Mastcam-Z Analog Spectral Imager.

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Introduction: The Mars 2020 rover mission is scheduled to launch in July of 2020. Mastcam-Z (MCZ), a stereoscopic multispectral imager with zoom capabilities [1], will be one of the seven primary science instruments on board the rover. The rover will land in Jezero Crater, a once overfilled paleolake. The mineralogy of this region will be constrained by MCZ, including possible hydrated clays, iron oxides, and mafic minerals. The goal of this study is to test the capabilities of MCZ as a multispectral tool before the rover lands on the surface of Mars. Herein we present an off-the-shelf simulation of MCZ called the Mastcam-Z Analog Spectral Imager (MASI). For this study, we transported MASI to two Mars analog sites where the strengths and limitations of MASI and MCZ could be assessed.

Instrument Summary: MASI was designed for three purposes: (1) as a testbed for practicing the MCZ pre-flight calibration procedures, (2) as a field instrument to study MCZ's capabilities and develop observations strategies at Mars analog sites, and (3) to characterize any anomalies identified during MCZ's calibration.

By using the KAI-2020 detector and the engineering model filters, MASI's multispectral capabilities are similar to MCZ's. MASI is equipped with MCZ flight spare filters that have the same central wavelengths and bandpasses (Figure 1) as the flight units. MASI was also engineered to have the same stereo separation and toe-in. The spectral throughput of the lenses and detector cover, however, suppress infrared efficiency beyond 900 nm. Since the dark current is negligible, however, longer exposure times permit MASI to obtain the same SNR in these filters as MCZ will on Mars. Temperature -dependent effects are the same as those observed during MCZ calibration. This is mitigated by operating MASI at a constant CCD temperature.

Due to the changes in illumination that occur while imaging outdoors (due to clouds, haze, the motion of the sun, etc.), MASI multispectral calibration requires inclusion of a reflectance standard in each science image (Spectralon). Relative reflectance ("IOF") is derived by dividing the flat-fielded, bias subtracted frames by the values of the reflectance standard when it is normal to the Sun's incidence.

MASI's geometric calibration is identical to the techniques used for the MCZ photogrammetric calibration [2], which allows for stereo imaging and coregistered between various zoom, focus and filter camera states. These results are then converted to the standard CAHVOR camera mode format.

Mastcam-Z Left (L) and Right (R) Filters [2]

Filter Number	**λ_{eff} ± HWHM (nm)**	
L0/R0 (Red Bayer)	634 ± 43	634 ± 43
L0/R0 (Green Bayer)	542 ± 42	542 ± 42
L0/R0 (Blue Bayer)	476 ± 45	476 ± 45
L1 / R1	801 ± 9	800 ± 10
L2 / R2	754 ± 10	866 ± 10
L3 / R3	677 ± 11	910 ± 12
L4 / R4	605 ± 9	939 ± 13
L5 / R5	528 ± 11	978 ± 10
L6 / R6	442 ± 12	1017 ± 18
L7 (RGB) / R7	590 ± 88, ND6	880 ± 10, ND5

Fig. 1 – λ_{eff} is the effective band center wavelength including optics and CCD spectral responses. HWHM is the half-width at half-maximum for each filter. L0/R0 λ_{eff} are slightly shifted in MASI due to the presence of a cover glass and a second generation CCD.

Analog Sites:

Palisades Sill, Fort Lee, NJ and Alpine, NJ. The Palisades Sill, dated at 201 ± 1 Ma [3] exhibits differentiations trends which are typically tholeiitic, indicating an enrichment in iron minerals such as magnetite. Reversals in these trends may indicate that the Palisades sill is composed of multiple magma injections [4]. 10 m above the basal contact, there exists an olivine enriched unit called the Olivine Zone (OZ). Due to the purposes of this study, a multispectral dataset was collected from an upper region of the sill in Alpine, NJ, which is expected to contain Fe-rich diorites [4] and magnetite.

Painted Hills Unit, John Day National Monument Mitchell, OR. The origin of the John Day National Monument throughout central Oregon is volcanic in nature. Post-deposition hydrous alteration converted many of the tuffs into tuffaceous iron-rich clays, primarily in the form of laterites [5], The oxidation-reduction state of the laterites varies within the Painted Hills. This is useful in demonstrating MCZ's ability to detect crystal-field absorption, and will provide the opportunity to determine if the positions of the R5 and R6 filters are sufficient to detect an hydration band near MCZ's longest wavelength filter.

