MINERALOGY OF ANTARCTICA DRY VALLEY SOILS: IMPLICATIONS FOR PEDOGENIC PROCESSES ON MARS.

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Introduction: The Antarctic Dry Valleys (ADVs) located in the Transantarctic Mountains are the coldest and driest locations on Earth. The mean annual air temperature is -20°C or less and the ADVs receive 100mm or less of precipitation annually in the form of snow [1]. The cold and dry climate in the ADVs is one of the best terrestrial analogs for the climatic conditions on Mars [2].

The soils in the ADVs have been categorized into three soil moisture zones: subxerous, xerous and ultraxerous [3]. The subxerous zone is a coastal region in which soils have ice-cemented permafrost relatively close to the surface. Moisture is available in relatively large amounts and soil temperatures are above freezing throughout the soil profile (above ice permafrost) in summer months. The xerous zone, the most widespread of the three zones, is an inland region with a climate midway between the subxerous and ultraxerous. The soils from this zone have dry permafrost at moderate depths (30-75cm) but have sufficient water in the upper soil horizons to allow leaching of soluble materials. The ultraxerous zone is a high elevation zone, where both temperature and precipitation amounts are very low resulting in dry permafrost throughout the soil profile. The three moisture regime regions are similar to the three microclimatic zones (coastal thaw, inland mixed, stable upland) defined by Marchant and Head [4].

Although considerable work has focused on soil formation in the ADVs [5], little work has focused on the mineralogy of secondary alteration phases. The objective of this study was to characterize the alteration mineralogy of selected ADV soils. The style of aqueous alteration (e.g., subxerous vs. ultraxerous) in the ADVs may have implications for "pedogenic" processes on Mars.

Soil Profiles: Representative soil profiles from subxerous and ultraxerous zones were selected for detailed mineralogy. A subxerous soil was sampled in the coastal region of lower Taylor Valley. The soil location was 77.60°S, 163.14°E at an elevation of 22 ± 5.5 m. The soil was covered by a desert pavement and formed in glacial till and possibly volcanic ash and lake sediments from Lake Fryxell. Parent materials included gneiss, schist, diorite, sandstone, and possible pyroclastic ash. An ultraxerous soil was sampled in University Valley, which is a high elevation valley located above Beacon Valley. The soil location was 77.86°S, 160.71°E at an elevation of 1683 ± 5.9m. The soil formed in glacial till. Parent materials include sandstone and diorite. Soils were described according to standard soil classification techniques [6]. Representative materials from each soil horizon were returned to the laboratory in a frozen state.

Methods: Soil samples were fractioned into five sand-sized (2-1, 1-0.5, 0.5-0.25, 0.25-0.09, 0.09-0.053 mm), three silt-sized (53-20, 20-5, 5-2μm) and two clay-sized (2-0.2, <0.2μm) fractions following the standard method of Jackson [7] with the exception that a high pH dispersion agent was omitted to minimize dissolution of amorphous aluminosilicates. Mineralogy of all soil fractions was determined by X-ray diffraction (XRD) analysis on a Scintag XDS2000 X-ray Diffractometer using CuKα radiation from 2-70 °2θ. Sand and silt samples were prepared as random-oriented mounts. Sand-sized fractions were ground by hand to <53μm prior to XRD analysis. The clay-sized fractions were saturated with Mg^{2+} and K^{+} and pipetted onto glass slides for preferred-oriented mounts. Mg-saturated clays were X-rayed at ambient temperature followed by glyceration, which causes 2:1 expandable phyllosilicates to expand to a characteristic d-spacing. K-saturated clay samples were X-rayed at ambient temperature, followed by heating to 110°C, 300°C, and 550°C. Expandable layer silicates may collapse upon K-saturation and subsequent heating, depending on their structure and unit layer charge.

Results: The Taylor Valley soil had a higher clay and silt content in the lower horizons compared to the near surface horizons (Table 1). This significant increase of finer particles with depth is likely due to translocation of clays and the wet environment at the soil and ice-cemented soil interface in the subxerous moisture regime. Liquid water flows vertically through the profile and horizontally in the soil along the ice-cemeneted soil boundary during the summer months. Mineralogy of the sand and silt fractions in the Taylor Valley soil is dominated by plagioclase and alkali feldspars, mica (mainly biotite), quartz, pyroxene, and amphibole along with trace amounts of kaolinite and vermiculite. Sand and silt mineralogy reflects the glacial till parent material containing diorite, schist, gneiss, and sandstone. Kaolinite and vermiculite in the coarse fractions is partly due to the omission of a dispersion agent during particle fractionation although these minerals may be alteration phases of feldspars and mica. Clay-sized fractions are dominated by X-ray amorphous or short-order aluminosilicates along with mica, feldspar, amphibole, kaolinite and vermiculite.

