Magma-Sediment Interaction Induced Alteration Mineralogy on Mars: Detectability and Analytical Method Comparison Using the Curtis Sandstone as a Terrestrial Analog. J.R. Crandall[1], J. Filiberto[2], S.L. Potter-McIntyre[3], S.P. Schwenzer[4], and S.M. Rimmer[3]. [1]Eastern Illinois University, Department of Geology & Geography, 600 Lincoln Ave., Charleston, IL 61920, USA (Jrcrandall@eiu.edu). [2]ARES, NASA Johnson Space Centre, 2101 E NASA Pkwy, Houston, TX 77058, USA. [3]Southern Illinois University Carbondale, School of Earth Systems and Sustainability, 1259 Lincoln Drive, Carbondale, IL 62901, USA. [4]AstrobiologyOU, School of Environment, Earth, and Ecosystems Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK.

Introduction: Basaltic magmatism is a ubiquitous feature of the Martian crust, and would have interacted with sediments and fluids through the geologic history of Mars to potentially produce higher temperature hydrothermal systems , and contact metamorphic rocks [1-4]. On Earth, comparable hydrothermal systems represent habitable environments, which can be used as an analog for Mars [5-10]. Nevertheless, evidence of aforementioned hydrothermal systems on Mars has remained elusive, despite the efforts of both orbital and in-situ analyses. Limited low grade metamorphic minerals typically indicative of hydrothermal systems (prehnite, zeolites, serpentine) have been detected in the Martian crust, though the detections are typically isolated occurrences, and do not necessarily indicate an in-place metamorphic sequence [3,4,11,12].

It is possible that orbital spectroscopy alone is not capable of detecting such an alteration front, with higher resolution in-situ analyses being required to detect the changes in mineralogy and species of alteration minerals associated with magma-sediment interaction. To constrain this, we have investigated a terrestrial analog on the Colorado Plateau, USA, where a mafic dike intrudes a quartz areinite of the Jurassic Curtis Sandstone. The investigation was carried out using Mars relevant instruments: Visible to Near-Infrared (VNIR) spectroscopy analogous to orbital spectroscopy, and X-ray Diffraction (XRD) analogous to CheMin on Mars Sample Laboratory Curiosity [13-17]. While quartz sandstones have not been, and are unlikely to be, detected on Mars, the relatively mineralogically uniform Curtis Sandstone serves as analog here as it avoids complications of multiple mineral systems or significant element exchange with the surrounding area.

Field Site: Samples were collected on the San Rafael Swell, Utah, USA where a mafic dike intrudes the Jurassic Curtis Formation (N38°43.491', W111°09.670'). In this area, the San Rafael Group of which the Curtis Sandstone is a part, is widely exposed. The Curtis Sandstone was deposited during a transgression of the shallow marine Sundance Sea in what is now the western interior of the United States [18,19].

Mafic Dikes: A mafic dike swarm and its associated sills and breccias intruded the San Rafael Group from approximately 4.6-3.7 Ma, and are likely synchronous with other mafic volcanic events occurring along the margin of the Colorado Plateau [20,21]. The approximately 60 km long and 30 km wide dike swarm intruding the San Rafael Group is basaltic to shonkinitic, with most dikes reaching an approximate thickness of one meter [21,22].

Methods: Samples were collected roughly linearly across the outcrop of host rock and the intrusion to represent a "cross-section" with respect to distance from the dike (Figure 1). Also collected was a distal sample (RS) of relatively unaltered Curtis Sandstone. The mineralogy of all samples was constrained via VNIR (ASD TerraSpec Pro) analyses and both bulk and oriented clay (2μm) fraction XRD (Rigaku Ultima IV) analyses.

