

**ACID DRAINAGE AND ASSOCIATED SULPHATE MINERAL FORMATION NEAR
EAGLE PLAINS, NORTHERN YUKON, CANADA:
ANALOGUE TO THE MERIDIANI PLANUM SULPHATES ON MARS**

Denis Lacelle¹, Richard Léveillé¹, Bernard Lauriol², Ian D. Clark³, Annick Doucet⁴

¹Canadian Space Agency, St-Hubert, QC, Canada; ²Dept. of Geography, University of Ottawa, Ottawa, ON, Canada; ³Dept. of Earth Sciences, University of Ottawa, Ottawa, ON, Canada;

⁴INRS, Quebec, QC, Canada; *denis.lacelle@space.gc.ca*

Introduction: Mg, Fe, Ca-sulphate minerals with imbedded hematite spherules was identified at the Meridiani Planum site on Mars by the Mars Exploration Rover Opportunity (1-2). The presence of the sulphate minerals including jarosite, gypsum, kieserite and hematite at Meridiani Planum and other locations on Mars (Valles Marineris, Aram Chaos, and close to the perennial northern polar ice cap) not only confirms the presence of past water in certain areas on the surface of the planet, but also implies that this water was acidic (3-4).

On Earth, there are only a few natural acidic environments that are being used as analogue to the aqueous processes in Meridiani Planum and to the early environment that generated the sulphate minerals. These include the Rio Tinto River acidic aqueous system in Spain (5) and the Iron Mountain site in California (6). However, these sites are located in warm environments, which fail to meet certain environmental properties that characterized Meridiani Planum when water was present on the surface of Mars, namely: semi-arid to arid climate regimes, prevailing freezing temperatures, and frozen soils forming a thick layer of permafrost (7). A better Mars analogue to the aqueous processes and sulphate minerals formation at Meridiani Planum could be found in the continuous permafrost in polar regions. There are a few sites in the Canadian Arctic where sulphate minerals are precipitating from natural acid drainage (i.e. near Eagle Plains, YT [8]; the Golden deposit near Fort Norman, NWT [9]; and at the Houghton impact crater, NU [10]). In this study, the hydrogeochemical processes responsible for acid drainage near Eagle Plains and its implication to early Mars aqueous geochemistry is examined.

Chemical and isotopic composition of waters: East of the Dempster Highway, near Eagle Plains, acidic Ca-Fe-SO₄ waters discharge from sandstone bedrock overlying pyrite-rich shales (8). The stream affected by acid drainage has a pH averaging 3.1 ± 0.3 , whereas the unaffected

drainage has a pH greater than 4.4. The acidity and elevated concentration of SO₄²⁻ (2872 ± 640 mg/L), Ca²⁺ (368 ± 47 mg/L), Fe_{tot} (133 ± 118 mg/L), Al_{tot} (66.3 ± 11.9 mg/L), Si (7 ± 4 mg/L) and trace metals, such as Zn²⁺ (4.8 ± 1 mg/L), in the stream progressively decrease downslope from the excavated area.

The low pH and high amount of solutes in the surface and ground waters impacted the depth of seasonal thaw at the affected site, which is more than twice that measured at the unaffected terrain. The active layer soluble ions at the affected site have a low pH (< 3.8) and are dominated by SO₄²⁻ (1611 ± 326 mg/L), Ca²⁺ (257 ± 44 mg/L), Mg²⁺ (53.7 ± 12 mg/L) and Al_{tot} (48.3 ± 2.2 mg/L) solutes and their concentration progressively increases with depth.

Hydrogeochemical modeling using PHREEQC predicted that the acidified waters are at or near saturation with respect to Fe-hydroxide and Ca, Fe sulphate minerals (Fig. 1), which is confirmed by the observation of gypsum, jarosite and Fe oxides along the acidified stream. Stable S-O isotope ratios of dissolved sulphate, with constant values ($\delta^{34}\text{S}$: $7.5 \pm 0.5\text{‰}$; $\delta^{18}\text{O}$: $-12.4 \pm 0.3\text{‰}$), provide evidence of microbial sulphate reduction (11) and possibly a microbial mineral precipitation. The acidophilic and psychrophilic microbial diversity present in the soil and water is currently being investigated.

Evolution of acid drainage: The high concentration of SO₄²⁻ and Fe_{tot} in the stream and active layer porewaters are the result of the oxidation of the pyritiferous shales under open system conditions, whereas the high amounts of Al_{tot} and Ca²⁺ are produced during the dissolution of clay minerals in the acidic environment and the dissolution of the carbonates / gypsum present in the shales respectively. Given that the solute concentrations of the acidified stream and active layer soluble ions versus SO₄ plot on very similar slopes (Fig. 2), it is suggested that the solutes are

being sequestered in the residual water during the freeze-back of the active layer, a process that operates in the near ground surface in periglacial regions.

