MULTISPECTRAL MICROSCOPIC IMAGER: PETROGRAPHY ON MARS WITH A COMPACT, CONTACT INSTRUMENT.

R. G. Sellar[1] , J. D. Farmer[2], J. I. Núñez[2], and S. Smith-Dryden[3]. [1]California Institute of Technology, Jet Propulsion Laboratory (glenn.selar@jpl.nasa.gov); [2]Arizona State University, School of Earth and Space Exploration; [3]Ohio State University, Department of Physics.

Introduction: Microscopic imagers are powerful, indeed essential, tools for geology and geobiology. Based on the microtexture revealed by a *hand lens*, a trained field geologist can assign a rock to one of three basic petrogenetic categories (igneous, sedimentary, or metamorphic). Subsequent analyses of thin sections under a *petrographic microscope* add compositional information in relation to the microtextural context, enabling assessments of primary formation processes, environmental conditions, how environments and processes changed over time (diagenesis), and information about a variety of fossil biosignatures [1,2]. For planetary missions, such information is also considered crucial for prioritizing limited samples for further investigations.

While the current generation of microscopic imagers on MER, Phoenix, and MSL have and will continue to significantly advance our understanding of Mars [3,4] no imager providing information comparable to that from a petrographic microscope has yet been flown. Conventional petrographic microscopes observe in transmittance, requiring preparation of a thin-section by cutting, mounting on a transparent substrate, and polishing the sample to 10's of µm in thickness before delivery to the instrument - an impractical approach for in-situ missions. Analytical instruments, such as X-ray Power Diffraction (XRPD), and various geochemical analyses, provide sophisticated and in-depth analyses of composition. XRPD, however, requires powdered samples, which leads to the loss of important microspatial context information.

Multispectral Microscopic Imager (MMI): As an arm-mounted contact instrument, the MMI observes *unprepared* rocks (as well as brushed or abraded rocks) and in-situ soils in *reflectance* rather than transmittance [5,6,7]. Light-emitting diodes (LEDs), a lens, and a focal-plane-array (FPA) sensitive to visible and infrared wavelengths are used to provide spatially co-registered sets of multispectral microimages, consisting of visible-to-infrared reflectance spectra of every pixel in the field of view (FOV). Analyses of these data apply to *microscale* imaging the same spectroscopic approaches already found highly productive for *macroscale* imaging (remote sensing from orbit). Development models of the MMI (Fig. 1) use sets of LEDs including up to 21 different wavelengths from 0.45 µm (blue) to 1.7 µm (shortwave infrared) to illuminate the sample, sequentially acquiring images in each of the spectral bands. The custom-designed lens provides spatial resolution (63 µm), field-of-view (40 x 32 mm), and depth-of-field (5 mm) comparable to that provided by a geologist's hand lens. Alternative trades between field-of-view (FOV), spatial resolution, and depth-of-field can be obtained by using a lens with a different focal length, and FPAs and LEDs are available to extend the spectral range to longer wavelengths.

Fig. 1: Multispectral Microscopic Imager. Illuminator has 102 LED emitter dies; set of 4 emitting at 635 nm activated in this photograph; scale is marked in inches and cm.

Capabilities: Data from the MMI are presented in Fig. 2. Reflectance spectra of this sample exhibit absorptions at 0.52 and 0.97 µm associated with ferric iron and 1.05 µm associated with ferrous iron as well as features centered at 1.43 and 1.52 µm associated with stretching/bending overtones of OH/H_2O. Spectra of components in the matrix are consistent with hydrated minerals (mapped in green, magenta, light blue), nontronite (orange); and Fe-oxide/oxyhydroxide + nontronite (red). Spectra of the clasts (blue) are consistent with basalt, while the rind of the central clast (purple) is consistent with augite + hydrated mineral.

Interpretation. Volcanic breccia composed of basaltic clasts cemented by Fe-oxides and hydrated minerals (most likely as clay minerals, iron oxides/oxyhydroxides, and hydrated silica). Subrounded clast shapes indicate moderate transport from the source. The uniformity of clast texture and composition (monolithologic) is consistent with derivation from a single volcanic source. The composition of the cements and alteration rinds on basaltic clasts are consistent with alteration at low temperatures. Rinds on basaltic clasts may contain hydrated silica, a common aqueous alteration product of basalt.

