

MARTIAN SOIL ANALOGS FROM ANTARCTICA: CHEMICAL AND MINERALOGICAL WEATHERING SCENARIOS. P. Englert¹, J. L. Bishop^{2,3}, L. D. Hunkins^{2,3,4} and C. Koeberl^{5,6}. ¹University of Hawaii, Mānoa, HI, penglert@hawaii.edu. ²SETI Institute, Mountain View, CA. ³NASA Ames Research Center, Moffet Field, CA. ⁴University of South Florida, FL. ⁵Natural History Museum, Vienna, Austria. ⁶Department of Lithospheric Research, University of Vienna, Vienna, Austria.

This investigation of chemical and mineralogical weathering of Antarctic Dry Valleys soils found more extensive physical than chemical alteration. This may provide insights into weathering scenarios on Mars.

Introduction: Extensive remote and *in situ* chemical analysis of Martian soil and rock are available through Mars Odyssey and Mars Exploration Rover missions [1,2], and more detailed data are expected from Mars Science Laboratory. Mineralogical data of the surface has been obtained from the MGS Thermal Emission Spectrometer [3], from the Mars Express OMEGA [4] and the MRO CRISM [5] instruments. Differences exist in the overall chemical and mineralogical composition of Martian meteorites and Martian surface areas [6]. Only “Bounce Rock” in Meridiani Planum has a basaltic shergottite composition [7]. Some of these differences can be explained as alteration by physical or chemical weathering. Studies of soil and sediment alteration in cold and dry environments on Earth can contribute to understanding such processes on Mars. Similar to conditions on Mars, Antarctic Dry Valley (ADV) soils exhibit slow and complex weathering in a low temperature and dry environment [8,9].

Methods: Our work focuses on elemental abundance measurements and visible/near-infrared (VNIR) and mid-infrared (mid-IR) reflectance spectroscopy. Coordinated evaluation of Martian analytical results

with the chemistry and mineralogy of ADV soils will provide insights into weathering processes that may be relevant to Mars. For this study we characterized 24 samples collected directly adjacent to ADV Lakes Fryxell (F), Vanda (V), and Brownworth (B) by Neutron Activation Analysis, other geochemical analysis methods, and reflectance spectroscopy. Over 50 elements and chemical parameters were determined. The analyses complement previously obtained data for Lake Hoare sediment cores [10,11]. A total of over 60 samples with complete data sets, not including literature data, are available for interpretation.

Results: Reflectance spectra of ADV soils from Lake Fryxell in Taylor Valley and Lake Brownworth in Lower Wright Valley are shown in Figure 1. The VNIR spectra show Fe²⁺ (electronic) pyroxene bands for less altered soils/sediments. H₂O and OH bands and CO₃ bands are visible in more altered surface sediments. The mid-IR spectra show vibrational bands of quartz, pyroxene, and feldspar. Orthopyroxene/clinopyroxene ratios are ~40/60 for most samples with higher pyroxene abundances near Lakes Vanda and Brownworth.

The soils from each of the ADV Lakes F, V, and B selected for this study show distinct major and minor elemental abundance patterns and elemental carbon concentrations indicating that each lake environment may represent different soil formation and weathering