Figure 1: *Basaltic dike intruding the Curtis Sandstone. Numbers show approximate spatial relationship of "cross section" samples CD-1 through CD-4. Note that the CD-4 collection site is outside of frame, as is the distal "relatively unaltered" sample.*

Results: VNIR analyses show that with increasing proximity to the dike, significant changes can be observed with respect to the "unaltered" sample (Table 1). Sample RS displays reflectance minima and maxima consistent with the detection of Fe/Mg chlorite and muscovite mica. Since the Curtis Sandstone is sedimentary in origin, both of these detected phyllosilicates are likely detrital, and not indicative of hydrothermal alteration. Though detected in bulk XRD analyses, no quartz or feldspars were detected via VNIR due to wavelength limitations.

Beginning with the contact between the dike and the Curtis Sandstone, sample CD-1 shows a change

from the previously detected phyllosilicates to phengite and gypsum, which is curiously the only sulfate detected in this system. Moving a few inches from the contact, the dominant mineralogy of CD-2 is montmorillonite and calcite, both of which, along with the addition of siderite, are found a few feet away from the contact in sample CD-3. The least altered sample of the "cross section", CD-4 is dominated by montmorillonite, with ankerite and siderite also detected.

Sample	Description	VNIR Mineralogy	XRD Bulk Analysis Mineralogy and Estimated Weight Percent	XRD Clay Fraction Analysis Mineralogy
RS	Roadside grab-bag, unaltered	Chlorite Fe/Mg, Muscovite	Quartz: 60.3% Calcite: 24.69% Bytownite: 15.1%	Illite/Chlorite
CD-1	Contact between Curtis and dike	Gypsum, Phengite	Quartz: 84.9% Albite lo: 11.3% Calcite: 3.9%	Smectite Group
CD-2	Near contact, further up-section	Montmorillonite, Calcite	Quartz: 66.9% Calcite:16.6% Albite hi: 5.3% Bytownite: 4.3%	Smectite Group
CD-3	Curtis 1-2 feet from dike	Montmorillonite, Calcite, Siderite	Quartz: 67% Labradorite: 18.8% Calcite: 14.2%	Vermiculite
CD-4	Curtis 3-4 feet from dike	Montmorillonite, Ankerite, Siderite	Quartz: 83.6% Calcite: 14.1% Euclase: 1.2% Altisite: 1.1%	Montmorillonite

Table 1: *Sample description, and detected mineralogy for VNIR, bulk, and clay fraction XRD analyses.*

Bulk XRD analyses detected quartz, calcite, and felspar in every sample. Quartz and calcite detections were manually confirmed, while the remainder of species were identified with the JADE software. The various species detected by JADE are likely minor feldspars whose signal has been overwhelmed by the dominant signals of quartz and calcite in each sample.

The mineralogical assemblage detected in the clay fraction analyses allows for more detailed insight into the behavior of phyllosilicate species in the system than the VNIR and bulk XRD analyses. Sample RS contains illite and muscovite as its primary phyllosilicate species, with illite likely being a weathering product of muscovite. Samples CD-1 and CD-2 are both dominated by smectite group minerals, while further from the contact, sample CD-3 adds the definitive detection of vermiculite. Furthest from the contact, CD-4 contains montmorillonite, as well as other smectite group minerals.

Conclusions: VNIR, bulk, and clay fraction XRD analyses each returned unique mineral assemblages, further reinforcing the difficulty of distinguishing such systems remotely. Further, most samples displayed significant mineralogical changes with respect to one another within each analytical technique. With the total "cross section" only ranging a few feet from the contact, the difficulty of remote detection is further amplified with respect to spatial resolution. The unifying feature across the analyses was that each assemblage suggests higher temperature alteration near the contact, with lower temperature minerals becoming dominant with increasing distance from the intrusion. While VNIR and XRD analyses together were sensitive to quartz, calcite, and micas, it would be difficult to determine the exact type of metamorphic environment based on these analyses alone. The distinct assemblage provided by clay fraction XRD analyses proved effective in further constraining small mineralogical changes grading away from the intrusion. When viewed individually, the limitations in resolution and detection amongst the analytical methods confirms the difficulty in identifying these systems remotely, suggesting that more detailed in-situ measurements are required if we are to positively detect these systems on Mars.

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