SPECTRAL AND CHEMICAL CHARACTERISTICS OF LAKE SUPERIOR BANDED IRON FORMATION: ANALOG FOR MARTIAN HEMATITE OUTCROPS.

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Introduction: Lake Superior iron formation serves as an analog to the gray, crystalline hematite on Mars discovered by the Thermal Emission Spectrometer (TES) [1]. Spatial analyses of the hematite sites at Sinus Meridiani, Aram Chaos, and Valles Marineris suggest that the hematite exists within a stratigraphic layer, and is of a sedimentary nature [2]. These sites are not associated with volcanic activity due to the lack of volcanic features such as lava flows and fissures. One of the formation mechanisms for crystalline, gray hematite is through precipitation of ferric oxides in Fe-rich waters as in terrestrial banded iron formation (BIF). Increased hydration signatures in Mariner 6 and 7 data of the Meridiani and Aram Chaos sites also supports an aqueous formation mechanism [3]. Subsequent burial metamorphism would crystallize the deposit.

Banded iron formations across the globe are similar in their chemistry and mineralogy, however the Huronian age (1.8Ga) Lake Superior Type (LST) BIF differs from the majority based on its origin [4-6]. While most BIF is associated with volcanic activity, for example the Hamersley and Transvaal Basins, the LST iron districts are not. Gross (1983) illustrated the origin differences using North American BIF and classifying the Algoma and Lake Superior types. Algoma type BIF is in close proximity to volcanic centers and suggests a sub-aqueous hydrothermal origin similar to modern day sea-floor spreading. Lake Superior Type BIF retains many of its sedimentary features, such as ripple marks and ooliths, which suggests deposition in a a near-shore shelf like environment.

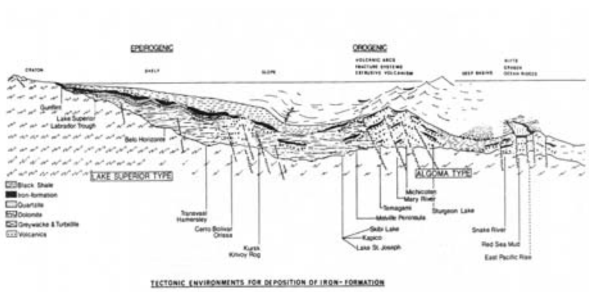

Figure 1. Taken from Gross, 1983 illustrating the differences in geological environments of deposition between Algoma and Lake Superior Type BIF.

Lake Superior Type BIF consists of four facies: sulfide, carbonate, silicate, and oxide [7]. The oxide facies is composed of magnetite and several forms of gray, crystalline hematite. The hematite occurs as distinct, thin bands alternating with chert bands in typical BIF structure, and in a more metamorphosed state as bulk, crystalline hematite with a schistose texture. Samples of both types have been collected in the Marquette and Gogebic iron districts of northern Michigan. We have also collected samples from the silicate and carbonate facies and are in the process of identiying minerals and spectral features in those samples. Samples were measured for their spectral reflectance and thermal emittance in the laboratory to characterize their spectral properties, and thin sections have been acquired to help constrain the mineralogy. Spectra are re-sampled to TES and mini-TES resolution for direct comparison.

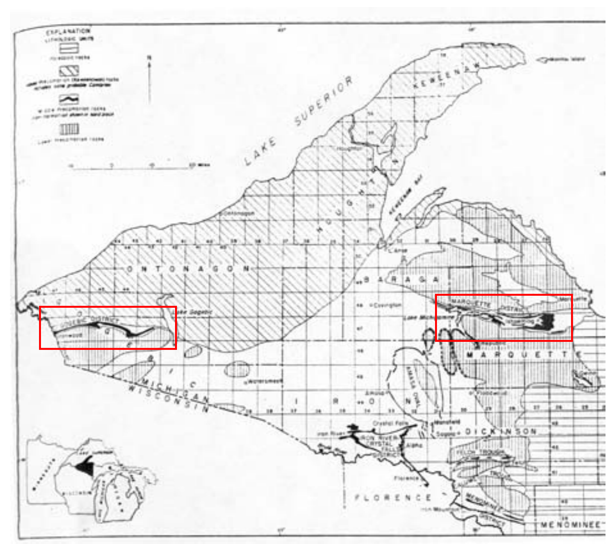

Figure 2. Regional map of northern Michigan, showing the Marquette and Gogebic iron districts in red.