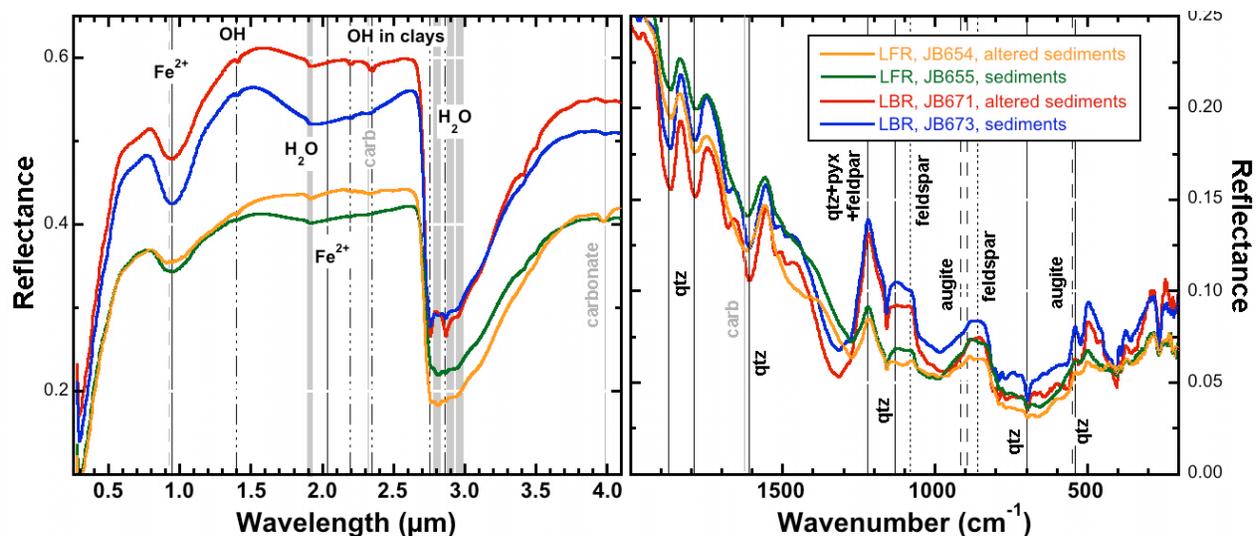


Figure 1. Reflectance spectra of Dry Valleys soils from the Taylor Valley near Lake Fryxell and the lower Wright Valley near Lake Brownworth. The VNIR spectra (left) show stronger Fe²⁺ electronic pyroxene bands for the less altered surface sediments that are replaced by H₂O and OH bands in clays and CO₃ bands in carbonate for the more altered surface sediments. The mid-IR spectra show vibrational bands due to the primary silicates (quartz, pyroxene and feldspar).

conditions. For example, K/Th ratios in the sample suite range from 522 to 5077, and are below 3000 for all but 3 samples, with Lake Vanda soils clearly distinguished by ratios systematically below 2000.

Important chemical parameters for provenance and weathering are K and Th abundances. Figure 2 shows K/Th ratios and K abundances [ppm] for ADV lake surface sediments, their potential source rocks, ADV Granitoids and Ferrar Dolerite [12,13], Mars Odyssey Gamma Ray Spectrometer (MOGRS) average regional and global surface areas [14] and Martian (SNC) meteorites [15,16]. For the purpose of comparison, K/Th is normalized to bulk planet ratios of 2900 for Earth and 5300 for Mars, following Taylor et al. (2006) [17].

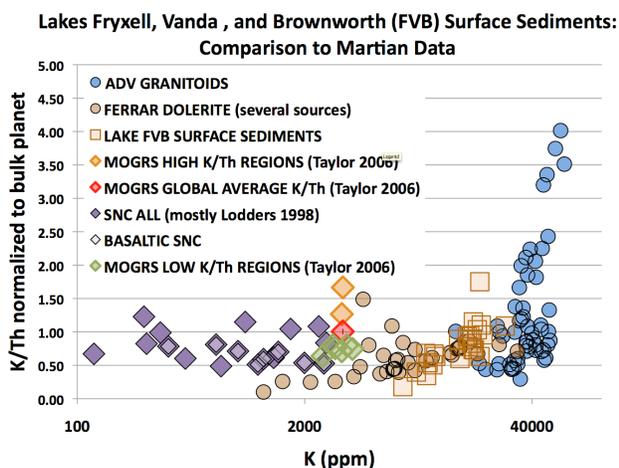


Figure 2. K/Th ratios for ADV samples compared with Martian meteorite and Martian surface data.

