ZEOLITE FORMATION AND WEATHERING PROCESSES WITHIN THE MARTIAN REGOLITH: AN ANTARCTIC ANALOG. E.K.Gibson[1], D.S. McKay[1], S.J. Wentworth[2], and R.A. Socki[2], [1]SR, ARES, NASA-JSC, Houston, TX 77058 and [2]Lockheed Martin, C23, 2400 NASA Rd. 1, Houston, TX 77058 (everett.k.gibson@jsc.nasa.gov)

As more information is obtained about the nature of the surface compositions and processes operating on Mars, it is clear that significant erosional and depositional features are present on the surface [1]. Apparent aqueous or other fluid activity on Mars has produced many of the erosional and outflow features observed. Evidence of aqueous activity on Mars has been reported by earlier studies. Gooding and colleagues championed the cause of pre-terrestrial aqueous alteration processes recorded in Martian meteorites (e.g. [2,3]). Oxygen isotope studies on Martian meteorites by Karlsson et al. [4] and Romenek et al. [5] gave evidence for two separate water reservoirs on Mars. The oxygen isotopic compositions of the host silicate minerals was different from the oxygen isotopic composition of the secondary alteration products within the SNC meteorites. This implied that the oxygen associated with fluids which produced the secondary alteration was from volatiles which were possibly added to the planetary inventory after formation of the primary silicates from which the SNC's were formed. The source of the oxygen may have been from a cometary or volatile-rich veneer added to the planet in its first 600 million years.

Several Martian meteorites show evidence of low-temperature aqueous alteration products (i.e. phyllosilicates, carbonates, sulfates, hydrates, etc.) along with evaporite minerals. Wentworth et al., [6] argued that evidence of water on Mars could be seen from the petrographic record within the Martian meteorites. Wentworth et al. [6] also noted the Martian secondary environment apparently contains many of the components critical for life on Earth, such as water, potential nutrients dissolved in the water, organic phases [7] and temperatures compatible with those known to support biogenic activity on Earth. The Martian meteorites show a wide range of crystallization ages (from 4.5 Ga to 165 Ma) along with different ages of their secondary weathering products. Because of these differences, it is believed that conditions on Mars may have been favorable for water to be present throughout the history of the planet. The presence of water and its alteration products offer a unique venue to study pedogenic processes which may be operating on Mars.

Terrestrial weathering processes in cold-desert climates such as the Dry Valleys of Antarctica may provide an excellent analog to chemical weathering and diagenesis of soils on Mars. Detailed studies [8] of soil development and the chemical and mineralogical alterations occurring within a soil column in Wright Valley, Antarctica show incredible complexity in the upper meter of soil. Previous workers (ref. in [8]) noted the ice-free Dry Valleys on the Antarctic subcontinent are the best terrestrial approximations to contemporary Mars. Important similarities to Mars that exist in these valleys are: mean temperatures always below freezing (-20 ^{o}C), no rainfall, sparse snowfall rapidly removed by sublimation, desiccating winds, diurnal freeze-thaw cycles (even during daylight hours), low humidities, oxidative environment, relatively high solar radiation and relatively low magnetic fields. The Dry Valley soils also contain irregular distributions and low abundances of soil microorganisms that are somewhat unusual on Earth.

Physical processes-such as sand abrasion along with effects of frost and wind-are the dominant mechanisms of rock weathering the Antarctica. However, chemical weathering is also an important process even in such extreme climates. For example, [9] noted ionic migration occurs even in frozen soils along liquid films on individual soil particles. Also, [10] showed that water with liquid-like properties is present in soils at temperatures on the order of ~-80°C and[11] observed that the percentage of oxidized iron increases with increasing soil age and enrichments in oxidized iron occurs toward the surface.

In common with soils from other arid parts of the world, high soluble salt concentrations near the surface are characteristic of Dry Valley soils. The salts are typically concentrated immediately below the top of the soil horizons[8]. The presence of a light-colored band of possible evaporites beneath the duricrust at both the Viking 1 and 2 and Pathfinder sites suggests similar salts may also be present on Mars. In the Dry Valley soils, a sharp increase in iron oxides near the top of the soil columns, especially relative to fresh ferromagnesian minerals, demonstrates increased oxidation toward the surface. Evaporites indicate ionic migration and chemical activity even in the permanently frozen zone. Halite abundances decrease systematically from the salt layer near the surface to depths as great as one meter. The presence of evaporites indicates that chemical weathering of rocks and possibly soils has been active because some of the water soluble ions (Ca^{2+}, Mg^{2+}, K^{+} and CO_3^{2-}) in Antarctic evaporites originated by rock weathering [12].

Individual silicate mineral fragments in both the active and permanently frozen zones in the Dry Valley soils show evidence of chemical weathering. Characteristic effects of chemical weathering on the surfaces

of minerals in temperate climates is dissolution along crystallographically-controlled zones of weakness [13]. Such dissolution features are common on the surfaces of susceptible silicate fragments (silicates, amphliboles and pyroxenes) throughout the soil columns. Differential weathering along exsolution lamellae is present in some pyroxenes. Because such delicate features would probably not survive sedimentary transport, particularly by wind erosion and transport, they are evidence for *in situ* chemical weathering.

Zeolites identified in the Dry Valley soil columns must also be authigenic because they are fragile; i.e. they are euhedral, unabraded, and unfractured, strongly suggesting *in situ* formation. Their presence in the Antarctic samples is another indication that diagenetic processes are active in cold desert environments. Chabazite and other zeolites have been previously identified in the Dry Valley Drilling project rock cores but their origin was attributed to hydrothermal processes. Zeolites of sedimentary or pedogenic origin are fairly common in other terrestrial climates [14]. The chabazites in the Dry Valley soil columns are consistent with other occurrences in that they form in arid environments under saline, alkaline conditions [15].

The Dry Valley data [8] show that significant mineral corrosion, secondary mineral formation, and transport of soluble ionic species can occur within permanently frozen ground. They also show that extreme variation in chemistry can occur with depth in the upper meter or less. These data lend strong support to the need to sample Martian regolith to depths of at least a meter on future missions.

It is well known that the Martian surface conditions may be favorable for chemical weathering [16,17] and sufficient evidence is seen within the Martian meteorite suite that aqueous weathering processes operated throughout Martian history. Primary Martian silicates would be expected to be reactive minerals such as pyroxenes, olivines, and feldspars. Because of the possible existence of an extensive subsurface system of water ice or even liquid water [18], it seems likely that water is available to assist in the weathering of the primary Martian silicate minerals. Such weathering would result in the formation of clays, sulfates, carbonates, hydrates and zeolites. The formation of pedogenic zeolites under cold, arid Antarctic conditions opens the possibility of zeolites may also form in the Martian regolith. Terrestrial zeolites are especially common in soils derived from volcanic ejects [15], and such soils may be common on Mars. Zeolites are well-known for their volatile exchange and storage properties. Consequently, the possible presence of a significant abundance of zeolites in the Martian regolith might have a profound effect on the volatile budget of Mars. Specifically, zeolites could be a repository of atmospheric gases including CO_2, O_2 and H_2O. Changes in pressure and temperature might induce Martian zeolites to take up or release large quantities of volatiles. The abundant surface features (i.e. [1,19], indicating movement of fluid phases may be, at least in part, the result of release of volatiles from zeolites within the Martian regolith. In summary, zeolites must be considered a candidate for storage of significant quantities of subsurface waters-or other fluids on Mars.

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