Surface horizons in the University Valley soil have higher clay contents than subsurface horizons (Table 1). Soils are frozen (i.e., below 0ºC) throughout the entire year; hence little liquid water (if any) flows through Univeristy Valley soils. Sand and silt fractions of University Valley soils are dominated by quartz with lesser amounts of feldspar, pyroxene, and illite. The sand mineralogy reflects the glacial till parent material containing sandstone (Beacon sandstone) and diorite (Ferrar dolerite). The silt fraction also contains trace amounts of laumontite, pyrophyllolite, chlorite, and kaolinite. Laumontite, pyrophyllolite, illite, and chlorite may have formed by hydrothermal alteration of feldspar during the intrusion of the Ferrar dolerite into the Beacon sandstone (e.g., [8]). Clay fractions are dominated by illite with lesser amounts of amorphous phases, quartz, pyrophyllite, laumontite, kaolinite, chlorite and hematite. Additional analyses are underway to quantify minerals (Rietveld analysis) and determine Fe mineralogy (Mössbauer spectroscopy).

Implications for Mars: Cold temperatures in University Valley prevent free flowing liquid water through soil pedons; however, aqueous alteration is occurring in the upper horizons of these soils as suggested by oxidation of Fe (hematite and likely nanophase Fe-oxides formation) and presence of X-ray amorphous materials. Higher clay content and Fe oxidation in surface horizons suggests oxidative, aqueous alteration occurs primarily at the surface. We hypothesize that the aqueous alteration is due to thin films of water on particle surfaces similar to the hypothesis recently suggested for the formation of aquoues phases in Mars Phoenix soils [Boynton et al., 2009]. Alteration and oxidation of upper soil horizons in University Valley soils provide a mechanism for the formation of Fe-oxides and possibly poorly crystalline aluminosilicates in Mars soils. Atmospheric water vapor transport into Martian soils interacts at surfaces of basalt particles (i.e., thin films) resulting in aqueous alteration and Fe oxidation. University Valley soils are excellent terrestrial analogs to characterize "pedogenic" processes that may be occuring in Mars soils, i.e., aqueous alteration by thin films of water.

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Table 1. Particle-size distribution and X-ray diffraction (XRD) mineralogy of a Taylor Valley subxerous soil and a University Valley ultraxerous soil [Q=quartz, F=feldspar, Px=pyroxene, Ab=amphibole, M=mica, V=vermiculite, K=kaolinite, Am=amorphous, I=illite, Pp=pyrophyllite, L=laumontite, C=chlorite, H=hematite, An=anatase].

Horizon	Depth (cm)	Size Fraction (wt %)			XRD Mineralogy		
		sand	silt	clay	Sand	Silt	Clay
Taylor Valley Subxerous Soil							
D	0-1	95	4	1	F,M,Q,Px,Ab,K,V	F,M,Px,Ab,Q,K,V	Am,M,F,Ab,K,V
B1w	1-9	94	4	2	F, M,Q,Px,Ab,K,V	F,Am,M,Px,Q,Ab,K,V	Am,M,F,Ab,K,V
2BCjjb2	9-12	94	4	2	F,M,Q,Px,Ab,K,V	F,Am,M,Px,Q,Ab,K,V	Am,M,F,Ab,K,V
2BCwb3	12-17	87	9	4	F,Q,Px,Ab,M,K,V	F,Am,M,Px,Q,Ab,K,V	Am,M,F,Ab,K,V
2BCo3	17-20	71	23	5	F,M,Q,Ab,Px,K,V	F,Am,M,Px,Q,Ab,K,V	Am,M,F,Ab,K,V
2BCz4	20-24	91	7	2	F,M,Q,Ab,Px,K,V	F,Am,M,Px,Ab,Q,K,V	Am,M,F,Ab,K,V
2C1	24-28	60	23	18	F,M,Ab,Px,Q,K,V	F,Am,M,Ab,Px,Q,K,V	Am,M,F,Ab,K,V
2Cfm2	28+	41	39	20	F,Px,M,Ab,Q,K,V	F,M,Px,Ab,Q,K,V	Am,M,F,Ab,K,V
University Valley Ultraxerous Soil							
Bffowz	1-9	83	11	6	Q>>F,Px,I	Q>I,Pp,L,F,Px,K,C	I>Am,Q,Pp,L,K,H,C
C1ffjjo	9-20	77	15	8	Q>>F,Px,I	Q>I,Pp,F,L,C,K	I>Am,Q,Pp,L,H,K,C
C2ffjj	20-34	82	14	4	Q>>F,Px,I	Q>I,Pp,F,L,K,C	I>Am,Q,M,Pp,L,K,H,C
Cfm	34+	81	16	4	Q>>F,Px,I	Q>I,Pp,L,Z,K,C	I>Am,Q,Pp,L,H,K,C,An