Normalized K/Th ratios for Lake F, V, and B surface sediments have only a slightly wider spread, but K abundances, as expected, are higher than those for Mars. To first order, different proportions of the source materials can explain the K/Th vs. K pattern for ADV lakes: a high K/Th and high K component of the ADV Granitoids, and a relatively low K/Th and K abundance component of the local Ferrar Dolerite. MOGRS K/Th ratios vary from 0.64-1.66. The SNC meteorite K/Th ratio range is somewhat lower. MOGRS K abundance data form a cluster at about 3000 ppm [13]. SNC meteorite K abundance data are very low and overlap with the MOGRS range only in a few instances. Based on the ADV provenance model, a major contribution to Mars soil development processes could be explained by mixing of several basic source materials. However, the counterpart to the role that ADV Granitoids play for Lake F, V, and B samples, a component with relatively high K/Th ratios and K abundances, is missing on Mars.

The Chemical Index of Alteration (CIA) can be used to assess weathering processes in ADV soils [18,19] by comparing source rock material CIAs with

those of soils. The CIA is based on mobility of major elements Al, Ca, Na, and K. Fresh basalts have a CIA of about 30-45 while completely weathered kaolinite has a CIA of 100. CIAs for ADV Lakes Hoare, F, B, V and other locations are low, for high sulfate samples in particular. Our results for lake ADV surface sediments show that mixing of source materials is dominating, while leaving the option of iso-chemical weathering open.

Applications to Mars: We have used the CIA approach (formally) to evaluate the relation between Gusev and Meridiani abraded (RR) rocks and undisturbed soils [20]. The formal CIAs of Martian rocks and soils are coherently low, indicators of little or predominantly iso-chemical weathering, probably in an acidic and dry environment [21]. However, care has to be taken in applying the formalism. The Martian CIAs, rock or soil, are SO_3 content dependent and corrections for this are under development.

ADV Lake Brownworth and Vanda samples, like Martian soil show chemical weathering signatures – the presence of clay minerals and water. A comparison of chemical data from Lakes Hoare, F, V, and B with data on local source rocks shows that mixing of source rock is a major factor in determining the composition of these soils/sediments. Chemical weathering is a minor factor.

Comparison to Martian chemical composition data may imply that mixing of source rocks is a very likely major mechanism of soil formation on Mars; however, a high K abundance source is not evident. Chemical weathering may be a less important process and is probably iso-chemical in nature. Developing a Chemical Index of Alteration for Mars that incorporates the high SO_3 levels may be useful.

References: [1] Gellert R. et al. (2004) *Science*, 305, 829-832. [2] Boynton W.V. et al. (2007) *JGR* 112, doi: 10.1029/2007JE002887. [3] Christensen P.R. et al. (2003) *Science*, 300, 2056-2061. [4] Bibring J.P. et al. (2005) *Science*, 307, 1576-1581. [5] Murchie S. et al. (2009) *JGR* 114, doi: 10.1029/2009JE003344. [6] McSween H.Y. Jr. et al. (2009) *Science*, 324, 736-739. [7] Zipfel J. et al. 2011 *MAPS* 46, 1-20. [8] Campbell I.G. and Claridge G.G.C. (1987) *Elsevier Science Publishers, Amsterdam*, (368pp). [9] Gibson E. K. et al. (1983) *JGR* 88, A912-A928. [10] Bishop J. L. et al. (1996) *GCA* 60,765-785. [11] Bishop J. L. et al. (2001) *GCA* 65:2875-2897. [12] Allibone A.H. et al. (1993) *NZ J. Geol. Geophys.*, 36, 299-316. [13] Elliot D.H. et al. (1999) *EPSL* 167, 89-104. [14] Taylor G. J. et al. (2006) *JGR* 111, E03S08, doi: 10.1029/2006JE002679. [15] Meyer, C., Jr. 2009 *Mars Meteorite Compendium JSC#27672*. [16] Lodders, K. (1998) *Meteorol. Planet. Sci.*, 33: A183-A190. [17] Taylor G. J. et al. (2006) *JGR* 111, doi: 10.1029/2006JE002676. [18] Nesbitt H.W. & Young G.M. (1982) *Nature* 229, 715-717. [19] Fedo C.M. et al. (1995) *Geology* 23, 921-924. [20] Brückner J. et al. (2008) *In: The Martian Surface* (Ed. J. Bell), 58-101. [21] Hurowitz J.A. & McLennan S. (2007) *EPSL*, 260, 432-443.