Potentially Observable Signals: There are several situations in which it is unclear whether MCZ will be able to identify certain spectral features. Examples include:

Magnetite Inclusions. The ability of MCZ to detect the presence of magnetite inclusions is determined by several factors. The grain size must be sufficiently large that MCZ is able to resolve individual grains. The resolution scale will vary with distance to the target in question. General exposure and dust coverage on the surface of the sample may further inhibit MCZ's ability to detect the spectral signature of magnetite inclusions, although fine-grained, disseminated magnetite would likely darken and spectrally flatten spectra.

Nanophase Iron Oxides: Weathering components produced on Mars are comprised of nanophase iron-oxides and iron-oxyhydroxides [6]. Previous reflectance spectra of Mars' surface have been obscured due to the spectra of nanophase iron oxides, which exhibit much shallower band depths than their crystalline counterparts [6]. It is likewise unclear if MCZ will be able to detect the crystal field absorption bands used to identify iron-bearing minerals.

Hydrated Minerals: Most hydration features appear outside the wavelength range of MCZ's detectability, however absorption from the $2\nu_1\nu\ +{}_3$ H_2O bands and the 3ν OH overtone band are located near MCZ's longest wavelength filters, R5 and R6 (Fig. 2.) This spectral feature is positioned from ~980-1000 nm [7]. Both the band depth and the position of the filter's central wavelength will determine if MCZ will be able to discern this feature.

Results:

Multispectral data collected from the Palisades Sill does not indicate the presence of exposed magnetite inclusions. Further observations of hand samples collected from the Palisades will be tested to asses MASI's ability to detect magnetite inclusions.

The normalized spectra of six hand samples collected from the Painted Hills are compared in Figure 3. A 535 nm absorption band common in iron oxides is most visible in the poorly consolidated red clay sample (Region 7), and slightly less visible in the well-consolidated Fe-oxide clay (Region 3). The nanophase iron oxide coating in Regions 1 and 2 of the weathered basalt both display the 535 nm feature. These are less prominent than in either Region 7 or 3, but are still perceptible. A 978 nm feature, which is also associated with iron oxides is clearly visible in all samples.

Although the samples collected from the Painted Hills have undergone hydrous alteration, the spectral signature does not appear to be visible in the collected samples. A broad absorption band centered near ~980 nm is consistent with observations of Fe-bearing minerals. The expected downturn in I/F from filter R5 to R6 is not present in the collected spectra [7]. However, the R6/R5 ratio of veins in the Alpine Region of the Palisades in Figure 2 is consistent with IOF downturn due to hydration.

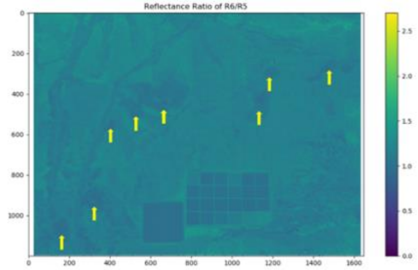

Fig. 2 – The normalized reflectance ratio of filters R6 and R5 (R6/R5) from the upper Alpine section of the Palisades Sill. White veins (see arrows) appear darker, reflecting less NIR light to MASI This is consistent with the presence of a hydrated carbonate mineral.

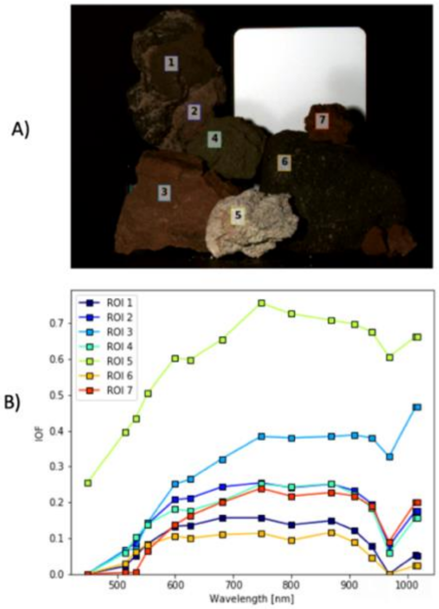

Fig. 3 A) An L0/R0 image of six hand samples collected from the Painted Hills Unit (two regions of Sample 1 were analyzed). B) The normalized I/F of the samples in 3A from all MASI filters. Spectra were normalized by dividing by the reflectance of the unshadowed region of the Spectralon target.

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