

SPECTRAL DIVERSITY OF TERRESTRIAL BANDED IRON FORMATIONS AND ASSOCIATED ROCKS: IMPLICATIONS FOR MARS REMOTE SENSING

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Introduction: Banded iron formations (BIFs) are iron oxide- and silica-rich chemical sedimentary rocks, most of which were deposited in great abundance during an ~800 my span from late-Archean to mid-Proterozoic (ca. 2.7-1.9 Ga) [1]. At this time the terrestrial atmosphere was changing in composition from early anoxic conditions to a more oxygenated state, mainly due to the increasing activity of photosynthetic organisms [2, 3]. It has been suggested that Mars and Earth were more similar during this time period than today, with both planets initially being blanketed by thick reducing atmospheres that moderated surface temperatures and stabilized large bodies of liquid water [4]. On Earth, rocks associated with BIFs contain some evidence of early life [5, 6]. With these possible linkages to redox transitions, water and life, Martian BIFs, if such exist, would be favored sites for astrobiological exploration [6, 7]. Here, we examine spectra of well-preserved terrestrial BIFs to determine which characteristics might aid their remote sensing detection.

Methods: Samples of BIFs and associated rocks were collected from Carajas, Brazil, and the Hamersley Basin, of Australia, both localities where the ancient sediments were subjected to low-grade metamorphism [8]. Although both areas are deeply weathered, drill core and other samples obtained from open pit iron mines permitted access to unweathered BIFs. Directional hemispherical reflectance spectra of rock chips were measured in the visible to short-wave infrared (VSWIR, 0.4-2.5 μm) and the mid to thermal infrared (MTIR, 2.5-14.0 μm) wavelength ranges. In general, where distinct layers of two different mineral compositions were interleaved, the samples were positioned to obtain composite spectra. Samples were also analyzed by X-ray powder diffraction, and by thin section petrography.

Results: Typical BIFs have alternating bands of cherty quartz and iron oxides that produce characteristic VSWIR and MTIR spectral features. Samples CaraC, CaraD, and H6 in Figure 1a illustrate distinctive "pointed" quartz reststrahlen features between 7.5-9.5 μm , a peculiar shape that appears related to the high purity and interlocking grain fabric of the chemically deposited chert layers. Sample CaraT is an altered BIF, in which the silica has been replaced by carbonate producing major reflectance maxima near 6.4 and 11.2 μm . Smaller scale absorption features in the 3.0-7.0 μm wavelength region are overtones and combination tones of the quartz and carbonate fundamental vibrations [9]. The VSWIR wavelength range (Fig. 1b) displays spectral features related to iron oxides, water, and carbonate. Hematite is the dominant iron oxide and is responsible for bands near

0.50 and 0.86 μm in samples CaraC, CaraD, CaraT and H18. Goethite also is abundant in sample H6 and produces absorptions at 0.64 and 0.92 μm , which broaden the composite hematite + goethite band near 0.9 μm . Water absorptions are evident in several samples near 1.9 μm and carbonate produces the band near 2.31 μm in sample CaraT. H18 is "canga", a surface weathering cap formed by lateritic weathering of exposed iron ore deposits. Canga is nearly pure hematite with minor goethite; therefore it lacks silicate and

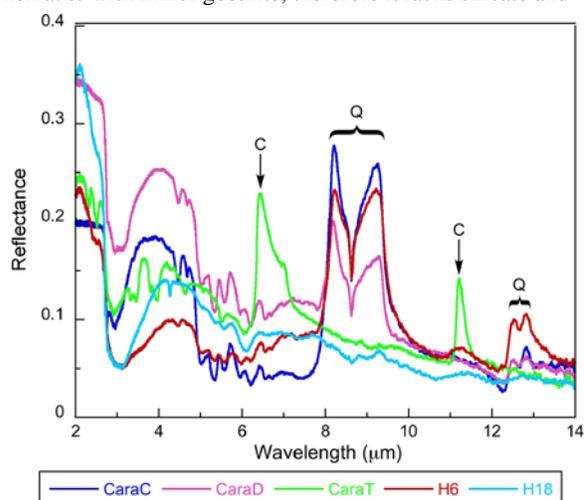


Figure 1a. Laboratory MTIR reflectance spectra of typical BIFs and related rocks. Cara=Carajas; H=Hamersley; Q=quartz; C=carbonate.

