COLD POLAR DESERTS: WEATHERING RATES, MECHANISMS, AND IMPLICATIONS FOR REMOTE SENSING OF MARS; Edward A. Cloutis, Department of Geology, University of Alberta, Edmonton, Alberta T6E 4S6

Introduction: Polar and alpine desert regions (cold deserts) offer the best terrestrial field analogues to weathering conditions on Mars [1]. A suite of rock samples from the Northwest Territories in Canada has been spectrally characterized in order to better understand the weathering processes prevalent in cold deserts and to examine the implications for remote sensing of Mars. Since these samples have presumably been subaerally exposed only since the last period of glaciation, they are useful for examining how relatively short-term physical and chemical weathering affect spectral properties.

The samples were collected from the Yellowknife Bay area (basalt) and Contwoyo Lake-Point Lake region in the Slave Province. The samples include a basalt (JMP2), an iron formation (SPLJ009), a volcanoclastic (4PLJ011), a schist (SPLJ001), and a granite (SPLJ001). Both weathered (exterior) and unweathered (interior) surface spectra of each sample were measured. It is known that weathering operate at low rates in cold, dry deserts. The unique environment of these regions affects the relative importance of different weathering processes [2]. The most common alteration phenomena which have been amply documented are the formation of ferric iron oxides/hydroxides, as evidenced by rust-colored staining on rock surfaces and in soils [3,4,5,6], and the formation of clays [7,8].

Results: Basalt: The weathered and unweathered surface spectra of a basalt are shown in Figure 1. The weathered surface spectrum shows strong evidence of ferric iron at shorter wavelengths—absorption edge near 0.53μm, and two broad absorption bands near 0.65 and 0.9μm. The wavelength position of the latter band (0.85μm) and its broadness are consistent with multiple hydrated ferric species such as goethite, ferrihydrate, and ferricyclate [9,10]. The interior surface spectrum suggests a greater ferric iron component and is similar to other unweathered basalt spectra [11,12]. At longer wavelengths both spectra are similar. The various absorption bands can be assigned to clay lattice-OH absorption bands involving both Mg and Al, as expected for a basalt. The presence of these bands in the interior surface spectrum indicates that the interior has been slightly metamorphosed.

Iron Formation: Sample SPLJ009 is composed of magnetite, chert, and siderite. The degree of visible weathering is small enough so that the underlying banding is still visible. The weathered surface spectrum is again dominated by ferric iron absorption features. The broad band near 1.9μm indicates that weathering has produced multiple hydrated species and/or poorly-crystallized phases (Figure 2). The interior surface spectrum is dominated by siderite, which exhibits a broad absorption band between 1.0 and 1.4μm. However, the expected strong carbonate absorption bands at 2.35 and 2.56μm [13] are absent.

Volcanoclastic: The weathered surface spectrum of a felsic-pyritic metatuff is again dominated by ferric iron bands at shorter wavelengths (Figure 3). A broad pyrite absorption band expected near 1μm is not evident. The weakness of various clay lattice-OH bands suggest that the formation of well-crystallized hydrated species has not been significant. The interior spectrum shows almost no evidence for ferric iron absorption bands. The broad feature centered near 1.05μm is characteristic of ferrous iron and pyrite.

Schist: The weathered and unweathered surface spectra of a cordierite-biotite knotted schist differ markedly from each other (Figure 4). In both cases there is a general lack of diagnostic absorption bands. The general reflectance rise towards longer wavelengths and lack of well-defined absorption bands in the exterior spectrum suggests that weathering has generated a number of poorly crystallized phases which absorb incident radiation over a range of energies, probably through charge transfers.

Granite: Granite differs from the other samples in its general lack of iron-bearing minerals. This is reflected in the lack of ferric iron absorption bands in the spectrum (Figure 5). Both the interior and exterior surface spectra show the same types of long wavelength absorption bands, indicative of aluminum.

Discussion: In spite of the presumed low rate and duration of weathering which has presumably affected these samples, exterior (weathered) and interior (unweathered) surfaces of the same sample vary from very similar (Figure 1) to radically different (Figures 4 & 5). It is apparent that significant spectral changes can be effected by even the low weathering rates prevalent in cold desert regions. The formation of ferric iron species results in the appearance of an absorption edge near 0.53μm, a shoulder or band near 0.64μm, and an absorption band near 0.9μm [9,10]. These features are most apparent in the most iron-rich samples such as basalt, iron formation and volcanoclastic. The reflectance spectra amply confirm the physico-chemical and spectral importance of ferric iron oxide/hydroxide formation in cold deserts.

Aluminum- and magnesium-rich lithologies give rise to Al-OH and Mg-OH absorption bands respectively in weathered surface spectra in cases where the absorption bands are resolvable. For example, the absorption bands present in the exterior granite spectrum at 2.20, 2.32 and 2.35μm can be assigned to Al-OH vibrations. There is no clear evidence for an Mg-OH absorption band expected near 2.4μm. This is consistent with the aluminum-rich composition of the granite.

A general lack of well-defined absorption bands attributable to specific hydrated phases indicates that cold desert weathering is generally not accompanied by the formation of well-crystallized phases, but that clay formation is nevertheless an important process. The broadness of the ferric iron absorption bands also suggests that poorly-crystallized phases are important. The formation of poorly-crystallized phases in cold deserts is consistent with interpretations of martian telescopic spectra as indicating semi-amorphous or amorphous phases such as palagonite [14].

The spectral changes associated with cold desert weathering include variations in overall spectral slope, the appearance/disappearance of absorption bands, shifts in absorption band minima wavelength positions, and changes in band shapes and intensities. Dramatic spectral differences between interior and exterior surface spectra are present even when weathered surfaces are thin enough so that underlying petrofabrics are still visible.

In spite of the small number of samples in the current suite, the data indicate that cold desert weathering of carbonates may be sufficient to render them virtually indistinguishable. In addition, the oxidation of ferrous to ferric iron proceeds regardless of whether the iron is derived from silicates (basalt), oxides (iron formation), carbonates (iron formation), or sulfides (volcanoclastic). It is clear that unweathered, interior rock sample spectra are generally not useful for the interpretation of remote sensing data for targets such as Mars which are subject to subaerial weathering.
COLD DESERT SPECTROSCOPY: Cloutis, E.A.

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References:

Figure 1. Reflectance spectra of interior and exterior surfaces of basalt sample JML2.

Figure 2. Reflectance spectra of interior and exterior surfaces of iron formation sample SPLJ009.

Figure 3. Reflectance spectra of interior and exterior surfaces of felsic-pyritic-metatuff (volcaniclastic) sample 4PL301.

Figure 4. Reflectance spectra of interior and exterior surfaces of cordierite-biotite knotted schist sample SPLT001.

Figure 5. Reflectance spectra of interior and exterior surfaces of granite sample SPLJ001.