Potential for preservation of biosignatures. Mineral assemblage comprising cements and alteration rinds on clasts strongly supports transport and alteration of primary basaltic volcaniclasts by aqueous fluids. The mineral assemblage is consistent with low to moderate hydrothermal alteration temperatures and suggests habitable conditions (liquid water, redox-based energy sources, and nutrients to support metabolism) during deposition that could have supported a meso- to hyper-thermophilic chemotrophic biota. Similar lithotypes on Earth have been shown to harbor putative bioalteration fabrics [8] and cellular microfossils [2], imparting a high priority for astrobiological sampling and analysis. Strong indication of formation in a habitable environment. High preservational potential due to pervasive and rapid early cementation [1].

Costs versus Benefits: The challenge of constrained budget outlooks for planetary science prompts a fresh look at the costs of both instruments and platforms for future missions. *Curiosity's* payload is vastly more capable than that of her predecessors, but these instruments were also much more costly: both directly to develop the instruments themselves and indirectly to accommodate them in terms of required mass, power, volume, integration with the complex sample acquisition and handling system, testing, and operation. While an MMI provides greatly advanced capabilities compared to previous and current microimagers, it remains comparable to MER's MI instrument in terms of complexity and accommodation. The illuminator measures only 36 x 42 mm and the FPA (sensitive from 0.45 to 1.7 µm) operates at +18 C. A flight version would mass ~0.5 kg (slightly higher than the MER-MI). Addition of a thermoelectric cooler (a space-qualified technology with no moving parts) would allow extension of the MMI spectral range further into the IR, at a mass of ~1 kg. Required power is <6 W and duty cycles would be a few minutes/day.

Conclusion: The Multispectral Microscopic Imager provides crucial petrologic and astrobiological information for exploring Mars, with only MER-class resource requirements in mass, cost, and complexity.

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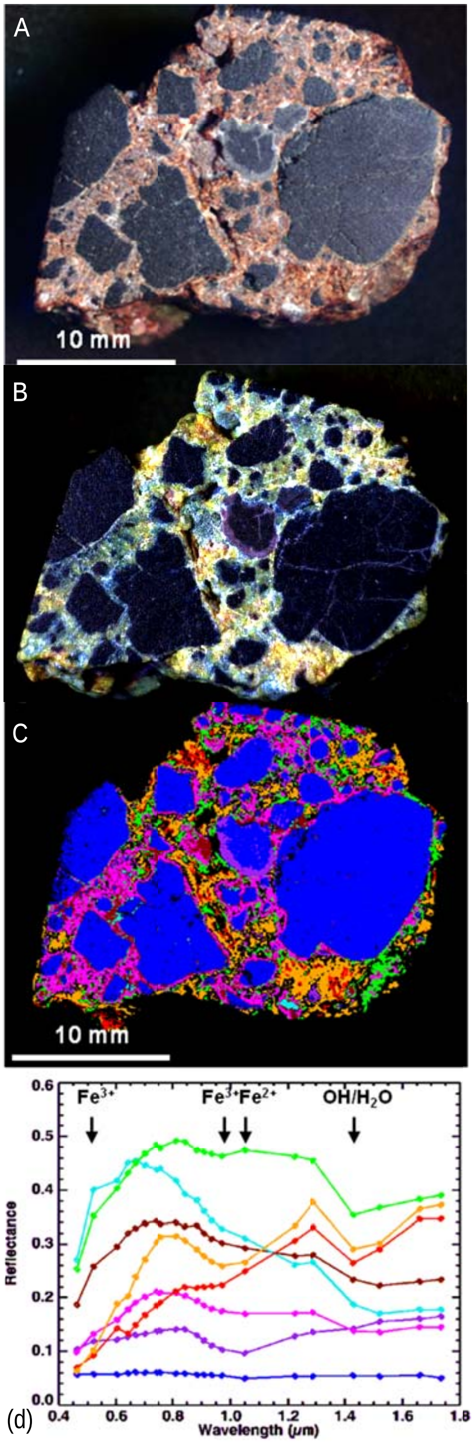

Fig. 2: 25 x 30 mm subframes acquired with the MMI; (a) Natural-color composite of composed of 0.46, 0.52, 0.64 µm bands; (b) translated-color composite image composed of 0.52, 0.91, 1.43 µm bands; (c) mineralogical map based on 21-band reflectance spectra. (d) reflectance spectra of the endmembers mapped in (c).