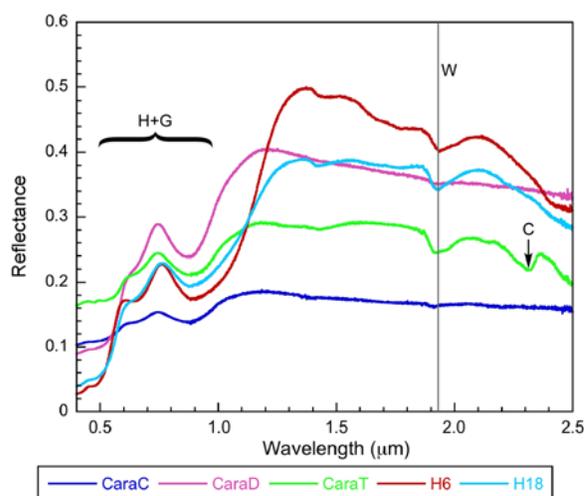


Figure 1b. Laboratory VSWIR reflectance spectra of typical BIFs and related rocks. Cara=Carajas; H=Hamersley; H+G=hematite + goethite; C=carbonate; W=water.

carbonate spectral features.

MTIR spectra of several rock types associated with BIF are shown in Fig. 2a. Sample MB1b is dark gray chert from the 3.5 Ga Marble Bar locality in Western Australia [10]. It shows the "pointed" quartz reststrahlen features typical of many cherts as noted above. The VSWIR spectrum of sample MB1b is relatively featureless due to opaque carbonaceous matter (Fig. 2b). Sample H2 is cherty impure BIF from the Mt. McRae formation, a shaley lateral facies associated with Hamersley iron formations. Its MTIR spectrum is more complex than that of pure BIF (comp. Fig. 1a), and the quartz reststrahlen feature at 9.2 μm is modified in shape due to the presence of clay (kaolinite). Weak clay features

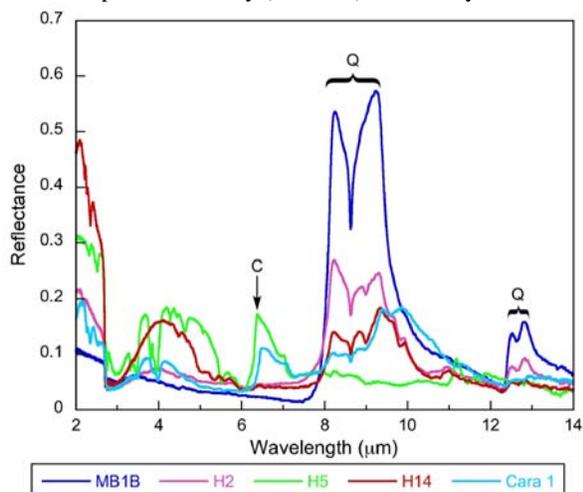


Figure 2a. Laboratory MTIR reflectance spectra of other rocks associated with BIFs. MB=Marble Bar; H=Hamersley; Cara=Carajas; Q=quartz; C=carbonate.

