THE BADWATER GABBRO AS AN ANALOGUE FOR THE WEATHERING OF MARTIAN BASALTS.

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Introduction: The best way to study the surficial processes of other planets, apart from direct observation through rovers and orbiters, is through the use of analogues. Studying the surface of Mars has become a popular topic as more sophisticated, direct measurements are undertaken using analytical techniques such as Laser Induced Breakdown Spectroscopy (LIBS) and Alpha Particle X-Ray Spectrometry (APSX) on board the Mars Science Laboratory (MSL) Curiosity Rover. Studies of Martian meteorites, observations from orbit and observations from rovers suggest the late crust of Mars is primarily basaltic with some felsic igneous rocks [1,2,3]. Through weathering, the basaltic crust was broken down and now comprises material analyzed by Curiosity. Therefore, investigating the possible effects of weathering on basalts in a low oxygen atmosphere is important in order to better understand data retrieved from rovers such as Curiosity.

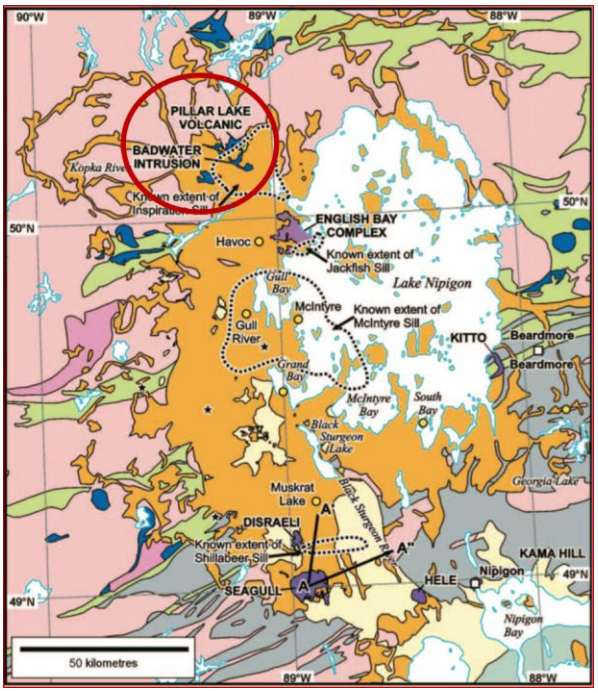

Figure 1: Geological map of the Nipigon Embayment, north of Lake Superior, highlighting the location of the Badwater Gabbro [4].

Objectives and Methods: Here, we aim to assess viability of the uppermost weathered zone of the Badwater gabbro as an analogue for weathering of basalts on Mars. Drill core samples were analyzed using optical microscopy, field emission scanning electron microscopy / energy dispersive spectroscopy (FE-SEM-EDS), inductively coupled plasma – mass spectrometry and atomic emission spectroscopy (ICP-MS & AES) with a focus on the effects of weathering.

Background: The Badwater Gabbro is a 1598 ± 1.1Ma, coarse-grained, intrusive unit that is disconformably overlain by the pillowed Pillar Lake Volcanics (PLV) (Fig. 1) [5,6]. The gabbro has a striking paleoweathering profile developed in its upper five meters. The age of this weathering profile is poorly constrained, but it is Mesoproterozoic, constrained between the age of the Badwater gabbro and an 1100 Ma Midcontinent Rift related sill, which cuts the Pillar Lake volcanics. Sandstones present interbedded with the volcanics are similar to those of the ~1400 Ma Sibley group, which outcrops to the south [6]. Data was collected from drill core samples obtained by East West Resources Corporation in 2004 during their search for PGE mineralization, near Armstrong, Ontario.

Results and Discussion: Trends in the whole rock geochemistry are some of the most telling features of the Badwater gabbro. Potassium was found to increase from 0.482%, 1612cm below the contact with the Pillar Lake volcanics to 2.508% to 3.573% towards the Pillar Lake volcanics contact (hereafter referred to as "the contact") (Fig. 2a). Similarly, the magnesium increased from 7.319% to 14.602% towards the contact (Fig. 2b). Aluminum and sodium showed little variance near the contact, with an average aluminum composition of 13.341±1.889% (Fig. 3a), and an average sodium concentration of 4.325±1.502% (Fig. 3b) were found.

Aluminum is immobile during weathering, so the aluminum data reflects the lack of overall loss or gain in the major elements. Therefore, it is likley that the trends in magnesium and potassium do not reflect mass loss in the system. Similarly, sodium follows the same trend as aluminum, but is a much more mobile element and is usually lost during weathering in subaerial or freshwater environments [7]. The upward increase in magnesium and potassium is unusual as these elements, in particular potassium, are commonly depleted during weathering. The upward enrichment in magnesium and potassium without a similar enrichment in aluminum suggests they were being added from above during the weathering process.