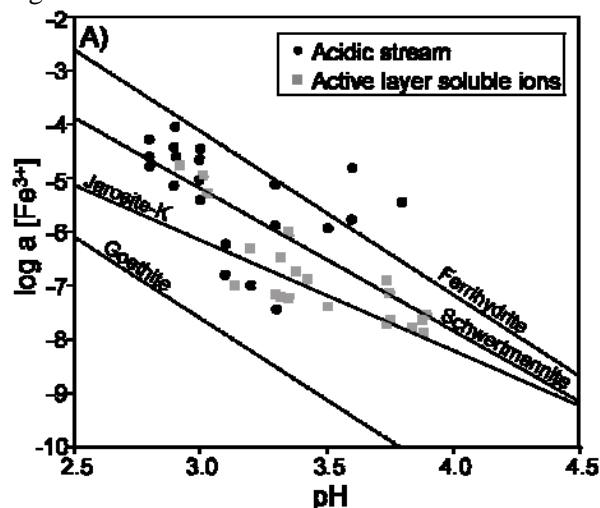


Figure 1: Log Fe^{3+} versus pH diagram for intermittent stream and active layer soluble ions.

After acid drainage was initiated, it is suggested that the seasonal freeze-thaw of the active layer played an important role in temporarily storing the acidity within the active layer. During the freeze-back of the active layer, gypsum, jarosite and Fe oxides minerals would precipitate, thus producing a large amount of H^+ that would be stored as sulphuric acid, or allowed to slowly circulate in a residual talik (confirmed by T measurements). During the thaw season, this acidity would be mobilized, thus enhancing further dissolution of clays and aluminosilicate minerals. Therefore, the seasonal freeze-thaw of the active layer in periglacial regions, a previously unrecognized process, might be an effective way of temporarily storing acidity, solutes and trace metals in the near-surface environment. However, some of the minerals could precipitate as efflorescent salts during the dry summer season.

Implication for Mars: The evolution of groundwater at Eagle Plains has potential relevance to early Mars hydrology and mineralization processes. At Eagle Plains, acidic Ca-Fe- SO_4 waters discharges year-long from permafrosted sandstone bedrock overlying pyrite-rich shales and precipitates gypsum, jarosite and Fe oxides minerals. A similar flowpath though permafrosted pyritiferous shales was also observed at the Golden deposit site near Fort Norman, NWT

(9). The fact that these natural acidic sites are located in regions where the environmental conditions are similar to early Mars, makes them very interesting analogue to further understand the formation of Mg, Fe, Ca-sulphate minerals on Mars.

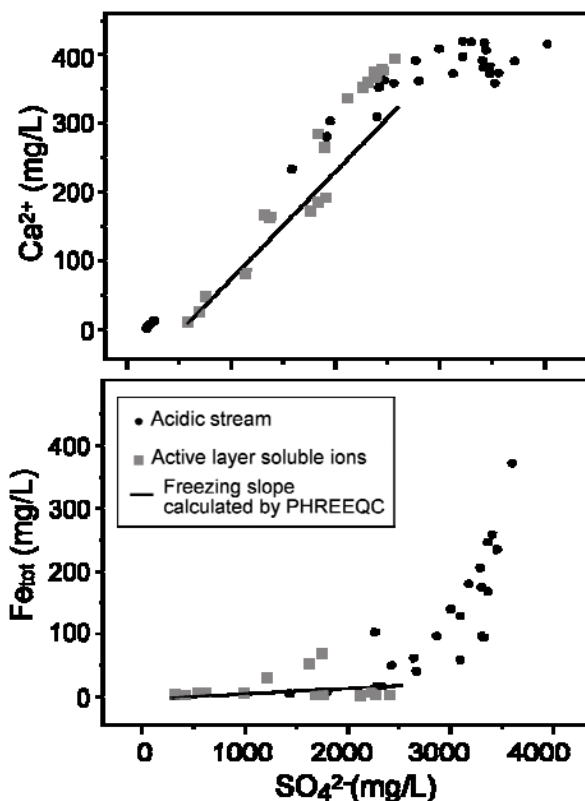


Figure 2: Variations of Ca^{2+} and Fe_{tot} versus SO_4^{2-} in the acidified stream and active layer soluble ions. The freezing slope was calculated using PHREEQC where the concentration of solutes was recorded by progressive freezing of the water.

References [1] Klingelhofer et al. Science 306, 1740-1745, 2004; [2] Rieder et al., Science 306, 1746-1749, 2004; [3] Christensen and Ruff, J. Geo. Res. 109E, 1-14, 2004; [4] Bibring et al., Science 307, 1576-1581, 2005; [5] Fernandez-Remolar et al., Plan. Spa. Sci. 52, 239-248, 2004; [6] Nordstrom and Alpers, The environmental geochemistry of mineral deposits, Rev. Econ. Geol. 6A, 133-160, 1999; [7] Marchant and Head, Icarus 192, 187-222, 2007; [8] Lacelle et al. Chem. Geol. 243, 157-177, 2007; [9] Van Everdingen et al., Can. J. of Earth Sci. 22, 1689-1695, 1985; [10] Leveille, R.J. GSA abstract 103-9, 2007; [11] Fritz et al., Chem. Geol. 79, 99-105, 1989.