REMOTE SENSING IMAGE ANALYSIS AT LEVIATHAN MINE, CA: A SEDIMENTARY SULFATE MARS ANALOG SITE.

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Introduction: The identification of various iron and magnesium sulfates in data from the Mars Exploration Rovers (MER), OMEGA on Mars Express, and CRISM on MRO [e.g. 1-5] provides the impetus to explore analog environments that produce these minerals on Earth. A number of mechanisms have been proposed as models of Martian surface conditions and given the diversity of surface locations on Mars where sulfates have so far been identified, a number of geochemical environments may be involved. It should also be noted that terrestrial analogs may address the geochemical and mineralogical constituents without necessarily mimicking the geologic and morphologic environment or alternately, that geomorphologic similarity to Mars does not usually incorporate similar geochemistry [6].

One of the most common areas where mineralogy similar to the acidic deposition environment inferred for the Meridiani Planum MER landing site occurs is in metal ore or other hydrothermal deposits that have been subject to alteration through exposure to air, water and microbial processes. The Leviathan Mine site was selected as an alternate to well–studied sites such as Rio Tinto, Spain [7,8], and saline lakes in Australia [9,10] due to the difference in elevation, source rock, and type of alteration setting, yet expected presence of primary and sedimentary sulfates that could be mapped in-situ and remotely for comparison with a broad range of Martian data sets and geochemical pathways.

Geologic Setting: The site is located in Tertiary volcanic rocks of the Eastern Sierra Nevada, and was used economically for an elemental sulfur vein, 1-2 feet thick, first mined underground and eventually converted to an open pit operation in the 1950's [11]. Wachter [12] mapped alteration minerals in the Monitor Pass region and note extensive outcrops of jarosite throughout the quadrangle as well as other surface exposures of small sulfur seams. While the origin of the elemental sulfur at Leviathan is unclear, it has been speculated, due to the large overburden of siliceous cap rock, that the system may represent a relic volcanic vent, sulfur condensing under impermeable cap rocks or sulfur precipitation sealing overlying tuff. The open pit area, while creating water quality problems for Leviathan creek, provides an excellent exposure for comparison of various remote sensing technologies of different wavelength and spatial resolutions. Run-off from the area is channeled into retaining ponds that are allowed to evaporate creating a man-made environment similar to the transient wet-dry cycles suggested for Meridiani sediments [5].

Figure 1: *Field photo of the Leviathan mine site. Drainage from seasonal snows is channeled into a series of retaining ponds that are allowed to evaporate over the summer. Abundant iron oxide and alteration exposures are also present in the pit walls.*

Data Sets: Analysis to date has included low spatial and spectral resolution image data sets acquired by the satellite sensors ALI and ASTER, and high spatial and spectral resolution airborne data acquisitions in the visible and shortwave infrared using the ProSpecTIR instrument, and thermal infrared using SEBASS. The ProSpecTIR data provides 356 spectral channels (5 nm resolution) from 0.45 to 2.45 µm, a ground resolution of 2m and are an analog to OMEGA and CRISM data. SEBASS provides 128 spectral channels from 8 to 13.5 µm, also at 2m ground resolution and is similar to TES and Mini-TES.

Low Resolution Data: ALI and ASTER data were combined to create a 13 filter image data set spanning the spectral range from 0.4 to 2.5 µm, after the method of Hubbard and Crowley [13]. Four unique surface endmembers were identified within mine site exposures in Leviathan and neighboring Zaca, and inferred to be possible deposits of sulfate minerals alunite and jarosite, as well as more common clay alteration minerals and iron oxides. The combined 13 wavelengths provide a much better identification of iron oxides and iron sulfates that the ASTER data set alone. Based on this encouraging initial analysis, high spectral resolution airborne data acquisitions were flown in the summer of 2007.