are seen at 2.2 and 1.4 μm in the VSWIR spectrum (Fig. 2b). Sample H5 is dolomite from the Wittenoom formation, an early platform carbonate [5]. It displays characteristic features of dolomite in both the MTIR and VSWIR. Although fresh surfaces of the Wittenoom sample display weak absorption features related to ferrous iron carbonate [11], the weathered surface spectrum in Fig. 2b-H5 instead displays typical hematite features. Mud-cracked samples of the Wittenoom formation are highly non-stoichiometric Ca-Mg-Fe-Mn carbonates suggestive of variable PO_2 conditions during initial precipitation and/or diagenesis [12]. Samples H14 and Cara1 are chloritized basalts that occur stratigraphically below the Hamersley and Carajas BIF sequences. H14 displays MTIR features typical of quartz + impurities (comp. H2). The quartz in this case evidently is a byproduct of weathering [13]. The VSWIR spectrum shows hematite spectral features as well as distinctive chlorite features near 2.25 and 2.34 μm . Sample Cara1 is unweathered but contains veins of secondary calcitic carbonate, which exhibit spectral features in the MTIR. Chlorite features are evident in the VSWIR including broad ferrous iron bands at 0.7-1.1 μm .

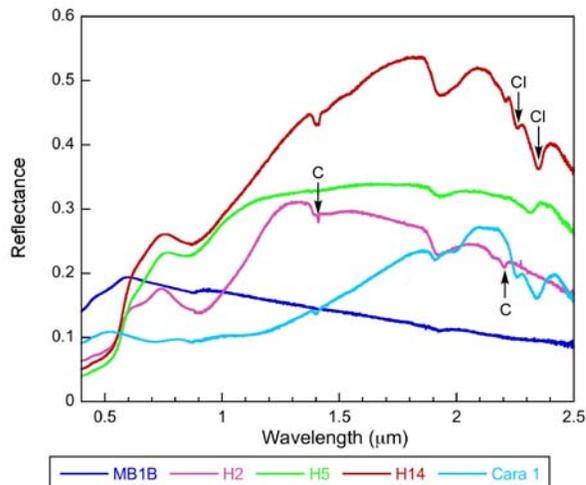


Figure 2b. Laboratory VSWIR spectra of rocks associated with BIFs. MB=Marble Bar; H=Hamersley; Cara=Carajas; H+G=hematite + goethite; Cl=chlorite; C=clay.

Discussion: Although the terrestrial BIFs and associated rocks originally formed under relatively anoxic conditions, most of the samples have become oxidized through time to yield mainly hematite spectral signatures in the VSWIR. Such signatures, by themselves, are not a very good indicator of either process or lithology. However, the distinctive "pointed" quartz reststrahlen bands believed to be uniquely produced by high-purity, polycrystalline chert may be a useful MTIR spectral marker for BIFs and other chemically precipitated silica deposits. Combined cherty quartz plus hematite spectral signatures appear to be diagnostic of many terrestrial BIFs although the extension to Mars is still uncertain. High spectral and spatial resolution remote sensing data, such as THEMIS and CRISM imagery, can be used to explore for such materials within Martian layered deposits. Also, recent work [14] provides a chemical modeling basis for studying BIF-like iron precipitates that might have formed under colder Martian conditions.

References: [1] Klein, C., 2005, *Am. Min.* 90, 1473-1499. [2] Cloud, P., 1973, *Econ. Geol.* 68, 1135-1143. [3] Kasting, J.F., 2001, *Science* 293, 819-820. [4] Pollack, J.B. et al., 1987, *Icarus* 71, 203-224. [5] Simonson, B.M., et al., 1993, *Precamb. Res.* 60, 287-335. [6] Fallacaro, A. and Calvin, W.M., 2006, *Astrobiology* 6, 563-580. [7] Schaefer, M.W., 1996, *Geochem. Soc. Sp. Pub.* 5, 381-393. [8] Dalstra, H., and Guedes, S., 2004, *Econ. Geol.* 99, 1793-1800. [9] Salisbury, J.W., et al., 1987, *JGR* 92,702-710. [10] Hickman, A.H., 1983, *Geol. Surv. W. Aust. Bull.* 127, 268 p. [11] Hunt, G.R. and Salisbury, J.W., 1971, *Mod. Geol.* 2, 23-30. [12] Kargel, J.S. et al., 1996, *Global Planetary Change* 14, 73-96. [13] Kraft, M.D., et al., 2003, *GRL*, 30, n. 24, 2288. [14] Marion G.M., et al., 2008, *Geochim. Cosmochim. Acta* 72, 242-266.