. Weathering efflorescences are common on rock surfaces, and holes dug into the morainal surface often reveal stratified layers of evaporitic materials. Some of these layers are dramatic in scope, reaching several meters in maximum dimension (Figure 1). Studies of a few small returned samples show that these blocks consist of masses of euhedral nahcolite (NaHCO3), trona (Na2H(CO3)2 • 2H2O), borax (Na2B4O7 • 10H2O) and an unknown hydrous sulfate species [1]. Jarosite, halite, calcite and phosphates have also been identified in recovered samples but have not yet been described in the literature.

Formation mechanisms: The proposed cryogenic formation mechanism is relevant to understanding similar evaporite production on Mars. On a few days during the Antarctic summer, the dark rocky surface of the Lewis Cliff moraine can warm to a few degrees above freezing, in spite of air temperatures around -10°C. This moraine conducts heat downward to its periglacial substrate, where small amounts of melting occur; local annual snow also melts where it contacts the moraine, as does ice within the moraine from earlier warming periods. The small volume of water produced from these sources infiltrates the porous moraine, leaching soluble components from the regolith to create a brine. Simultaneously, evaporation of this brine at the top of the moraine produces an upward flow gradient ("evaporative wicking") (Figure 2). As the brine approaches the surface, two processes can produce crystallization. The extremely low humidity of polar plateau air causes rapid evaporation and continuous precipitation of salts and other phases when conditions allow the liquid brine to reach the exposed surface of the moraine. Alternatively, the return to colder conditions often causes the rising brine to freeze, "squeezing out" soluble components to form solids. The resulting near-surface ice later sublimes away in the next warming event. The seasonal and annual periodicity of these warm events, coupled with small-scale changes in solar illumination, air turbulence and air temperature, all create a dynamic evaporative environment where precipitation is fostered at a wide variety of locations within percolation fronts in the regolith profile during a given warm period, resulting in a layered appearance to the evaporites.

A Martian Analog: The relevance of the Lewis Cliff evaporites to possible current-day and historical Martian production of evaporites is significant.

Figure 1. An exposed section of layered evaporites within the moraine at Lewis Cliff, Antarctica. The full layer is roughly 1 m thick and shows several laminations on the cm scale.
Evaporite production mechanisms requiring large volumes of fluid (such as seas, lakes or ponds) demand atmospheric conditions that are dramatically different than those observed today or in the recent Martian past. Models for the history of Mars suggest that the planet was warmer, wetter, and possessed a greater atmospheric pressure within the first billion years as compared with present conditions, and Mars may have had an active hydrologic cycle during those early times [e.g., 2, 3]. Associated with this hydrologic cycle would be the active chemical weathering of silicate minerals and the consumption of atmospheric CO₂ and deposition of carbonate and silica [4]. This process of consuming atmospheric CO₂ would eventually greatly diminish the greenhouse effect and result in cooling conditions on the planet. Once the Martian surface became too cold to support a hydrologic cycle, weathering processes would slow and therefore CO₂ uptake by silicate weathering would likewise be slowed. Simulated freezing and evaporating a hypothetical Martian ocean using the FREZCHEM model [5] showed that, depending on the alkalinity of the fluid, freezing would be sufficient to precipitate large volumes of evaporite minerals. As a consequence of this freezing process the Martian oceans then become sources of CO₂ instead of sinks.

In contrast, the production of evaporites by evaporative wicking requires only small, ephemeral volumes of water, does not require that water be stable very long, and can proceed with surface temperatures and pressures observed today. Such processes can sequester significant amounts of evaporitic materials through repetitive, low-volume cycling rather than massive single-stage volume reduction. There is growing evidence for current or recent short-term production of small volumes of liquid water at or near the Martian surface to form gullies [e.g., 6, 7 and references therein]. Although theories concerning the formation mechanism of these gullies continue to evolve, recent work strongly suggests that shallow, liquid-water aquifers are the most plausible source of fluid [7]. The depth at which water is stable as a liquid remains relatively unconstrained, given uncertainties in the thermal conductivity and ice content of the overburden and the salinity of the water itself. Furthermore, liquid water can theoretically be present in a wide variety of simultaneous settings, from abundant briny solutions in a free-flowing aquifer to thin films in pores and on grain surfaces within a wet soil. However, most authors agree that the environment is one of significant surface desiccation and repetitive condensation/coldtrapping and freeze-thaw cycling [e.g., 9, 10]. Whatever the source, daily surface temperatures, pressures and water vapor observations from a variety of spacecraft platforms strongly suggest transient availability and evaporation (or sublimation) of water under current conditions [11]. Periodic obliquity changes could have made these small volumes of water commonplace over 10,000-year timescales [12]. Given the relative stability of the Martian crust on timescales measured in millions of years, repetitive cryogenic cycling of small volumes of water suggest an environment where evaporative wicking can be a major mechanism for the formation of volumetrically important evaporites within the Martian crust.

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