SEARCHING FOR SEDIMENTARY IRON FORMATIONS USING CRISM FACTOR ANALYSIS AND TARGET TRANSFORMATION. N. H. Thomas\textsuperscript{1} (nhthomas@caltech.edu), A. A. Fraeman\textsuperscript{2}, E. S. Amador\textsuperscript{1}, B. L. Ehlmann\textsuperscript{1,2}, J. L. Bandfield\textsuperscript{3}, and K. Stack Morgan\textsuperscript{2}, \textsuperscript{1}Geologic and Planetary Sciences, California Institute of Technology, Pasadena, CA, \textsuperscript{2}Jet Propulsion Laboratory, Pasadena, CA, \textsuperscript{3}Space Science Institute, Boulder, CO.

Introduction: In the sedimentary rock record, iron phases, including oxides, oxyhydroxides, phyllosilicates, and sulfates, are useful for studying redox changes in aqueous geochemistry and atmospheric composition. On Earth, iron formations (> 15 wt. % Fe), iron oxide-rich sedimentary rocks that formed during the Archean Eon (~2.5-4 Ga), provide evidence for iron mobilization in a reducing atmosphere. The martian crust has a higher abundance of iron (~14 wt. %) than the Earth’s crust (~8 wt. %) \cite{1}, and it has been hypothesized that analogs for terrestrial iron formations could have formed on early Mars when a reducing atmosphere permitted transport of reduced iron, which subsequently oxidized \cite[e.g.,][]{2}.

Previously, iron oxides have been observed on Mars in sedimentary outcrops by orbital and landed missions, however, these are not analogous to primary iron oxides in terrestrial iron formations. Gray, specular hematite has been detected in Meridiani Planum, Aureum Chaos, Iani Chaos, Aram Chaos, and at other locations associated with the interior layered deposits throughout Valles Marineris using the Thermal Emission Spectrometer (TES) \cite{3-8} (Figure 1). Finer grained red hematite has been detected by CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) and OMEGA (Observatoire pour la Minéralogie, l’Eau, les Glaces et l’Activité) in the Valles Marineris interior layered deposits, chaos regions, and areas around Meridiani Planum \cite{9} (Figure 1). Both of these types of deposits are hypothesized to have formed through secondary diagenetic processes associated with regional groundwater upwelling \cite[e.g.,][]{10}. In addition, hematite has been detected at Mawrth Vallis in association with Al-rich and sometimes Fe/Mg phyllosilicate layers \cite{11,12} and may have formed from intense leaching processes.

Gale crater provides the sole example known to date where hematite detected in Mt. Sharp by orbital \cite{13} and in situ \cite{14} observations may be either a primary authigenic phase that precipitated from a redox stratified lake \cite{13,15} or a secondary diagenetic product \cite{14}, or both.

Objective: We will perform a systematic survey of the shorter wavelength CRISM data to characterize the

\begin{figure}[h]
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\includegraphics[width=\textwidth]{image.png}
\caption{Map of locations of previously identified hematite detections as well as locations of stratified outcrops to be surveyed \cite{17}.}
\end{figure}
Fe mineralogy of stratified outcrops on Mars. This will allow us to systematically search for terrestrial-like iron formations on Mars. The paucity of primary iron oxide sedimentary deposit candidates on Mars could mean that the hypothesized iron formations [2] did not form on early Mars, and/or that other Fe-bearing phases such as Fe-phyllosilicates or Fe-sulfates were favored. Alternatively, this could be an observational bias. High resolution CRISM data has been useful for determining the global distributions of secondary minerals such as phyllosilicates and carbonates using the longer wavelength range (~1-2.5 μm), but, in comparison, the shorter wavelengths (~0.5-0.9 μm) have been underutilized.

**Survey Methods:** Factor analysis and target transformation techniques have been applied to the CRISM dataset to automate the identification of spectral endmembers and reduce noise [16]. These methods have been used to successfully map the global distribution of minerals associated with serpentinization [17], but have not been previously applied to wavelengths shorter than 1.7 μm. Here, we apply factor analysis to data from the short wavelength (S) detector of CRISM (~0.4-1.0 μm). The four characteristic absorptions used to identify ferric oxides with these wavelengths are broad and may prove challenging for factor analysis techniques which have been most successful with narrow absorptions.

In a study of ~17,000+ images collected by the High Resolution Science Imaging Experiment (HiRISE) camera, thousands of candidate sedimentary, stratified outcrops have been identified [18]. Hundreds of these outcrops have coincident CRISM data coverage (Figure 1). In addition, Goudge et al. [19] has cataloged 205 candidate closed-basin lakes on Mars. We will survey CRISM images using factor analysis and target transformation in search of ferric and ferrous phases.

**Preliminary Results:** We are beginning by applying factor analysis and target transformation to CRISM images with known detections of hematite to test the effectiveness of our methods for identifying the characteristic broad absorptions in the S detector data. The CRISM type locality detection of hematite is located in Valles Marineris [10, 20]. We applied factor analysis to 1 in every 3 pixels in 1 in every 3 rows and found a good match to a laboratory hematite spectrum using target transformation (Figure 2, blue). 10 eigenvectors were required to produce the fit shown. The technique confirms the presence of one of the previously identified broad exposures of hematite in Valles Marineris.

We also applied our methods to the previously identified exposures of hematite in Gale crater [13]. We identified hematite, although more eigenvectors (20) are required than the previous example to produce a good fit (Figure 2, red). In both cases, there are some spikes, or noise, in the fit, but the characteristic absorptions, particularly the one at 0.86 μm fit well.

**Future Work:** We will continue to validate our application of factor analysis and target transformation for identifying iron-bearing phases in the CRISM S detector data by generating statistical criteria for determining the success or failure of the target testing, initially with hematite. We plan to use “goodness of fit” or spectral similarity parameters such as the spectral angle distance (SAD) [21]. The SAD index will allow us to identify where in a given CRISM image hematite is located. Once our methods have been validated, we will apply them to CRISM images containing previously identified candidate sedimentary, stratified outcrops and closed-basin lakes. This will allow us to identify where or if iron oxide deposits are located in sedimentary outcrops.

**Acknowledgements:** This work was supported by a NSF GRFP grant no. DGE-1144469 to N.H.T. and NASA MDAP grant to A.A.F.