High Spatial and Spectral Resolution Thermal Infrared Data: The SEBASS data acquisition occured in July of 2007, when one of the two large retaining ponds was partially dry and a small pond within the mine was also dry. Simple decorrelation stretch methods highlight sulfate and quartz-dominant silicates in yellow, clays in magenta, and vegetation in green/cyan (Fig 2).

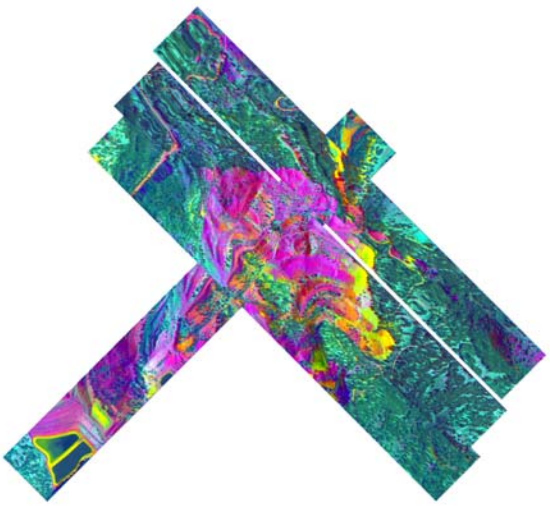

Figure 2: *DCS of the 4 SEBASS flightlines. Colors described in the text.*

The data were analyzed using both expert systems as well as statistical analysis approaches. The expert system uses color composites to identify small regions where unique spectra are identified and then maps similar pixels using a spectral angle approach. The statistical method uses noise segregation and prinicipal component transforms to identify unique spectral endmembers [14]. Both methods identified a small location of gypsum ($CaSO_4{\cdot}H_2O$) adjacent to predominantly alunite ($KAl_3(SO_4)_2(OH)_6$) in the small dry pond and zonation of mixed jarosites ($KFe^{3+}(SO_4)_2(OH)_6$) and possibly coquimbite ($Fe^{2+}(SO_4)_3{\cdot}\ 9H_2O$) around the margins of the larger ponds. Sulfo-halite ($Na_6(SO_4)_2FCl$) is also a likely component in the drying end of a larger pond, but this endmember was only identified through expert analysis (Figure 3). Statistical analysis of all four flight lines finds alunite and jarosite surrounding the ponds, the same gypsum/alunite in the dry pond, identifies alunite and jarosite on slope walls, and a also found a small location of carbonate, likely used as remediation material.

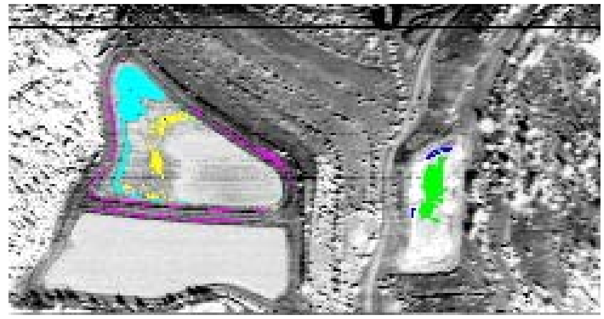

Figure 3: *Map of sulfates around retaining ponds. Blue/green (right side) are gypsum/alunite. Magenta/yellow are mixed jarosites, possibly coquimbite. Cyan likely includes sulfo-halite.*

Conclusions: Both expert and statistical approaches identify endmembers with good correspondance to library spectra of a variety of sulfate minerals. Compositional zonation is noted, probably due to changing conditions upon evaporation. Additional exposures are noted on tailings slopes. The combination of high spectral and spatial resolution allows separation of diagnostic mineral signatures in close proximity to one another. Detailed mapping shows that the DCS (Fig 2) confuses areas of sulfates and quartz suggesting limited wavelength instruments such as THEMIS will also be unable to separate these minerals on Mars. Future work will include analysis of the ProSpecTIR data and field collections for laboratory validation of remotely identified minerals.

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