THE ROLE OF SULFIDE WEATHERING IN FORMATION OF THE NORTH POLAR GYPSUM ON MARS. A. Szyrkiewicz, D. M. Borrok, and J. P. Merrison, Geological Sciences, University of Texas at El Paso, 500 W. University Ave., El Paso, TX 79968 (aaszyrkiewicz@utep.edu, dborrok@utep.edu), Mars Simulation Laboratory, Aarhus University, DK-8000 Aarhus C, Denmark (merrison@phys.au.dk).

Introduction: Hydrated sulfates such as gypsum occur within the low-elevation areas around the polar ice cap of Planum Boreum on Mars [1,2]. Although the highest concentrations of gypsum have been observed within the circumpolar dunefield of Olympia Undae, the hydrated sulfates appear to be an important component of the entire plain region around the polar ice cap [2]. Dry and windy conditions likely account for the widespread distribution of sulfate minerals in the polar region of Mars [3]. However, the presence of gypsum and hydrated sulfates implies some water activity in the past. Models attempting to explain the origin of polar sulfates on Mars include: i) weathering of basaltic sand in contact with snow containing sulfuric acid derived from volcanism, ii) precipitation of evaporites during major meltwater outflows, and ii) in-situ gypsum formation due to sulfide weathering enhanced by percolating meltwaters through the dunes [1,4].

In order to evaluate previous models, we focused on investigating the terrestrial sulfur (S) cycle in both temperate and polar conditions. Both systems involve the precipitation of sulfate minerals derived from surface snow/rain water interaction with bedrock containing sulfide minerals like pyrite. Given that volcanic centers are far away from Planum Boreum, we believe that sulfide weathering of aeolian basaltic sand (with minor sulfide abundance) better explains the formation of sulfate minerals in the polar region of Mars. We have used terrestrial analogue sites from the high mountains of the Rio Grande watershed (northern New Mexico) and a small glacier catchment in southern Spitsbergen (Svalbard Archipelago) to evaluate the quantities of sulfide-derived sulfate (SO$_4^{2-}$) in temperate and polar hydrological systems. In addition to our geochemical investigations of analog sites, we conducted a laboratory experiment designed to simulate gypsum transport over ~2,000 km to determine whether gypsum grains could remain intact during long-distance aeolian transport. If so this could help to explain its wide-spread distribution around Planum Boreum on Mars.

Terrestrial S cycle: Despite minor amounts of sulfides in most terrestrial rocks, sulfide oxidation generates elevated SO$_4$ flux into the hydrological system in both temperate and polar settings [5,6,7]. Sulfides are reactive minerals and rapidly oxidize in contact with snow/rain water and O$_2$. However, deposition and preservation of sulfate minerals derived via sulfide weathering in surface and near-surface environments appear to be greatly controlled by climate.

In temperate and wet conditions such as in the Rio Grande watershed, the SO$_4^{2-}$ fluxes attributable to sulfide weathering varied seasonally, from ~21,000 kg/day during the fall of 2009 (base-flow condition) to ~231,000 kg/day during the spring of 2010, after major snow melt. Winter conditions with large amounts of snow cover in high elevation mountain areas seem to accelerate sulfide oxidation in surface and near-surface environments. This appears to be controlled by physical environmental factors such as long-term snow/ice-bedrock interaction and the large surface areas of contact while snow accumulation increases over the winter season. The multiple episodes of partial snow melting and subsequent freezing allow for chemical weathering to occur. Afterward, the accumulated products of sulfide and silicate/carbonate/evaporite weathering are abruptly leached out into hydrological system in a final stage of snow melt during the spring. Because of prevailing wet and open topographic conditions in the Rio Grande watershed, the sulfide-derived SO$_4$ is transported downstream and after mixing with other SO$_4$ sources (e.g., evaporites, biological, atmospheric) discharges to the global sea (Fig. 1A).

In polar conditions such as in southern Spitsbergen, the sulfide-derived SO$_4$ fluxes are also significant, and in summer of 2008 accounted for 6,200 kg/day [7] in the glacier catchment ~250 times smaller than the studied Rio Grande watershed. Because of prevailing low temperatures, the freezing of glacier melt waters combined with evaporation lead to precipitation, accumulation, and temporary storage of sulfide-derived SO$_4$-rich salts on the surface of proglacial zones. This type of precipitation of SO$_4$-rich salts does not occur in the Rio Grande watershed, mostly because of wetter conditions that keep the sulfide- and evaporite-derived SO$_4$ continually dissolved in the aquatic system. Most of the proglacial SO$_4$ salts in Spitsbergen, however, are also subjected to a poor preservation in the proglacial setting, because these salts are re-dissolved either later in the same summer season during rain events or elevated glacial melt flow or during the following year’s snow melt (Fig. 1B).
**Polar S cycle on Mars:** Extensive glacial flows and glacier catchments have not been observed around the polar ice cap on Mars [3]. However, widespread occurrences of polygonal surfaces in various stratigraphic sections of the basin unit suggest that some thawing of polar ice and subsequent freezing were likely important during evolution of the aeolian dune system underlying the current polar ice cap [2,3]. From a hydrogeochemical point of view, the aeolian sediments of basaltic composition in this region possess many of the physical and chemical properties expected for enhanced polar sulfide weathering. These properties include the fine-grained texture of the rock particles, high porosity, and physical abrasion of aeolian particles, which can significantly increase surface grain-water/ice interaction [7]. Many of these physical factors are in good agreement with the processes controlling sulfide weathering in the high mountains of the Rio Grande watershed during the winter. The episodic thawing of surface/subsurface ice in the basin unit of Planum Boreum could have accounted for a great deal of chemical weathering of fine-grained basalt particles and led to deposition and accumulation of hydrated sulfates in the plains with circumpolar dunes during subsequent freezing. This likely occurred in similar way as it is observed in the proglacial zones of Spitsbergen where seasonal sulfide-derived SO$_4$-rich salts actually precipitate on the ground surface due to evaporation and freezing of glacial waters (Fig. 1B).

We infer that on Mars limited water activity and the prevailing dry conditions on the surface likely accounted for the broad aeolian distribution of hydrated sulfates around Planum Boreum (Fig. 1C). Our erosion experiments indicate that in spite of (or possibly due to) its softness, gypsum sand may be transported large distances without significant loss of mass i.e. dust/silt formation. In the course of 221 days of tumbling, simulating aeolian transport over a distance of ~2,000 km, gypsum barely eroded and no discernable decrease of grain size or change of grain shape was observed. Less than 3 % by volume of gypsum (>125µm) was broken down to dust particles (< 60 µm) during the experiment. In comparison to experiments using quartz sand, as much as 21 % of the quartz by volume was broken down to dust-sized particles under the same conditions. It appears that the harder and more brittle mineral, quartz, is more prone to impact fracture and therefore erodes faster as compared to the softer and perhaps more malleable mineral, gypsum. At least this was the case for our experiments.

**Conclusions:** Although Martian and Earth’s polar settings greatly differ with respect to geology (e.g., very different bedrock texture), snow/ice accumulation, and on the availability of water on the surface, the geochemical S cycle related to sulfide weathering seems to operate in a similar way on both planets. On Mars, however, drier conditions and episodic water activity led to larger gypsum preservation on the surface and its relatively fast incorporation into a sedimentary S cycle. On Earth, cold conditions favor sulfide weathering but prevailing wetter conditions on the surface likely account for long hydrological transport of sulfide-derived SO$_4$, with its limited incorporation into a sedimentary S cycle, and final deposition in the global ocean.