A petrologic approach for assessing ancient habitability of Mars at the microscale. J. D. Farmer[1], J. I. Nuñez[1], R. G. Sellar[2] and Paul B. Gardner[2], [1]Arizona State University (School of Earth and Space Exploration, Arizona State University, PO Box 871404, Tempe, AZ 85287-1404; jfarmer@asu.edu; jorge.nunez@asu.edu), [2]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena, CA 91109; glenn.sellar@jpl.nasa.gov and paul.b.gardner@jpl.nasa.gov).

Introduction: Petrology is the integrated study of microtexture and mineralogy of rocks, to interpret their petrogenesis. The microtexture of geologic materials may be defined as the spatial interrelationships of constituent mineral grains in rocks, pore spaces and secondary (authigenic) minerals (e.g. alteration phases, pore-filling cements). In combination with mineralogy, microtexture provides essential data for inferring both the primary processes that formed a rock and the secondary (diagenetic) processes that altered a rock once formed. Accurate petrologic interpretations require spatially-coordinated studies of mineralogy and microtexture. In the field, an experienced geologist usually obtains preliminary compositional and textural information in real time using a simple handlens, or portable field microscope. This is usually followed in the lab by the preparation of petrographic thin sections of rocks and their study under transmitted, cross-polarized light. This work provides a microspatial context for more detailed, targeted analyses (e.g. electron or ion microprobe, x-ray diffraction, organics analysis, etc.). Despite the clear value of spatially-integrated mineralogical and microtextural data for formulating petrogenetic interpretations, the complexities of developing thin section preparation and transmitted light microscopy systems for flight have so far frustrated attempts to develop robotic systems that could bring petrological methods to mainstream planetary exploration.

Mars habitability at the microscale: For astrobiological exploration, petrological observations are key for creating scale-integrated paleoenvironmental interpretations to assess the nature and persistence of past habitable zones and their potential for supporting life. Until recently, assessments of past habitability on Mars were largely inferred from macroscale geomorphic features (e.g. fluvial channel systems), or, in the case of MER, mesoscale structures (e.g. cross-beds) visible in outcrop. However, over the history of Mars, the most persistent near surface habitable zones may have well been much finer scale microhabitats that are invisible at larger scales (e.g., primary and secondary pore spaces, vesicles in volcanic rocks, microfractures, and/or fluid inclusions in aqueous minerals [e.g. 2], and ices, captured as they were precipitated). While spatially insignificant to humans, it is notable that a tiny fluid-filled fracture in a rock may constitute an "ocean" for a microbe. The factors that control the capture and preservation of microbial bioisgnatures are often strongly mediated by microscale processes and environments, which are often biologically-controlled. Terrestrial experience strongly suggests that the most valuable precursor data sets for selecting rock samples for *in situ* fossil biosignature analysis (or sample return), are spatially-correlated maps of minerals and microtextures, followed by focused analysis of samples in onboard labs of targeted samples collected from microfacies that represent particularly favorable microenvironments for preservation.

Microfractures and primary pore spaces in rocks as potential targets for fossil biosignatures of subsurface microbial life: Figures 1 and 2 present data from a hydrothermally-altered sedimentary sequence in the Cady Mts., Mojave Desert, southeastern California. The samples analyzed were collected from in a vein-hosted hydrothermal deposit that was emplaced in a bedded sulfate evaporite sequence during the Miocene.

Figure 1 shows high resolution, transmitted light photomicrographs from thin sections, including a plane light image (Fig. 1A) at a total magnification of 10x and a cross-polarized image (Fig. 1B), at a magnification of 100x.

Figure 2 shows reflected light images of the same rock obtained with the Multispectral Microscopic Imager (MMI), a prototype instrument presently being developed for future planetary missions [2]. The instrument is designed for deployment on a robotic rover to support traverse characterization, geologic mapping and sample selection for onboard analysis or sample return, based on imaging and spectroscopy at the scale of a geologist's handlens. The instrument acquires a spectral image cube at 62 microns/pixel, including 21-band visible to shortwave infrared (0.45 to 1.7 micron) reflectance spectra for every pixel in the image.

Results: Both the petrograhic thin section analysis (Figure 1) and the MMI-based spectral analysis (Figure 2) produced data consistent with the identification of Fe-oxides, silica, and microfibrous celadonite as the predominant phases of the rock (this mineralogy was also confirmed using x-ray powder diffraction).

Figure 1 shows thin section photomicrographs of the rock imaged for Figure 2A. Dark areas in the thin section are opaque iron oxides (hematite and goethite), white areas are megaquartz. Light green areas are dominated by microfibrous celadonite. Microtextures suggest that Fe-oxide precipitation occurred first, followed in time by the infilling of primary pore space by microfibrous celadonite and ultimately, quartz. In Figure 2B, the images show that along the margins of original void spaces, Fe-oxides developed a finely filamentous microstructure, similar to biomediated fabrics observed a variety of modern Fe-oxide precipitating hydrothermal systems [3]. Similar biomediated filamentous fabrics in modern systems have been shown to persist through diagenesis and are common biosignatures in many ancient iron spring deposits. In most modern systems, hydrothermal Fe-oxides precipitate as amorphous ferrihydrite, which quickly orders to hematite, and/or goethite. Ferrihydrite can also appear as a later weathering product in near-surface outcrops.