Spectra: TES identified gray, crystalline hematite based on its oxide features at 300, 450, and 525cm^{-1} [1]. *Lane et al., 2002* looked at the spectra of gray, crystalline hematite in which the grains were oriented in a schistose texture, and illustrated the presence of a weaker 390cm^{-1} in emission spectra of *non* c-faces of hematite crystals. Emission spectra from the c-faces themselves do not have a 390cm^{-1} band, and match the

TES spectra. This suggests the presence of oriented grains in the martian hematite outcrops. Recently, *Glotch et al., 2003* [9] studied the effects of precursory mineralogy on hematite spectra and concluded that goethite (FeOOH) that has been dehydroxylated to form hematite (Fe_2O_3) provides the best match to the Sinus Meridiani (SM) hematite spectra. This is one possible formation mechanism among synthetic samples.

Our samples were measured in VNIR/SWIR region by an ASD field spectrometer at the Arthur Brant Laboratory for Exploration Geophysics at the University of Nevada, Reno. The emission spectra were acquired with a Nicolet Nexus 670 FTIR interferometric spectrometer at $4cm^{-1}$ resolution at Arizona State University [10].

Oxide samples. As noted above, the oxide facies consists mainly of hematite with minor magnetite. The thinly banded hematite that occurs in typical banded iron structure has distinct minima in the VNIR region at 0.65 and 0.85μm. In the TIR, this hematite shows emission minima at approximately, 300, 465, and $550cm^{-1}$, matching the SM hematite.

The more metamorphosed hematite with the schistose texture does not show distinct hematite features in the VNIR region. It does however exhibit the same hematite oxide features in the TIR as the banded hematite. These features are two to three times stronger in the schistose samples than in the banded samples. The lack of features in the VNIR region could be due to a substantial amount of magnetite in the sample.

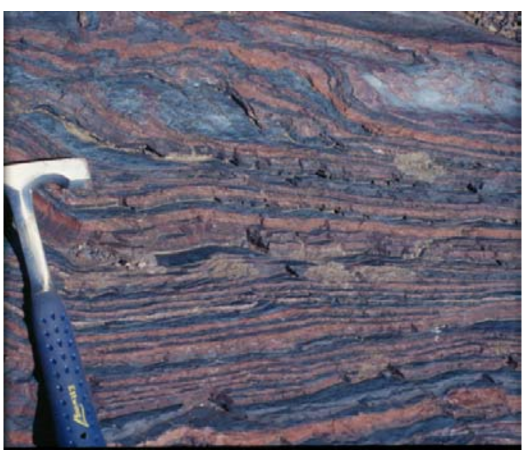

Figure 3. Field photo illustrating gray, crystalline hematite in typical banded iron formation structure. The red bands are chert.

Figure 4. Field photo illustrating more metamorphosed crystalline hematite with a schistose texture.

The magnetite samples have a typical featureless spectrum in the VNIR/SWIR. The TIR spectra are dominated by quartz features most likely from the fine grained chert throughout the sample. Petrographic analysis should reveal how much quartz/chert is present in the sample.

Carbonate samples. The carbonate facies of banded iron formation consists of alternating bands of siderite and chert. The VNIR/SWIR spectra of these samples typically do not show any distinct carbonate features in the 2.3 to 2.5μm range, or at most have a weak feature at 2.3μm. They do have broad 1μm bands indicating the ferrous iron component of siderite ($FeCO_3$). One sample shows weak carbonate features in the TIR at 7 and 11.3μm. The geochemical analysis to determine how much carbonate is present will be presented at the meeting.

Silicate Sample. The VNIR/SWIR spectra of the silicate sample resembles many of the magnesium (Mg) endmember serpentines [11]. However, the low albedo (10%), and the narrow 0.7μm feature indicate a high iron content.