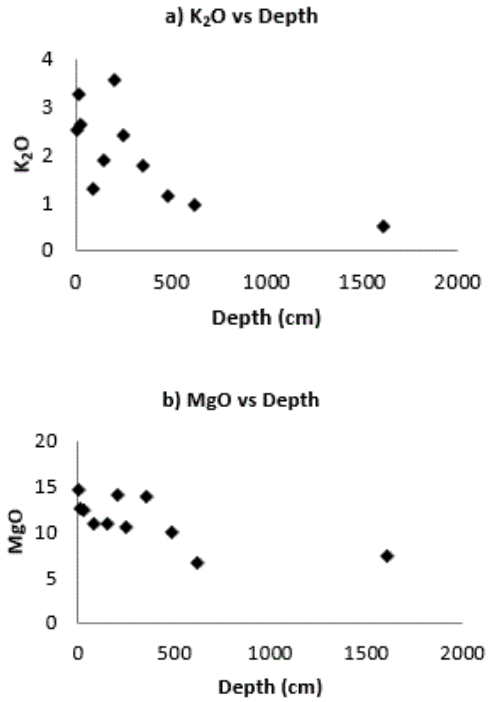

Figure 2: 2a) K_2O vs depth. 2b) MgO vs depth. Both preceding oxides exhibited increased concentration through the weathered zone towards the PLV contact, where 0 cm depth represents the contact with the PLV.

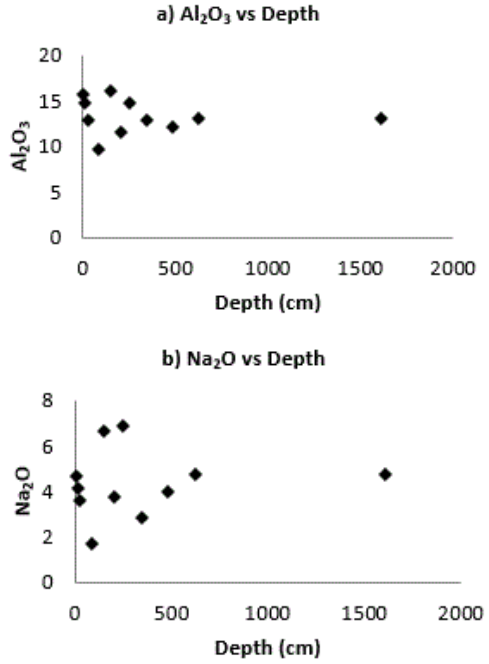

Figure 3: 3a) Al_2O_3 vs depth. 3b) Na_2O vs depth. Neither of the preceding oxides exhibit any notable increase or decrease in concentration towards the PLV contact, where 0 cm depth represents the contact with the PLV.

Sodium's lack of mobility, and the increase in magnesium and potassium suggests the host environment was likley saline. If the host environment was saline, then weathering may have occurred in the presence of a saline lacustrine system or groundwater system with close proximity to a saline lake; possibly resulting in the incorporation of magnesium and potassium into the loose sediment of the weathering profile. The overlying pillowed basalts of the PLV are a strong indicator that the host environment was lacustrine. Furthermore, the neighboring Sibley Group contains saline lacustrine systems [8], which attest to the development of the appropriate climatic conditions.

Saline lakes would have low amounts of sulfur thus invoking less of a restriction on dolomite production. The magnesium derived from the dolomite is the likely source of the anomalous magnesium values. These conclusions are consistent with the widely accepted magnesium concentrations and dolomitic evaporites in the Mezoproterozoic Sibley lakes [8].

Conclusions: Given that weathering is dominated by the presence of saline water in a low oxygen environment it has these characteristics in common with weathering on the Mars as its water mass decreased [9]. However, during this period on Mars the water became acidic resulting in iron being transported and iron sulfates commonly forming, whereas the non-acidic waters studied were capable of forming potassic clays and magnesium evaporites [10]. While the Badwater Gabbro may not make for a perfect analogue, its striking similarities to our current understanding of weathering on Mars makes it a strong, Earth based analogue site.

Referemces: [1] Sautter V. et al. (2015) Nature Geoscience, 8, 605-609. [2] Wray J.J. et al. (2013) Nature Geoscience, 6, 1013-1017. [3] Mezger K. et al. (2012) Space Science Reviews, 174, 27-48. [4] Hart T.R. & MacDonald C.A. (2007) Canadian Journal of Earth Sciences, 44, 1021-1040. [5] Hart T.R. et al. (2007) Canadian Journal of Earth Sciences, 44, 1021-1040. [6] Heaman et al. (2007) Canadian Journal of Earth Sciences, 44, 1055-1086. [7] Nesbitt H. (2003) Geochemistry of Sediments and Sedimentary Rocks: Evolutionary Considerations for Mineral Deposits, 4, 39-51. [8] Franklin J.M. et al. (1980) Canadian Journal of Earth Sciences, 17, 633-651. [9] Tosca et al. (2008) Science, 320, 1204-1207. [10] Tosca et al. (2005) Earth and Planetary Science Letters, 240, 122-148.

Acknowledgements: The authors acknowledge the funding contributions of the Canadian Space Agency (CSA) through the Astromaterials Training and Research Opportunity (ASTRO), and the technical support of the Lakehead University Instrumentation Laboratory (LUIL) team.