Figure 2A is a natural-color composite image composed of three of the 21 bands acquired by the MMI (463, 522 and 641 nm). The image is of a slab that was ground flat to simulate preparation by the MER Rock Abrasion Tool (RAT). The MMI is a potential analog for a future flight instrument that could be used to visualize rocks and soils in color, at handlens scale. Again, each pixel of an MMI image provides spectral information for 21-bands, sampled over the wavelength range, 0.45-1.7 microns. Figure 2B is a spectral end member map generated from the MMI image in Figure 2A, using ENVI's Supervised Classification, Spectral Angle Mapper [4]. Figure 2C shows a plot of reflectance versus wavelength (microns) for each end member spectrum extracted from the data cube, along with suggested mineral identifications, based on comparisons with the USGS spectral library. Interpretations follow: Red spectrum = goethite, based on broad Fe^{+3} absorption at ~0.95 microns and hydration feature at ~1.45 microns; Blue spectrum = Fe-bearing phase (a mica, possibly celadonite); Yellow spectrum = hematite, based on an Fe^{+3} absorption min. at ~0.85 microns; Light green spectrum = Mixture of hematite and celadonite. Dark green spectrum = Whole rock spectrum, dominated by hematite.

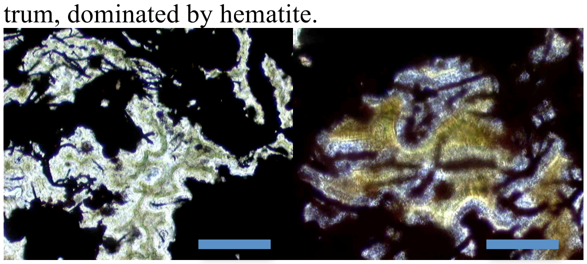
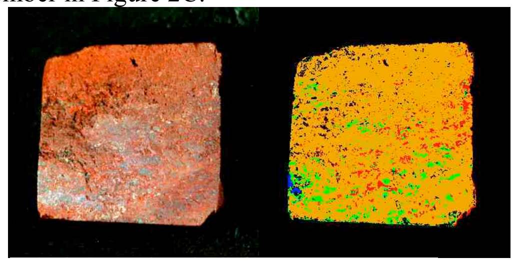


Figure 1A (Left) Plane light photomicrograph of a thin section taken from the sample shown in Figure 2A (Scale bar = ~1 mm). **Figure 1B:** (Right) Cross-polarized light photomicrograph (Scale = ~0.2mm). The pore-filling quartz/celadonite (white/green) areas in Figure 1 correspond to bluish-grey areas visible in the bottom half of the hand sample shown in Figure 2B. These areas map as the light green spectral end member in Figure 2C.



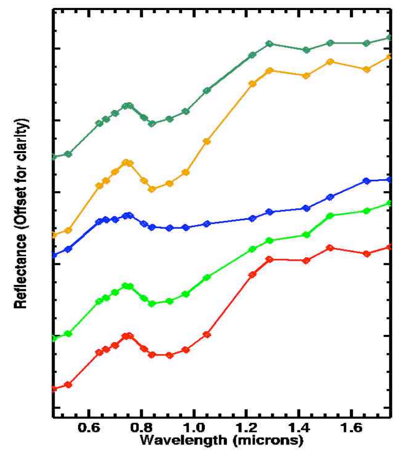


Figure 2A (Upper Left): Natural-color composite image consisting of the following bands: 463, 522 and 641 nm. Sample is ~1.5 cm^2. **Figure 2B** (Upper Right): Spectral end member map. **Figure 2C** (Lower Middle): Plot showing spectral signatures of the end members mapped in Figure 2B (see text for mineral interpretations.

Conclusions: Mapping of spectral end membes from MMI images show evidence for four discrete microtextural/mineralogical domains that are closely consistent to what is observed in petrographic thin sections**.** Spectral identifications support two major Fe-oxide phases: Hematite (Fe_2O_3) and goethite ($Fe^{+3}O(OH)$, plus celadonite, a phyllosilicate ($K(Mg,Fe^{+2})(Fe^{+3},Al)[Si_4O_{10}](OH)_2$). The integrated spectrum (dark green line in Fig. 2C) reflects a predominance of hematite, again consistent with what is seen in hand samples. Invisible at MMI resolution, but clear in thin section at 100x, are filamentous iron oxides that grew into open pore spaces that were later infilled with celadonite and quartz. These features are interpreted to be biologically-mediated fabrics (biofabrics), based on modern analogs.

References: [1] Lowenstein et al. (2010) GSA Today 21(1) doi: 10.1130/GSATG81A.1. [2] Sellar R. G. et al. (2006) *Proc. SPIE 6309, 63090E*. [3] Hofmann and Farmer (2000) *Planet. Space Sci.* 48: 1077-1086. [4] Clark et al. (2007) USGS Digital Spec. Lib. splib