The TIR spectra of the silicate facies exhibit a $500cm^{-1}$ feature common to many of the Mg endmember serpentines such as clinochore and lizardite, but lack a $600cm^{-1}$ feature characteristic of these minerals. The features between 1000 and $900cm^{-1}$ are consistent with the Mg endmember amesite. An odd feature at $1220cm^{-1}$ has not yet been identified. XRD and petrographic analysis will help identify the mineral composition and will be presented at the meeting.

Resampling. All sample spectra will be resampled to TES and mini-TES resolution using a gaussian convolution approach. At TES resolution, a direct comparison can be made between the SM hematite spectra, and the hematite spectra from the oxide facies of LST BIF. Mini-TES resolution will provide insight for observations made by the Mars Exploration Rover (MER) at the SM landing site. Samples from the carbonate and silicate facies are examples of possible auxiliary minerals for the martian hematite sites. This spectral data will help constrain the combination of features, identifiable by MER that will be indicative of a BIF like process on Mars.

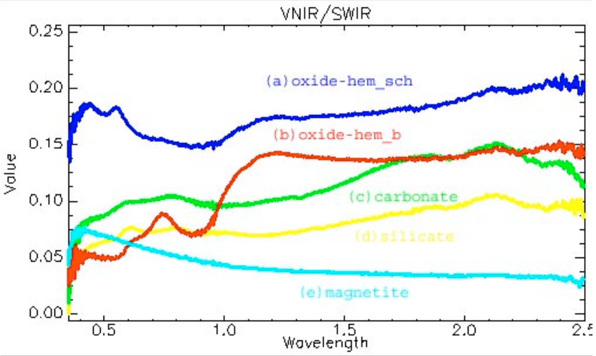

Figure 5. VNIR/SWIR spectra of (a) schistose hematite, (b) typical banded hematite, (c) carbonate, (d) silicate, (e)magnetite.

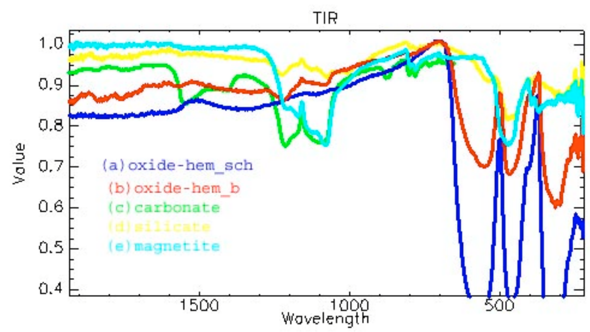

Figure 6. TIR spectra of (a) schistose hematite, (b) typical banded hematite, (c) carbonate, (d) silicate, (e) magnetite.

Geochemistry: Thin sections have been acquired of the samples in order to further constrain the mineralogy. Sample textures should provide further clues to the nature of origin. Electron microprobe and XRD analyses will also be done to obtain elemental percentages that can be related to specific mineral species. These results will be presented at the meeting.

Mars Exploration Rovers: Instruments onboard the MER will examine the SM hematite deposit for composition and texture at a much finer spatial scale. Data from the Mossbauer spectromer, mini-TES, APXS, and the microscopic imager can be directly compared to our hand samples in order to constrain an origin of the SM hematite.

References: [1] Christensen et al. (2000) *JGR, 105, E4,* 9623-9642. [2] Christensen et al. (2000) *JGR,106,E10,* 23,873-23,885. [3] Baldridge and Calvin (2003) *in press*. [4] Gross (1983) *Precambrian Research, 20*, 171-187. [5] Trendall (1968) *Geol. Soc. Am. Bull., 79,* 1527-1544. [6] Trendall (2002) *Spec. Pub. #33 Int. Assoc. Sedimentol.*, 33-66. [7] James (1954) *Econ.Geology, 49,* 235-293. [8] Lane et al. (2002) *JGR, 107, E12,* 9-1 – 9-15. [9] Glotch et al. (2003) *LPS XXXIV,* Abstract #2008. [10] Thanks to Alice Baldridge for her assistance in acquiring spectra. [11] Calvin and King (1997) *Meteoritcs & Plan. Sci., 32,* 693-701.